# MATHEMATICAL MODELLING OF URBAN WATERSHEDS FOR DRAINAGE AND ENVIRONMENT IMPROVEMENT

## CASE STUDY OF TWO CATCHMENTS IN GREATER COLOMBO AREA

**M.Eng in Environmental Engineering and Management**

**Department of Civil Engineering**
**University of Moratuwa**
**Sri Lanka**



*Submitted By:*

**Eng. P.P.Ghnanapala**

*Supervised By:*

**Dr. N.T.S. Wijesekera**



November 2000

**STATEMENT:**

" This thesis was submitted to the Department of Civil Engineering of the University of Moratuwa, Sri Lanka, as a partial fulfillment of the requirements for the degree of Master of Engineering in Environmental Engineering and Management "



**DECLARATION:**

"This thesis has not been previously presented in whole or part to any University or Institute for a higher degree."

08/01/2001 ..............................

Date

..............................

P.P.Ghnanapala

## ACKNOWLEDGEMENT

I take this opportunity to express my sincere gratitude and appreciation to Dr. N.T.S Wijesekera for his guidance, encouragement and valuable advice given throughout this study. I was able to complete this report successfully due to his continuous support and encouragement.

I also wish to express my gratitude to Professor (Mrs.) N.Ratnayake - our course coordinator for making us aware of the importance of this research project and providing us with the required guidance and assistance to complete this study.

I wish to express my special thanks to the Deputy General Manager (Research & Designs) - Mr. H.M.K.S. Jayawardana and his Staff of the Research & Designs Division of Sri Lanka Land Reclamation & Development Corporation for their kind cooperation provided during the period of this study.



The assistance rendered by the Engineers of the Department of Irrigation, Ports Authority, National Water Supply and Drainage Board and the Department of Meteorology in the process of data collection for this study is invaluable.

I am grateful to my parents and all my teachers for the wisdom and guidance passed on to me, beginning from my early days and through higher education, in order that I could produce this publication.

I also most sincerely thank my wife for all the motivation, assistance and patience extended to the successful completion of this task.

## ABSTRACT

Due to the increase in population in the urban area more and more land is necessary for living. Therefore reclamation of marshy land in urban areas has taken place over the years without giving due consideration for stormwater drainage. It was observed that the flooding prolongs mainly due to the insufficient drainage sizes together with reduction in detention / retention areas. As a result there is uncontrolled flooding causing enormous problems. The disruption of business and community activities accelerate deterioration of the environment and increases health risks etc. In the planning process it is important, therefore, to be able to assess the probable impact of urbanization upon the magnitude of flood peaks.

In the light of above while designing a drainage system it is very important to know the peak discharge at required locations. Such an assessment could be made by several methods. In this study two mathematical models have been used to obtain the required results. They are:



1. the Basic Model HEC-1 that has been used to estimate Runoff and
2. HEC-RAS model that has been used to establish the Rating Curve.

In Sri Lanka especially in urban areas basic statistical data such as runoff data, land use data and important tested parameters are not available to assist runoff values for the designing of a drainage system.

However, availability of statistical data and literature to assess peak discharge is limited and hence, parameters are assumed based on available information and judgements. The objective of this study is to provide solutions to the drainage issue due to urbanization by studying urban hydrology and identifying the necessary parameters to model urban watersheds. Based on this the objectives are identified as follows:

1. Study the behavior of rainfall and runoff of urbanized area.
2. Develop a mathematical model for the drainage system.

3. Identify the important parameters and their values for mathematical modeling of watersheds to calculate peak runoff.

Two urban watersheds were gauged mathematically and modelled using the HEC model to identify the behaviour for urban watersheds in Colombo and also to identify parameters applicable to these.

The study area consists of two locations independent of each other but quite close within the Greater Colombo Area. They are:

1. Torrington watershed consisting of 290 ha located within the heart of Colombo &
2. Badowita - Attidiya watershed consisting of 270 ha located within the periphery of the Greater Colombo.

The distinct difference between the two areas is in the land use, which is a vital factor that contributes to the run-off. The stream network and storage area identified in both watersheds were linked to establish the model. Required data such as rainfall, land use, events of flood records, tide level data were collected and checked before using in the model.



Land cover of the watersheds showed that in the urbanized areas the pervious extent was approximately 62% while in less urbanized areas the previous extent was about 76%. Average Curve Numbers for the urbanized areas were 95 and 70 for impervious and pervious areas respectively.

The HEC rainfall-runoff model developed for both watersheds produced very good peak discharge matching and hence these models could be used for drainage environment improvement projects in urban areas. It was also found that Curve Number values, so obtained appear to be realistic and could be easily used for similar watersheds instead of general values.

Canal network of both watersheds were modelled and rating curves were developed and verified for both gauging stations. The established model for urban areas can be used for rehabilitation of existing drainage systems as well as for designing of new drainage systems.

Statement
Declaration
Acknowledgement
Abstract
Table of Contents
List of Tables
List of Figures
List of Notations
List of Abbreviation
List of Plans

## TABLE OF CONTENTS

1. **INTRODUCTION........................................................... 1-1**
1.1 General ........................................................... 1-1
1.1.1 Environmental Considerations ................................. 1-3
1.1.2 Provision of Adequate Drainage .............................. 1-3
1.1.3 Provision of Retention/Detention Areas....................... 1-4
1.2 Background ........................................................... 1-4
1.2.1 Urbanization Effects and Problems in Greater Colombo 1-4
1.2.2 Management Concerns and Constraints.................. . 1-8
1.3 Objectives of the Study........................................... 1-10
1.4 Scope of work and Layout of the Report ................................ 1-11
1.4.1 Scope of Work ..................................................... 1-11
1.4.2 Layout of the Report ............................................ 1-11

2. **LITERATURE REVIEW ................................................. 2-1**
2.1 Urbanization & Resultant Problems in Colombo ........................ 2-1
2.2 Urban Hydrology. ........................................................ 2-5
2.2.1 Components of Urban Hydrology ............................. 2-7
2.2.2 Separation of Hydrograph Components ..................... 2-8
2.2.3 Streamflow Gauging ......................................... 2-12
2.2.4 Problems of Urban Drainage ................................. 2-14
2.3 Typical Mathematical Models. ........................................ 2-15
2.3.1 Rational Method ............................................... 2-15
2.3.2 MCMath Method ............................................... 2-16

2.3.3 Synthetic Flood Hydrograph ................................ 2-17
2.3.4 Curve Number Method ...................................... 2-18
2.3.5 HEC Model .................................................. 2-24
2.3.6 HEC- RAS Model ............................................ 2-30
2.4 Mathematical Models ............................................ 2-31
2.4.1 Mathematical Modeling of Rainfall and Runoff........... 2-33
2.4.2 Parameter Optimization......................................... 2-35

**3. METHODOLOGY .......................................................... 3-1**
3.1 General ............................................................... 3-1
3.2 Study of Rainfall and Runoff ........................................ 3-1
3.3 Streamflow Modelling .................................. 3-1

**4. DATA COLLECTION AND OBSERVATION 4-1**
4.1 Data Collection ........................................................ 4-1
4.1.1 Torrington Watershed ........................................... 4-1
4.1.2 Badowita and Attidiya Watershed................................ 4-1
4.1.3 Stream Network and Sub Catchments ....................... 4-2
4.1.4 Watershed Parameters ........................................... 4-3
4.1.5 Detention/Retention Area and Canal Network .......... 4-3
4.1.6 Topography .................................................... 4-4
4.1.7 Rainfall & Evaporation ....................................... 4-4
4.1.8 Water Level Staff Gauges ...................................... 4-4
4.1.9 Discharge Measurements...................................... 4-4
4.1.10 Tide Levels ................................................... 4-5
4.1.11 Automatic Gauge and Staff Gauge Records................. 4-5
4.1.12 Rating curve ................................................ 4-6
4.2 Data Checking ........................................................ 4-6
4.2.1 Rainfall ......................................................... 4-6
4.2.2 Streamflow ...................................................... 4-7
4.2.3 Site Inspection ................................................. 4-7
4.2.4 Specific Field Visit Observations ......................... 4-8
4.2.5 Land Use Pattern ............................................. 4-8

5. **MODEL DEVELOPMENT AND RESULTS** **5-1**

5.1 Model Development For Torrington ... 5-1

5.1.1 Rating Curve ... 5-1

5.1.2 Canal Network Model ... 5-1

5.1.3 Effective Canal Roughness ... 5-2

5.1.4 Tidal Effect ... 5-2

5.1.5 Backwater Effect ... 5-3

5.1.6 Domestic Drainage ... 5-3

5.1.7 Flood Hydrograph ... 5-4

5.1.8 Rainfall Events ... 5-4

5.1.9 Development of Watershed Model ... 5-5

5.1.10 Parameter Estimation ... 5-5

5.1.11 Calibration ... 5-5

5.1.12 Verification ... 5-6

5.1.13 Final Results ... 5-6

5.2 Model Development For Badowita – Attidiya ... 5-6

5.2.1 Rating Curve ... 5-6

5.2.2 Canal Network Model ... 5-7

5.2.3 Effective Canal Roughness ... 5-7

5.2.4 Tidal Effect ... 5-8

5.2.5 Backwater Effect ... 5-8

5.2.6 Domestic Drainage ... 5-9

5.2.7 Flood Hydrograph ... 5-9

5.2.8 Rainfall Events ... 5-9

5.2.9 Development of Watershed Model ... 5-10

5.2.10 Parameter Estimation ... 5-10

5.2.11 Calibration ... 5-11

5.2.12 Verification ... 5-11

5.2.13 Final Results ... 5-11

5.3 Weighted Average Curve Numbers ... 5-12

**6. DISCUSSION** .................................................................. 6-1

6.1 Domestic Drainage Water .................................................. 6-1

6.2 Watershed and Canal Gradients ........................................ 6-1

6.3 Tidal Effect ........................................................................ 6-2

6.4 Hydrodynamic Modeling of Canal Network ........................ 6-2

6.5 Canal Network Roughness ................................................. 6-2

6.6 Backwater Effect on the Stream ......................................... 6-3

6.7 Rating Curve ....................................................................... 6-3

6.8 Delineation of Sub-Catchments ......................................... 6-4

6.9 Land Cover of Watersheds ................................................. 6-4

6.10 Mathematical Model for Torrington ................................. 6-5

6.11 Mathematical Model for Attidiya ...................................... 6-5

6.12 Mathematical Models for Environmental Improvement .......... 6-6

6.13 Comparison of Modelled Curve Number Values....................... 6-7

6.14 Comparison of Results of AMC Class II & AMC Class III ....... 6-8



**7. CONCLUSION** ............................................................ **7-1**

**8. FUTURE STUDIES** ....................................................... **8-1**

**9. LIST OF REFERENCES**.................................................. **9-1**

**10. ANNEXES** .................................................................... **10-1**

**Annex A** - Graphical Representation of Data Sets

**Annex B** - HEC Modeling Details of Torrington and Attidiya Watersheds

**Plans** - Plans of Torrington and Attidiya Watersheds

**List of Table**


| | |
|---|---|
| Table 2.1 | Canal Reservations |
| Table 2.2 | Computation of Divergence. |
| Table 2.3 | Typical Values of Runoff Coefficient for Urban Areas (ASCE) |
| Table 2.4 | Range of Rainfall Depth under Different Antecedent Moisture Conditions (AMC) |
| Table 2.5 | Runoff Curve Numbers for Different Antecedent Moisture Conditions (AMC) |
| Table 2.6 | Curve Number Values Used in the Greater Colombo Flood Control Project. |
| Table 2.7 | Runoff Curve Numbers for Urban areas |
| Table 2.8 | Typical Classification of Mathematical Models |
| Table 2.9 | Type of Objective Functions for Model Calibration. |
| Table 4.1 | Rainfall Data Sample at 15 Minute Interval in Colombo |
| Table 4.2 | Rainfall Data Sample at 15 Minute Interval in Ratmalana |
| Table 4.3 | Automatic Gauge Water Level at Torrington Bridge |
| Table 4.4 | Manual Water Level Reading at Torrington Bridge |
| Table 4.5 | Automatic Gauge Water Level at Badowita Bridge |
| Table 4.6 | Manual Water Level Reading at Badowita Bridge |
| Table 4.7 | Current Meter Measurement at RMV Bridge -Torrington Canal |
| Table 4.8 | Current Meter Measurement at Badowita Bridge -Attidiya |
| Table 4.9 | Daily Rainfall Records for Colombo - 1999 |
| Table 4.10 | Daily Rainfall Records for Colombo - 2000 |
| Table 4.11 | Daily Rainfall Records for Ratmalana - 1999 |
| Table 4.12 | Daily Rainfall Records for Ratmalana - 2000 |
| Table 5.1 | Details of Field Survey at 50m Intervals for Hydrodynamic Model - Torrington |
| Table 5.2 | Flood Events for Hyohodynamic Model Calibration -Torrington Watershed |
| Table 5.3 | Flood Events for Hydro Dynamic Model Verification -Torrington Watershed |
| Table 5.4 | Sample of Tide Levels at Colombo Harbour |
| Table 5.5 | Computation of Tidal Effect at Torrington Bridge - Flow Combination 1 |

| | |
|---|---|
| Table 5.6 | Computation of Tidal Effect at Torrington Bridge - Flow Combination 2 |
| Table 5.7 | Computation of Tidal Effect at Torrington Bridge - Flow Combination 3 |
| Table 5.8 | Computation of Tidal Effect at Torrington Bridge - Flow Combination 4 |
| Table 5.9 | Computation of Tidal Effect at Torrington Bridge - Flow Combination 5 |
| Table 5.10 | Computation of Tidal Effect at Torrington Bridge - Flow Combination 6 |
| Table 5.11 | Water Releases of Service Reservoirs in Greater Colombo Area |
| Table 5.12 | Initial Estimation of Parameters. |
| Table 5.13 | Final Curve Numbers for Torrington Watershed. |
| Table 5.14 | Details of Field Survey at 50m Intervals for Hydrodynamic Model - Badowita |
| Table 5.15 | Flood Events for Hydrodynamic Model Calibration - Badowita & Attidiya Watershed |
| Table 5.16 | Flood Events for Hydrodynamic Model Verification -Badowita & Attidiya Watershed |
| Table 5.17 | Computation of Tidal Effect at Badowita Bridge - Flow Combination 1 |
| Table 5.18 | Computation of Tidal Effect at Badowita Bridge - Flow Combination 2 |
| Table 5.19 | Computation of Tidal Effect at Badowita Bridge - Flow Combination 3 |
| Table 5.20 | Computation of Tidal Effect at Badowita Bridge - Flow Combination 4 |
| Table 5.21 | Computation of Tidal Effect at Badowita Bridge - Flow Combination 5 |
| Table 5.22 | Computation of Tidal Effect at Badowita Bridge - Flow Combination 6 |
| Table 5.23 | Initial Estimation of Parameters. |
| Table 5.24 | Final Curve Numbers for Badowita and Attidiya Watershed. |
| Table 5.25 | Computation of Weighted Average Curve Numbers for Torrington Watershed. |
| Table 5.26 | Computation of Weighted Average Curve Numbers for Badowita and Attidiya Watershed. |
| Table 6.1 | Land Use Groups in Torrington and Attidiya. |
| Table 6.2 | Curve Number Values for Torrington Watershed. |
| Table 6.3 | Curve Number Values for Attidiya Watershed. |
| Table 6.4 | Prediction of Peak Flow With Increased Urbanization - Torrington. |
| Table 6.5 | Prediction of Peak Flow With Increased Urbanization - Attidiya. |
| Table 6.6 | Comparison of Curve Numbers for Urban Watershed. |

Table B-1 Land use Pattern - Torrington Watershed.

Table B-2 Land use Pattern - Badowita - Attidiya Watershed.

Table B-3 Selected Current Meter Measurements at RMV Bridge - Torrington Canal.

Table B-4 Selected Current Meter Measurements at Badowita Bridge - Badowita Canal.

Table B-5 Details of Canal network for Torrington Watershed

Table B-6 Details of Structures at Outlet of Sub Basin of Torrington Watershed.

Table B-7 Selected Rainfall Events for Torrington

Table B-8 Sample Calculation of Parameter Optimization - Torrington

Table B-9 Results of Model Calibration for Torrington Watershed.

Table B-10 Results of Model Verification for Torrington Watershed.

Table B-11 Selected Set of Random Variation of Parameters.

Table B-12 Mean Ratio of Absolute Error for Random Variation of Parameters - Torrington Watershed

Table B-13 Computed and Observed Streamflow Data - Torrington - 20.01.99

Table B-14 Computed and Observed Streamflow Data - Torrington - 07.04.99

Table B-15 Computed and Observed Streamflow Data - Torrington - 09.04.99

Table B-16 Computed and Observed Streamflow Data - Torrington - 20.04.99

Table B-17 Details of Canal Network for Badowita &Attidiya Watershed

Table B-18 Details of Structures at Outlet of Sub Basins of Badowita - Attidiya

Table B-19 Selected Rainfall Events for Badowita - Attidiya.

Table B-20 Sample Calculation of Parameter Optimization - Badowita

Table B-21 Results of Model Calibration for Badowita - Attidiya Watershed.

Table B-22 Results of Model Verification for Badowita - Attidiya Watershed.

Table B-23 Mean Ratio of Absolute Error for Random Variation of Parameters - Badowita - Attidiya Watershed

Table B-24 Computed and Observed Streamflow Data -Badowita Bridge - 11.12.98

Table B-25 Computed and Observed Streamflow Data - Badowita Bridge - 12.12.98

Table B-26 Computed and Observed Streamflow Data - Badowita Bridge - 09.04.99

Table B-27 Computed and Observed Streamflow Data - Badowita Bridge - 20.04.99

***Note : Tables are Numbered According to Chapter Numbers and Annex Numbers***

## List of Figures


| | | |
|---|---|---|
| Figure | 1.1 | Effect of Urbanization on Hydrological Processes. |
| Figure | 1.2 | Components of an Urban Drainage Model |
| Figure | 1.3 | Drainage Canal Network of Greater Colombo Area. |
| Figure | 2.1 | Effects of Urbanization on Peak Flows for the Watershed. |
| Figure | 2.2 | Base Flow Separation of Simple Hydrograph |
| Figure | 2.3 | Derivation of a Master Depletion Curve |
| Figure | 2.4(a) | Procedure to Separate Baseflow. |
| Figure | 2.4(b) | Alternative Method of Separation of Baseflow |
| Figure | 2.4(c) | Determination of Recession Threshold Point |
| Figure | 2.5 | Typical drainage Flow in Urban Area |
| Figure | 2.6 | Basic Elements in Kinematic Wave Model. |
| Figure | 2.7 | Schematic of Flow Elements in Kinematic Wave Model. |
| Figure | 2.8 | Relationship Between Flow Elements. |
| Figure | 2.9 | Base flow Diagram. |
| Figure | 5.1 | Schematic Diagram of Canal Network Upstream of Wellawatta Outfall. |
| Figure | 5.2 | Layout of HEC-1 Model Network - Torrington Watershed |
| Figure | 5.3 | Schematic Diagram of Canal Network - Upstream of Attidiya Bridge. |
| Figure | 5.4 | Layout of HEC-1 Model Network - Badowita - Attidiya Watershed |
| Figure | A-1 | Current Meter Measurement at RMV Bridge - Torrington canal |
| Figure | A-2 | Current Meter Measurement at Badowita Bridge - Badowita canal |
| Figure | A-3 | Daily Rainfall Records for Colombo -1999 |
| Figure | A-4 | Monthly Rainfall Records for Colombo -1999 |
| Figure | A-5 | Daily Rainfall Records for Colombo (Jan - Aug 2000 ) |
| Figure | A-6 | Monthly Rainfall Records for Colombo (Jan - Aug 2000 ) |
| Figure | A-7 | Daily Rainfall Records for Ratmalana -1999 |

Figure A-8 Monthly Rainfall Records for Ratmalana -1999
Figure A-9 Daily Rainfall Records for Ratmalana (Jan - Aug 2000 )
Figure A-10 Monthly Rainfall Records for Ratmalana (Jan - Aug 2000 )
Figure A-11 Correlation of Discharge at Torrington Watershed.
Figure A-12 Correlation of Discharge at Badowita - Attidiya Watershed
Figure A-13 Torrington Water Level & Rainfall for 05.01.99 - 31.01.99
Figure A-14 Torrington Water Level & Rainfall for 01.02.99 - 28.02.99
Figure A-15 Torrington Water Level & Rainfall for 01.04.99 - 21.04.99
Figure A-16 Domestic Discharge Water Profile at Torrington Bridge
Figure A-17 Badowita Water level and Rainfall for 16.12.98 – 10.01.99
Figure A-18 Badowita Water level and Rainfall for 09.04.99 – 05.05.99
Figure A-19 Badowita Water level and Rainfall for 19.05.99 – 13.06.99
Figure A-20 Domestic Discharge Water Profile at Badowita Bridge
Figure A-21 Flow variation in some service Reservoirs in Greater Colombo Area

Figure B-1 Selected Sample Area for Land use Computation Torrington Watershed.

Figure B-2 Selected Sample area for Land use Computation for Badowita and Attidiya Watershed.
Figure B-3 Error Vs. Canal Roughness of Torrington and Kirulapona Canal Network - Torrington Watershed.
Figure B-4 Error Vs. Canal Roughness of Badowita - Attidiya Canal Network.
Figure B-5 Checking of Backwater Effect due to Adjoining Canals - Torrington.
Figure B-6 Checking of effect of Backwater due to Adjoining Canals - Badowita.
Figure B-7 Rating Curve at RMV Bridge - Torrington Watershed.
Figure B-8 Rating Curve at Badowita Bridge - Badowita Watershed.
Figure B-9 Mean Ratio of Absolute Error Vs. Number of Flood Events- Torrington Watershed

Figure B-10 Comparison of Observed and Computed Hydrograph - Torrington 20.01.99

Figure B-11 Comparison of Observed and Computed Hydrograph - Torrington 07.04.99

Figure B-12 Comparison of Observed and Computed Hydrograph - Torrington 09.04.99

Figure B-13 Comparison of Observed and Computed Hydrograph - Torrington 20.04.99

Figure B-14 Mean Ratio of Absolute Error Vs. Number of Flood Events - Badowita-Attidiya Watershed

Figure B-15 Comparison of Observed and Computed Hydrograph -Badowita Bridge -11.12.98

Figure B-16 Comparison of Observed and Computed Hydrograph -Badowita Bridge -12.12.98

Figure B-17 Comparison of Observed and Computed Hydrograph - Badowita Bridge -09.04.99

Figure B-18 Comparison of Observed and Computed Hydrograph -Badowita Bridge - 20.04.99




***Note : Figures are Numbered According to Chapter Numbers and Annex Numbers***

## List of Notations

| | | |
|---|---|---|
| A | - | Catchment area ( ha ) |
| C | - | Average runoff coefficient |
| F | - | Fall of water level (m) |
| h | - | Canal water level (m MSL) |
| I | - | Rainfall intensity (mm/hr) |
| n | - | Manning's coefficient |
| Q | - | Discharge ($m^3/s$) |
| s | - | Water Surface Slope / Slope of main drainage |
| $T_C$ | - | Time of Concentration. |

**List of Abbreviations**

| | | |
|---|---|---|
| ACEXS | - | Accumulated Excess in inches (mm) |
| ACRAN | - | Accumulated Rainfall depth in inches (mm) |
| AMC | - | Antecedent Moisture Condition |
| b/w | - | Breath / width of the canal |
| CN | - | Curve Number |
| d/s | - | Down stream |
| HEC-1 | - | Hydrologic Engineering Center - Flood Hydrograph Package 1 |
| HEC- HMS | - | Hydrologic Engineering Center - Hydraulic Modeling System |
| HEC- RAS | - | Hydrologic Engineering Center - River Analysis System |
| IA | - | Initial Surface Moisture Storage Capacity |
| $q_o(t)$ | - | Observed Flows |
| $q_o(mean)$ | - | Mean of Observed Flows |
| $q_o(peak)$ | - | Observed Peak |
| $q_s(peak)$ | - | Calculated Peak |
| $q_s(t)$ | - | Calculated Flows |
| QRCSN | - | Flow at which an Exponential Recession begins on the Receding Limb of the Computed Hydrograph |
| RTIOR | - | Ratio of a Recession Limb Flow Occurring One Hour Later |
| SCS | - | Soil Conservation Service |
| STRTQ | - | Initial Flow in the River |
| TRA | - | Trapezoidal Canal |
| UR | - | Urbanization Reaches |
| u/s | - | Upstream |

**List of Plans**


| | |
|---|---|
| Plan No. 1(a) | Land Use of Torrington Watershed |
| Plan No.1(b) | Contour Plan of Torrington Watershed |
| Plan No.2(a) | Land Use of Badowita - Attidiya Watershed |
| Plan No.2(b) | Contour Plan of Badowita - Attidiya Watershed |
| Plan No.1(c) | Longitudinal Section of Torrington Canal North |
| Plan No.1(d) | Longitudinal Section of Torrington Canal South & Torrington Canal |
| Plan No.1(e) | Cross Section of Torrington Canal |
| Plan No.2(c) | Longitudinal Section of Branch Canal - Huludagoda |
| Plan No.2(d) | Longitudinal Section of Main Canal - Badowita |
| Plan No.2(e) | Cross Section of Bridge at Badowita Housing Scheme |
| Plan No.3(a) | Landuse Pattern for Torrigtion Watershed. |
| Plan No.3(b) | Landuse Pattern for Attidiya Watershed. |