

# GROUNDWATER CONDITIONS IN SRI LANKA

A Geomorphic Perspective

C. R. Panabokke

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C. R. PANABOKKE

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National Science Foundation of Sri Lanka



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## CONTENTS

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<i>List of Figures and Tables</i>	ix
<i>Acronyms</i>	xi
<i>Foreword</i>	xii
<i>Preface</i>	xv
<i>Acknowledgement</i>	xvii

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<b>1 INTRODUCTION</b>	<b>19</b>
General Background	19
Main Characteristics of Groundwater	20
<i>Occurrence of Groundwater</i>	20
<i>Groundwater Movement</i>	22
<i>Aquifers and Rock Type</i>	23
<i>Aspects of Groundwater Quality</i>	24
Water Divining	26

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<b>2 PAST STUDIES AND INVESTIGATIONS CONDUCTED AND REPORTED IN SRI LANKA</b>	<b>29</b>
Period Prior to Establishment of Water Resources Board	29
Period After Establishment of Water Resources Board	30
Preparation of a Bibliography by Water Resources Board	31
Database of State Agencies – WRB and NWS & DB	32
Thematic Papers on Groundwater	33
Groundwater Maps of Sri Lanka	35
Recent Publications	37

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<b>3 GEOMORPHIC SETTING AND GENERAL DISTRIBUTION OF THE MAIN AQUIFER TYPES</b>	<b>43</b>
Some Basic Considerations	43
Shallow Karstic Aquifer	49
Deep Confined Aquifer	50

Metamorphic Hard Rock Region of the Dry Zone	52
<i>Shallow Regolith Aquifer</i>	52
<i>Deep Fracture Zone Aquifer</i>	54
<i>Distribution Patterns</i>	55
Shallow Aquifers on Unconsolidated Coastal Sands	55
Alluvial Aquifers	57
Laterite (Cabook) Aquifers of South West Sri Lanka	58
<hr/>	
<b>4 SHALLOW KARSTIC AQUIFER OF JAFFNA PENINSULA</b>	<b>61</b>
Previous Studies	61
Main Properties of Aquifer	63
<i>Geology</i>	63
<i>Hydrology</i>	63
<i>Groundwater Recharge and Discharge</i>	64
Special Hydrological Conditions	65
Present Utilization and Management Issues	65
<hr/>	
<b>5 CONFINED AND SEMI-CONFINED DEEP AQUIFERS OF THE NORTH WESTERN SEDIMENTARY FORMATIONS</b>	<b>67</b>
Previous Investigations and Studies	67
Hydrogeology of the Aquifers	69
Present Utilization and Potential Threats	72
<hr/>	
<b>6 METAMORPHIC HARD ROCK REGION OF THE DRY ZONE</b>	
<b>(i) Shallow Regolith Aquifer</b>	
<b>(ii) Deep Fracture Zone Aquifer</b>	
Previous Studies Conducted on Groundwater in the Hard Rock Region	
The Regolith Aquifer of the Hard Rock Region	77
Nature of Occurrence of the Regolith Aquifer	79
Dynamic Nature of the Regolith Aquifer	81
Groundwater Recharge	81
Rational Exploitation of the Regolith Aquifer	82
Present Utilization and Potential Threats	83
<hr/>	
<b>7 SHALLOW AQUIFERS ON UNCONSOLIDATED COASTAL SANDS OR COASTAL SAND AQUIFERS</b>	<b>85</b>
Previous Studies	85
Four Examples of Different Types of Coastal Sand Aquifers	87

<i>Kalpitiya Coastal Sand Aquifer</i>	87
<i>Nilaveli Coastal Sand Aquifer</i>	90
<i>Koggala Coastal Sand Barrier Beach and Incipient Dune</i>	91
<i>Katunayake Free Trade Zone – Coastal Sands on Old (Prior) Beach Plain</i>	93
Present Utilization and Potential Threats	95
<hr/>	
<b>8 AQUIFERS OF VARIABLE DEPTH ON ALLUVIUM, OR ALLUVIAL AQUIFERS</b>	<b>99</b>
Previous Studies	99
Main Properties	99
Rational Utilization	102
<hr/>	
<b>9 LATERITE (CABOOK) AQUIFERS OF SOUTH-WEST SRI LANKA</b>	<b>105</b>
Previous Studies	105
Main Properties	106
Present Utilization and Potential Threats	108
<hr/>	
<b>10 METAMORPHIC HARD ROCK REGION OF THE WET ZONE</b>	<b>109</b>
General Background	109
Groundwater Conditions in the Respective Landforms	109
Present Utilization and Potential Threats	111
<hr/>	
<b>11 SPRINGS IN SRI LANKA</b>	<b>113</b>
Large and Small Springs	113
Hot Springs or Thermal Springs	116
<hr/>	
<b>12 AN APPROACH TOWARDS SUSTAINABLE USE OF GROUNDWATER</b>	<b>119</b>
General Considerations	119
Threats to Groundwater Quality	119
Approach towards sustainable use of groundwater	120
<i>Regolith Aquifer of the Hard Rock Region</i>	121
<i>Coastal Sand Aquifer</i>	122
<hr/>	
<i>Appendices</i>	127
<i>Glossary</i>	143
<i>Index</i>	146

## LIST OF FIGURES

---

1 . 1	Classification of sub-surface water (modified from Driscoll, 1986)	22
2 . 1	Distribution of tube wells	34
2 . 2	Groundwater zones (after A.D.N. Fernando, 1968)	35
2 . 3	Hydrogeological map of Sri Lanka (after M.W. P. Wijesinghe, 1973)	36
3 . 1	Main aquifer types in Sri Lanka	47
3 . 2	Soil landscape (Soilscape) map of Sri Lanka	48
3 . 3	Karstic aquifer-Jaffna peninsula	49
3 . 4	Semi-confined aquifers of the Miocene Belt	51
3 . 5	Shallow dug wells and deep bore wells in fracture zone (after Dissanayake, 1989)	53
3 . 6	Typical regolith profile above crystalline basement rock	54
4 . 1	Groundwater conditions in the Jaffna peninsula (after C. H. L. Sirimanne, 1952)	62
5 . 1	Map of seven semi-confined aquifers excluding Jaffna (after M. W. P. Wijesinghe, 1973)	68
5 . 2	Conceptual model of the Vanathavillu aquifer	70
5 . 3	Geological cross section across Murunkan basin (after M. W. P. Wijesinghe, 1977)	71
6 . 1	Sketch showing groundwater in pockets of crystalline rocks	75
6 . 2	Behaviour of groundwater table	76
6 . 3	Schematic representation of soil-saprock-bedrock-fissures-joints	78
6 . 4(a)	Schematic representation of a small tank cascade	80
6 . 4(b)	Schematic representation of a groundwater area within a cascade	80
7 . 1	Groundwater in dune sand area-Hambantota (after C. H. L. Sirimanne, 1952)	86
7 . 2	Coastal sand aquifers of Sri Lanka	88
7 . 3	Schematic section across Kalpitiya peninsula	89
7 . 4	Hydrogeological section of Kalpitiya aquifer	89

7.5	Groundwater flow dominated by abstraction from irrigation wells	89
7.6	Schematic cross section of Nilaveli coastal sand aquifer	90
7.7	Koggala project area location	92
7.8	North South section of Koggala aquifer	93
7.9	Old beach plain from Chilaw to Kandana	94
7.10	Location of Katunayake Free Trade Zone	95
8.1	Schematic section across Mi Oya aquifer (after C. H. L. Sirimanne, 1957)	100
8.2	Schematic section across Kirama Oya aquifer	101
8.3	Flat alluvial plain of Kirindi Oya irrigation project	103
8.4	Schematic cross section (East-West) orientation showing the manner of recharge from old and new irrigation canals	103
9.1	Groundwater conditions in typical laterite at Ragama	105
9.2	Schematic section of laterite profile	107
10.1	Modal landscape of lower peneplain	110
10.2	Phreatic water table at the end of the rainy season	110
10.3	Transect of Udunuwara- Yatinuwara land system of the Kandy plateau	111
11.1	Approximate location and distribution of normal and thermal springs in Sri Lanka	114
11.2	Section across Matale Valley showing position of springs in lands of quartzite (after D.B. Pattiaratchi, 1956)	115

## **LIST OF TABLES**

---

1.1	Porosity and specific yield of differential geological materials	21
1.2	Range of hydraulic conductivity for main geological materials	23
1.3	Relative abundance of dissolved constituents in groundwater	24
3.1	Schematic table showing the main aquifer types and their equivalence with the corresponding soilscape unit	45
11.1	Chemical analysis and chemical classification of waters of five thermal springs	117
12.1	Classification of groundwater quality problems	120

## ACRONYMS

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ADA	Agriculture Development Authority
BGS	British Geological Survey
BOI	Board of Investment
CEA	Central Environment Authority
DANIDA	Danish International Development Agency
DOA	Department of Agriculture
FINNIDA	Finnish International Development Agency
GSD	Geological Survey Department (former)
GSMB	Geological Survey and Mines Bureau
GTZ	German Agency for Technical Cooperation
IFAD	International Fund for Agricultural Development
IFS	Institute of Fundamental Studies
IIMI	International Irrigation Management Institute (former)
IRDP	Integrated Rural Development Project
IWMI	International Water Management Institute
JICA	Japan International Cooperation Agency
NSF	National Science Foundation
NWSDB	National Water Supply and Drainage Board
ODA	Overseas Development Association (British)
PWD	Public Works Department
UNICEF	United Nations Children's Fund
UP	University of Peradeniya
USOM	United States Operation Mission (former)
WHO	World Health Organization
WRB	Water Resources Board

## FOREWORD

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Groundwater is one of Sri Lanka's most precious natural resources. A large number of people depend on it for their sustenance with no expense to the State. When compared with surface water, groundwater is a hidden resource, which is more reliable and also less subject to the type of year-round variation as in the case with surface streams and rivers.

Groundwater has been exploited from earliest times in Sri Lanka mainly for domestic use and where readily available for irrigation as well (e.g. in Jaffna). Almost 80% of the rural population in Sri Lanka rely on groundwater for their domestic needs today because of its excellent natural quality and sustained availability throughout the year. Main towns in Jaffna, Batticaloa, Mannar, Puttalam, Vavuniya depend almost 100 % on the groundwater supply.

Although a most precious resource, groundwater today is also a most threatened resource; threats to groundwater quality and quantity are varied and many. These include overuse of pesticides and agrochemicals, which leach into the water table; over-pumping; salt-water intrusion in coastal areas; contamination by pit latrines. Factors, like extraction and demand for groundwater have grown rapidly in recent times. Population increase in semi-urban areas, hotel and tourist industry in coastal sand aquifers, agro-well development in hard rock areas, shrimp farming in north west coastal plain, demand a reliable understanding of the nature of the groundwater in its different settings across the country.

Sri Lanka, within the climate change scenarios, will experience increasing dryness in the dry zone. This is already happening since late 1980's. Any further river diversions from the wet zone will be too expensive to undertake. It will not be possible to rely on the surface water sources because of the reduced and erratic rainfall. Groundwater will be the 'last bastion' of defence in a scenario of extreme water shortage.

Groundwater however, is yet insufficiently understood, irrationally exploited and inadequately protected, although it is now being widely used in almost all parts of the country (including the hill country springs). **The fear is that scientific ignorance may lead to its over-exploitation.**

Considerable research has been done in the past on the groundwater conditions in Sri Lanka. The pioneering studies of C. H. L. Sirimanne, described as 'the father of groundwater studies in Ceylon' [C. H. L. Memorial Volume compiled by S. Arumugam] set the firm basis for subsequent studies carried out by different agencies (WRB, NWSDB, GSD) from 1950 to

2000. Studies over the last 50 years are scattered and not readily available for reference. The National Science Foundation recognizing the need to redress this deficiency and with a view to preserving the valuable scientific knowledge built up in this country, invited the eminent scientist, Dr C. R. Panabokke to compile this book on *Groundwater Conditions in Sri Lanka*.

Dr C. R. Panabokke, served as the Director, Agriculture in the Department of Agriculture from 1979 to 1982. Since his retirement, he has served various international organizations including IIMI and IMWI. He had been a member of the Mahaweli Development Board, International Board for Soil Research and Management and Council for Agricultural Research Policy. Sri Lanka's highest scientific honour, *Vidya Jyothi* was conferred to him by HE the President in 1986. The University of Peradeniya recognizing his contribution to science bestowed upon him an honorary DSc in 1994. He has authored many publications and several books. The Board of Management of the National Science Foundation recognizing his intimate experience in irrigation and water management identified him as the ideal person to take up this challenge.

This publication goes a long way in filling the information void that existed after the initial foundation laid by C. H. L. Sirimanne. I congratulate the author for logical and detailed interpretation and analysis of studies carried out to date in order to provide a sound conceptual base for the proper understanding of the groundwater resources in Sri Lanka; in terms of both quantity and quality, in their different forms of occurrence, as applied to a variety of landscapes across the Nation. This also serves as a compilation of information on hydrology, geology, topography, water supply, and water quality taken from maps, reports, and data collected from 1950 to 2000. I hope that this valuable information would provide the basis for and play a constructive role in developing conceptual and mathematical models of groundwater flow, distribution and pollution in our hydro-geological systems.

This book is an invaluable resource to the State, Provincial, Private and Non-Governmental agencies to build a firm scientific foundation for policies governing the management and protection of our groundwater resources. It is my hope that this book will contribute to the use of such valuable policies and management practices to develop an effective, sustainable integrated water management culture in Sri Lanka.

**Prof. Sirimali Fernando**  
Chairperson, National Science Foundation  
Sri Lanka

June 2007

***“When the well is dry we know the real worth of water.”***

Benjamin Franklin, 1840

## **PREFACE**

---

In writing this book on '*Groundwater Conditions in Sri Lanka*' I have adopted a geomorphological rather than a hydrogeological approach for two special reasons. **Firstly**, the pioneering 'classical studies in groundwater carried out just prior to, and soon after independence in this country by late C. H. L. Sirimanne were strongly 'landscape' or landform oriented, and carried out entirely in the field at a period when air photography was not available in any form in this country. **Secondly**, the great diversity of groundwater types present in a country of Sri Lanka's size necessitates a geomorphic approach in order to be able to capture the essential attributes of the different aquifer types present in this island nation.

Looking back on my own scientific life which began in the early fifty's of the last century in the basement rock landscape at Maha Illuppallama, I was privileged to carry out and publish the very first study on groundwater behaviour in a 'hard rock' environment under the guidance of the late C.H.L. Sirimanne, then a member of the Geological Survey Department. It was the late Ernest Abeyratne who was primarily instrumental in launching this study for what he termed "the need for a fundamental understanding of the water table fluctuations in this environment mainly its influence on soil profile development." The results from this study, which was carried out at a research station in the early fifties where neither electricity nor 'water-on-tap' was available, were to subsequently have a high "pay-off" value in several significant aspects of land -soil- water management in the catenary landscapes of the dry zone of this country.

By the early nineties of the last century, the nature of occurrence of the small village tank cascades within the inland valley systems of the North Central landscape helped us to better understand the shallow groundwater dynamics in this small tank environment. This helped us enormously in the control and proper direction of the haphazard agro-well development that was then taking place in this region.

In Chapter 2 of this book I have attempted to bring together all available references to past studies and investigation carried out in this country. In the *Bibliography of Groundwater Studies* that was published by the Water Resources Board (WRB) in 2000, a total of 327 citations have been shown. These citations covered a wide range of reports, professional

papers and scientific journal articles. For the benefit of specialists and researchers I have made a list of 136 select publications and reports that are available for reference at the WRB Library. This select list is shown in Appendix 6 at the end of this book.

Chapter 3 should be considered the central theme of this book because it essentially brings out the geomorphic setting of the six main types of groundwater aquifers that have been identified in this country, and it also shows their geographic spread across the country. The equivalence between hydrogeological map units and soil landscape of soilscape map units is discussed in this Chapter; and Table 3.1 gives the main aquifer types and their equivalence with soil landscape units.

Subsequent Chapters 4 to 9 deal with each of the six main aquifer types of the country. Each Chapter consists of previous studies carried out on the aquifer, its main properties and its present utilization, including potential threats. Because of our incomplete understanding of groundwater conditions in the hard rock regions of the wet zone, Chapter 10 should be considered as introductory in its scope and content.

Chapter 11 on 'Springs of Sri Lanka' brings together widely scattered information on both large and small springs as well as hot 'thermal' springs occurring across the country. The final Chapter 12 attempts to address contemporary issues on sustainable use of groundwater in Sri Lanka.

The main impetus for writing this book came during my involvement in varying capacities with the Water Resources Board of Sri Lanka from 1999 to 2005, when I was able to acquire a first hand knowledge of the wealth of groundwater information that had been progressively built up and documented by the senior staff of the organization since the early eighties. Uppermost in my mind was the need to systematically assemble and document this wealth of scientific information that would otherwise have been lost to this country and to its future generations of scientists in general, and hydrogeologists in particular.

**C. R. Panabokke**

Nawala,  
Rajagiriya

July 2007

## ACKNOWLEDGEMENT

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In undertaking the task of writing this book I was greatly assisted by the far-sighted initiative taken by the then Chairman of the WRB, K. Yoganathan to have published the first *Bibliography on Groundwater Studies in Sri Lanka* in 1990, which I consider a landmark event. The support extended to me by the subsequent Chairmen, notably M. W. P. Wijesinghe and Athula Senaratne who were able to readily recognize the long term scientific values of my endeavours is gratefully acknowledged. I have to also express my thanks to the very enlightened senior officials of the Ministry of Irrigation and Water Resources during the period 1995-2002, (notably Jaliya Medagama and Ranjith Ratnayake) who facilitated my placement within the WRB, and also gave me a clear mandate to develop the Board's research programme and to organize the library and documentation services.

I owe much to both K. A.W. Kodituwakku and Ananda Hapugaskumbura, Senior Hydrogeologists of the WRB for providing me the much needed professional sustenance; and to R.N. Karunaratne (General Manager) for the institutional support that I received up to early 2006. Lasantha Perera of the WRB was of special assistance to me in innumerable ways in sharing the workload with me during this period, and he also helped in the WRB publication titled *Groundwater Resources of Sri Lanka* in January 2005. The other support staff of the WRB, namely the librarian, typist and draughtsperson provided me with much needed technical service and support.

I owe a special debt of gratitude to Mala Ranawaka for her selfless contribution in editing the whole script of this publication and for also scanning several key figures that accompany this text. To Chamika Hettiarachchi of the Editorial Office of NSF, a very special word of appreciation for her unfailing interest and support given at every stage in the compilation, processing and printing of this publication. I wish to also thank Yohan Thilakarathne for the innovative cover design.

Finally, I wish to express my sincere gratitude to Prof. Sirimali Fernando, Chairperson NSF, and Dr M. C. N. Jayasuriya, Director, NSF for their special interest and commitment in promoting and funding this important study that helps to document and interpret the wealth of scientific knowledge available to date on the country's very precious natural resource-its groundwater.

# 1

## INTRODUCTION

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### General Background

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Since the earliest times, water from beneath the ground or groundwater, has been exploited for domestic use, livestock and irrigated agriculture. Although the exact nature of its occurrence is not completely understood, successful methods of bringing water to the surface have been developed over the ages.

It is little realized that of the total volume of fresh water estimated to be present on this planet, about 22 percent occurs below the land surface in the form of groundwater storage. If one were to exclude the water locked in polar ice caps, groundwater would constitute 95 percent of all fresh water potentially available for human use. Lakes, swamps, reservoirs and rivers put together, account for only 3.5 percent of the total fresh water (Freeze and Cherry, 1979).

In comparison with surface water, groundwater is by its very nature, a hidden resource. As a result, users often have little or no understanding of its location, its dynamics as well as its real nature and availability. At the same time groundwater accounts for more than 85 percent of the safe drinking water in the rural areas of most Asian countries including Sri Lanka. Groundwater use on a global scale seems small when compared with surface water use, but becomes significant if drinking water is considered. It also has the advantage of being cleaner due to the filtering effect of the porous aquifer medium in which it occurs, and it is usually of drinking water quality and therefore does not require further treatment.

Because of its drought reliability, general excellent natural quality and continuous availability, groundwater has become immensely important for human water supply in both urban and rural areas of developed and developing nations. It is estimated that somewhere in the range of 1,600 to 2,000 million people worldwide now rely on this resource for their primary water supply. Groundwater is therefore considered as one of the most valuable natural resource possessed by many nations. It is however, still insufficiently understood, widely undervalued, irrationally exploited and inadequately protected.

In the rural areas of the USA, 96 percent of domestic water is supplied from groundwater (Todd, 1980). Some of the very large cities in the world are totally dependent on groundwater aquifers for their city water supplies. Many of the major cities of Europe, especially those in Denmark, Portugal, Germany, Italy and the Netherlands are more than 70 percent dependent on groundwater aquifers for their city water supplies.

In Asia and Africa most of the larger cities use surface water, but millions of people living in the rural areas are dependent on groundwater drawn from shallow dug wells, as well as deeper bore wells. In Sri Lanka, the towns of Jaffna, Batticaloa, Mannar, Vavuniya and Puttalam are more than 90 percent dependent on groundwater aquifers through municipal well fields and private boreholes. In the early part of the last century, the Hambantota town drew its total water requirement from the groundwater present within the sand dunes bordering the town.

From the early seventies, hydrogeologists in Sri Lanka have found that significant reserves of groundwater are present in the multitude of joints and fractures of the basement crystalline rocks in the country, and that these reserves could be drawn by drilling into the rocks. And so arose the concept of tube wells as they are termed today. In the African basement rocks they are referred to as *bore wells*. It is now reported that there are over 30,000 tubewells in the dry zone alone, although all of them are not of equally acceptable quality. However, earlier where rural women had to walk several kilometres each day to collect their pots of water for domestic use, these tubewells brought about a tremendous improvement to their general welfare. An increasing trend of groundwater use for municipal towns such as Nuwara-Eliya, Kandy, Kurunegala and Anuradhapura is also observed.

## **Main Characteristics of Groundwater**

### *Occurrence of Groundwater*

Groundwater occurs in many different geological formations. Almost all rocks in the upper part of the earth's crust possess openings called pores or voids. In unconsolidated groundwater materials such as coastal sands, the voids are the spaces between the sand grains, while in consolidated rocks such as our gneisses and granites, the only voids could be the fractures and fissures which are usually restricted but could be enlarged by the normal weathering processes. The volume of water contained in the rock depends on the percentage of these openings or pores or voids in a given volume of the rock, which is termed the porosity of the rock. More pore spaces result in a higher porosity and more stored water. Porosity values for different geological materials are shown in Table 1.1.

It is known that only a part of the water contained in the fully saturated pores can be abstracted for practical use. Under the influence of gravity, a part of this water drains from the pores and a part remains held by surface tension. The ratio of the volume of water that will drain under gravity from an initial state of saturation of the rock, to the total volume of water initially held in the rock is defined as the *specific yield of the material*.

Table 1 - 1

**Porosity and specific yield of differential geological materials**

<i>Material</i>	<i>Porosity %</i>	<i>Specific Yield %</i>
Gravel	25 - 35	15 - 30
Sand	25 - 45	10 - 30
Sandstone	5 - 30	3 - 15
Karst limestone	5 - 30	2 - 15
Weathered granite and gneiss	1 - 15	0.2 - 5.0
Fresh granite and gneiss	0.01 - 2.0	< 0.1

Source: Todd (1980)

Groundwater is not usually static but flows through the rock, and the ease with which this groundwater flows through the rock mass is defined as the *permeability of the rock*.

A geological formation that is sufficiently porous to store water, and is at the same time permeable enough to transmit water in quantities that can be readily exploited or be able to yield a useful supply in wells and springs is termed an *aquifer*. All aquifers have two fundamental characteristics, namely, a capacity for groundwater storage and a capacity to permit groundwater flow. However, as a result of the great diversity of natural geological conditions, aquifers vary very widely in their hydraulic properties (permeability and storativity) and reservoir volume (effective thickness and geographical extension).

When rain falls, some of it infiltrates into the soil. Part of this moisture is taken up by the roots of plants while the rest moves deeper under the influence of gravity. The empty spaces are partly filled with water and partly with air. This is known as the unsaturated or *vadose* zone as shown in Figure 1.1, and in this unsaturated zone, soil, air and water are in contact with each other. Downward movement of water in this unsaturated zone is very slow. At greater depths, all the empty spaces are completely filled with water and this is called the saturated zone. If a hole is dug or drilled down to this saturated zone water will flow from the ground into the hole and settle at the depth below which all the pore spaces are filled with water. This level is termed the water table, and the term groundwater refers only to this saturated zone below the water table. All water that occurs naturally beneath the earth's surface, including the saturated and unsaturated zones is referred to as sub-surface water, as shown in Figure 1.1.

For the most part groundwater systems are recharged by rain infiltrating the land surface. Many activities at the land surface can then threaten the quality and availability of these resources. The volumes of water stored underground are generally very large and thus the time scale of groundwater movement can be generally very long. Below the water table flow occurs at rates ranging from 10 m/day to less than 1 m/annum.

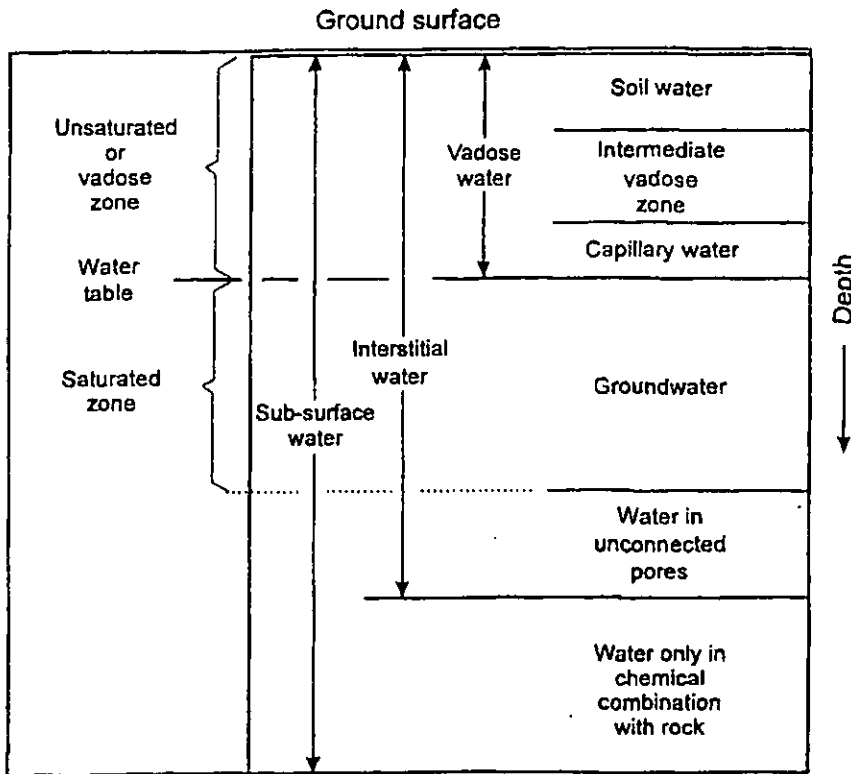


Figure 1.1 Classification of sub-surface water  
(Modified from Driscoll, 1986)

### Groundwater Movement

The rate of movement of groundwater depends on the ability of the aquifer to transmit the water and also on the difference in level between the points or location between which the flow takes place. In 1856, Henry Darcy, a French hydraulic engineer enunciated the principle, known later as Darcy's Law, which states that the rate of flow is directly proportional to the hydraulic gradient.

$$Q = -K i A$$

Where  $Q$  is the rate of flow through unit area  $A$  under hydraulic gradient  $i$ . The hydraulic gradient  $dh/dl$  is the difference between the levels of the potentiometric surface at any two points divided by the horizontal distance between them. The parameter  $K$  is known as the hydraulic conductivity and is a measure of the permeability of the material through which the water flows. Typical ranges of hydraulic conductivity for the main geological materials encountered in Sri Lanka is shown in Table 1.2.

**Table 1 . 2****Range of hydraulic conductivity for main geological materials**

	<i>Very High</i>	<i>High</i>	<i>Moderate</i>	<i>Low</i>	<i>Very Low</i>
<b>Unconsolidated Deposits</b>	Coarse	Fine sands Sands	Silts	Clays	-
<b>Consolidated Rocks</b>	Karst Limestone	Sandstone (jointed)	Fractured Weathered	Shales	Massive igneous and Gneisses metamorphic rocks (Unfractured)

Source: Todd (1980)

Darcy's Law provides a valid description of the flow of groundwater in most naturally occurring hydrogeological conditions. Although most of the flow in a fractured rock aquifer is through the fissures, very slow groundwater movement could take place through the interconnected voids of the matrix. The Darcy Law or Equation  $Q = -K i A$  is the fundamental assumption in all considerations of groundwater movement.

The importance of Darcy's Law is best stated by Todd (1980), "This statement, that the flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path, is known universally as Darcy's Law. It, more than any other contribution, serves as the basis for present day knowledge of groundwater flow. Analysis and solution of problems relating to groundwater movement and well hydraulics began after Darcy's work."

### *Aquifers and Rock Types*

Most of the world's important aquifers are of sedimentary origin. Igneous and metamorphic rocks are generally far less important as sources of groundwater. As a result of their mode of formation, igneous and metamorphic rocks have a very low initial porosity and permeability. With the passage of time and exposure to the natural weathering processes, joints and fractures could develop within the igneous and metamorphic rocks so that sufficient porosity and permeability is created within the weathered rock matrix to permit the development of an aquifer. It will be seen in the subsequent chapters that these weathered rocks of the basement complex in Africa and Sri Lanka can be vital sources of groundwater.

In contrast, sedimentary formations by their inherent nature have a high porosity and permeability. Sedimentary formations, originally formed at shallow depths and having a high inter-granular porosity and subsequently shifted by earth movements, have a well developed secondary porosity which helps the formation of productive aquifers. The flow of groundwater

in these sedimentary formations takes place both in the fissures as well as in the inter-granular spaces within the matrix.

Unconsolidated formations such as alluvium, coastal sands, dune sands, river terraces and buried valleys have a very high primary porosity with a very good inter granular flow of groundwater. Such formations are thereby able to support highly productive aquifers within the general matrix.

Deep consolidated sedimentary formations, such as those found in North-Western Sri Lanka, are characterized by slow groundwater movement, long residence times and ample opportunity for dissolution of minerals and, therefore, are often of poor natural quality.

### *Aspects of Groundwater Quality*

In this chapter only those aspects of water quality that have a bearing on the different aquifer types that will be taken up for discussion in the next ten chapters will be considered.

On the whole, the natural chemical quality of groundwater is generally good. However, the presence of different concentrations of several constituents can cause problems for water use. The relative abundance of these constituents dissolved in groundwater is given in Table 1.3.

**Table 1.3**

#### **Relative abundance of dissolved constituents in groundwater**

<i>Major constituents</i> (1.0 to 1,000 mg/l)	<i>Secondary constituents</i> (0.01 to 10.0 mg/l)	<i>Minor constituents</i> (0.0001 to 0.1 mg/l)
Sodium	Iron	Arsenic
Calcium	Aluminium	Phosphate
Magnesium	Potassium	Manganese
Sulphate	Carbonate	Barium
Chloride	Nitrate	Strontium
Bicarbonate	Fluoride	Lithium
Silica	Boron	Cadmium
	Selenium	Chromium
		Nickel
		Copper
		Cobalt
		Lead

Source: Todd (1980)

According to Dissanayake and Weerasooriya (1985), the groundwaters of Sri Lanka can be classified into the following four main water types.

- i. Calcium type
- ii. Magnesium type
- iii. Sodium / Potassium type
- iv. Non-dominant cation type

They have produced a map which illustrates the distribution of these four major types in Sri Lanka, and have been able to clearly show the influence of the underlying geology and climatic factors on the chemical quality of groundwater in Sri Lanka. When compared with Table 1.3, it could be observed that the major constituents are the dominant ones that govern groundwater quality in this country.

Both the range of concentration as well as the island-wide distribution patterns of chlorides, fluorides, manganese and iron of the groundwaters in Sri Lanka is explicitly shown in a set of maps (1:1,600,000 scale), along with supporting tables in the Hydrogeochemical Atlas of Sri Lanka by Dissanayake and Weerasooriya (1985).

High levels of fluoride have been reported for groundwater from some hard rock areas in the Anuradhapura, Polonnaruwa and Hambantota districts. It is also estimated that about 40 percent of the tube wells constructed in the dry zone districts during the last decade of the 20<sup>th</sup> century, had to be abandoned due to contamination from fluoride as well as from iron and manganese. High concentrations of fluoride in groundwater from dug wells have been reported in specific locations of the metamorphic hard rock terrains in India, Malawi and Tanzania.

High iron levels in groundwater are frequently reported from several developing countries where they are often an important water quality issue. Consumers tend to reject untreated groundwater from hand pump supplies if it has a high iron concentration, and opt for unprotected surface water sources with low iron levels but which may have bacterial pollution of several kinds. The situation is made worse in many areas by the corrosion of the ferrous well and pump components, and where the maintenance and servicing facilities are inadequate.

In a recent review article by S.L. Amarasiri (The Island, 2 February 2006) titled 'Can fertilizer harm drinking water quality?' he states that 'It is the nitrate levels in well water arising from fertilizer use that is the cause for much concern at present' He cites the findings of late S. Nagarajah in 1988 which showed that 15 of the 19 farm wells monitored in the Jaffna peninsula had more than the stipulated permissible levels of nitrate. Similarly, research at Kalpitiya in 1990 indicated that nearly 50 percent of the wells studied by Kuruppuarachchi had nitrate levels exceeding the acceptable limits. In the up-country wet zone, nitrate levels of 140-190 mg/litre in Nuwara Eliya have been reported in well waters by Jayakody and Nandasena. Amarasiri concludes that well waters could become unfit for human drinking in areas where high levels of nitrogenous fertilizers are applied to the soil.

## Water Divining

From very early historic times, the water diviners' fork or rod, and the value of water divining has been a matter of controversy. To date, there is very extensive literature on the subject, most of which is descriptive and has not helped to resolve the real issues. All evidence to date points to the existence of some subtle physical force acting on the fork or rod through the human body. Quoting Dr. D. N. Wadia, a former Director of the Geological Survey of Ceylon:

“ A quite fair number of individuals, without their knowing it, possess this power, in a greater or less degree, of transmitting this force from the ground over which they stand to the twig or fork held in their hands. But, from a large number of observations, there is no evidence to prove that the movements and reactions of the divining rod are actuated by the presence of water in underground strata or hidden channels of flowing water, nor is there any means of connecting the various deflections of this rod or fork with quantity, quality, direction of flow, or the depth of the water below the surface on which the demonstration is taking place. Evidence is wholly lacking on this most material point. Such claims are, however, often made and even supported by disinterested people, but have not been substantiated in a single scientifically controlled test or experiment.”

“ In my 33 years experience, I have come across numerous underground water investigation questions, but I have not seen a single indubitable case of successful locating of a large volume of subterranean water by means of the divining rod or fork, where other means failed.”

“ My late chief, Sir Lewis Fermor, FRS, Director of the Geological survey of India, who does not believe in finding stores of underground water by means of the divining rod, has this power himself. Another noted geologist, Alexander Du Toit of the South African Geological Survey, possessed this power, i.e., the rod moved actively and convincingly when held in his hands over certain sites, nevertheless he has collected abundant data to prove that the rod's movements and reactions have nothing to do with the occurrence of underground water.”

“ However, even if the claims of the diviner to locate water cannot be substantiated, we cannot lightly dismiss the phenomenon of the divining rod. A physical examination and measurement of the force actuating the various dowsing instruments yet remains to be made by employing modern laboratory and experimental methods, and the fundamental truth behind it sought out before science can dismiss or condemn this phenomenon as ‘not proven’.”

## References

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*The hydrogeochemical atlas of Sri Lanka*, NARESA, p. 106
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3. Todd D.K. (1980)  
*Groundwater Hydrology* 2<sup>nd</sup> edition, John Willey, New York, p. 535
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## 2

# PAST STUDIES AND INVESTIGATIONS CONDUCTED AND REPORTED IN SRI LANKA

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A *study* in this publication implies an enquiry conducted with a view to understanding the basic relationships between the different components of an aquifer.

An *investigation* refers to a standard or routine activity conducted in the field with a more limited objective of knowing the depth, quality and yield of the aquifer with a view to giving advice to the client.

While the result of a *study* is usually published in the form of a professional publication or journal article, the findings from *investigations* are usually recorded in the log books and field books deposited in the W.R.B. and the conclusions and recommendations are submitted in the form of a report to the client or agency concerned.

Until the country gained its independence in 1948, the water supply schemes in the country were handled by a *Water Works Branch* of the then Public Works Department (PWD). The advice of the Geological Survey Department (GSD) was occasionally obtained but there were no systematic investigations carried out on a continuing basis. Since its inception in the mid-forties, the GSD (earlier known as the Department of Mineralogy) has carried out studies in the fields of engineering geology and water supply, including public water supplies and location of wells in major colonization schemes in the dry zone. It has also advised a number of major towns such as Puttalam, Mannar, Jaffna, Batticaloa and Chilaw on the proper use and safe exploitation of groundwater aquifers. During the period 1945 to 1952, 58 water supply schemes were referred to the GSD for advice. The GSD continued its water supply investigations for major industrial enterprises and for expanding towns and urban settlements up to the late sixties, by which time the Department of Water Supply and Drainage, now National Water Supply and Drainage Board (NWSDB) took over the town supply responsibilities, while the GSD continued with other investigations.

### **Period Prior to the Establishment of the Water Resources Board**

By 1952 C. H. L. Sirimanne of the GSD was able to bring together the main findings from all past studies which had been completed in the country up to this period. In a landmark address

given to the Ceylon Association for the Advancement of Science in 1952 under the title *Geology for Water Supply*, he was able to identify and characterize the main types of aquifers occurring in the country and also comment on aspects of their utilization. It is to Sirimanne's credit that he was able to raise the status of groundwater investigations in the country to that of a scientific activity and thus set the tradition for scientific studies on the groundwater resources of this country.

Five other less well known, but equally significant papers prior to Sirimanne's 1952 paper were those of Tomalin (1921), *Water Supply Investigation in Hambantota district* (1929) and three papers by Mahadeva of the Water Works Branch of the PWD in 1932, 1933 and 1938. In Tomalin's presidential address to the Engineering Association in 1921 titled *Underground Water Resources of Ceylon* he discussed in some detail the prevailing use of dune water in the island which he considered as more wholesome than river water.

With the arrival in the island of experts from Israel in 1965, the Irrigation Department set up a Groundwater Branch for systematic drilling and exploration for groundwater in the north-west sedimentary zone of the island; and deep groundwater was raised for the first time in this country in July 1966. C. H. L. Sririmanne moved to this Groundwater Branch of the Irrigation Department and served as its head until his untimely demise in 1969. The main activity of this Branch was the systematic drilling and exploration for deep groundwater in the sedimentary zone of the north western regions of the country, which was hitherto a hidden but very significant resource in terms of its quantity and distribution.

## **Period After Establishment of Water Resources Board**

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With the setting up of the new (present) Water Resources Board (WRB) in January, 1978, the Groundwater Branch of the Irrigation Department together with its staff, were transferred to this newly set up Board, which then became the permanent institutional home for groundwater studies in this country. Alongside the mandate for groundwater studies being assigned to the WRB, the larger NWSDB also carries out special investigations for its specific needs which are more focused on town and country water supply. Many of these are assigned to private sector consultancy firms and other donor aid agencies.

From the time the WRB was assigned the mandate for groundwater studies in this country, it has been engaged in several studies and investigations. In the main, these include (a) characterization and mapping of the semi-confined aquifers in the North-West sedimentary formations; (b) detailed study and characterization of the Karstic aquifer of the Jaffna peninsula together with its water balance and water quality trends; (c) mapping of some alluvial and coastal plain aquifers; and (d) production of hydrogeological and groundwater maps for new development project areas.

Investigations carried out by the WRB from 1980 to 1995 for the Integrated Rural Development Projects (IRDP) funded by World Bank for the Kurunegala, Puttalam, Hambantota and Moneragala districts, covered mainly, the inland hard rock areas of the

above districts, as well as the drilling and installation of over 1,500 tube wells within the settled areas. A considerable number of supporting investigation reports and water quality findings are repositied within the library collection of the WRB and serve as scientific reference material.

In 1974, S. Arumugam, who was then a senior member of the former WRB, which was mainly an advisory body, compiled a publication titled *Studies on Groundwater in Sri Lanka* – as the C. H. L. Sirimanne Memorial Volume. He brought together ten key selected scientific papers, published up to that date, by recognized specialists in this field in this country. These 10 selected papers spanned the period 1921 to 1967. The titles and authors of these papers are given in Appendix 1 (a). This publication also includes Sirimanne's landmark publication of 1952, as well as a strategic programme for the exploration and development of groundwater in Ceylon proposed by John. W. Frink of the then USOM, in October 1958. This modest Volume of 10 papers serves as an excellent guide to any reader interested in undertaking a serious study of groundwater conditions in this country. Some selected items of bibliography from the Sirimanne publication of 1952 are also included in Appendix 1 (b) as these would help to bring out the state-of-the-art knowledge at that time.

### **Preparation of a Bibliography of Groundwater Studies by Water Resources Board**

Recognizing the need for an updated bibliography on groundwater studies carried out in this country up to the end of 2000, the WRB compiled a bibliography of a total of 327 available published papers on groundwater resources of the country, spanning the period 1950 to 1999. In his preface to this bibliography, the then Chairman of the WRB, K. Yoganathan states "a considerable amount of information on this resource is now available in various publications and reports. It is felt that there is a need for a bibliography on groundwater publication since this would be very useful for groundwater sector specialists, scientists, policy makers as well as water resources managers, water resources users and others concerned. With this in mind, the Water Resources Board decided on the compilation and publication of this bibliography".

As a first step in the preparation of this bibliography all available published literature on groundwater resources of the country spanning the period 1950 to 1999 were initially examined for their relevance and usefulness. The total number of publications perused in respect of the ten institutions where such documentation had been repositied, was as follows :

<i>Institution</i>	<i>Total number of Publications available</i>
1. Water Resources Board (WRB)	121
2. National Water Supply & Drainage Board(NWSDB)	72
3. Geological Survey and Mines Bureau (GSMB)	53
4. Dept. of Geology, University of Peradeniya (DG.UP)	30
5. Central Environmental Authority(CEA) in WRB Library	14
6. International Irrigation Management Institute (IIMI)- Selected titles	11
7. Dry Zone Research Inst., Maha Illuppallama (DZRI,MI)	09
8. National Science Foundation (NSF) of Sri Lanka	07
9. Irrigation Department (ID)	06
10. Institute of Fundamental Studies (IFS) in WRB Library	04
	<u>327</u>

The 327 publications above are in the form of specific reports based on field studies and related scientific investigations, reports based on secondary data, water quality reports, agro and tube well investigations, keynote and similar addresses, scientific journal articles, and a few review articles.

Of these 327 publications, a greater majority (233), fall within the category of findings of groundwater investigations and explorations, and 76 fall within the category of groundwater quality and groundwater pollution studies. There are only a total of 18 publications dealing with groundwater aquifer properties and their boundaries. Of these 18 publications there are 14 repositied with the WRB, and four repositied with the NWSDB. This in itself indicates the paucity of proper documented information in respect of aquifer boundaries in this country.

As the second logical step in this study, the available groundwater exploration field investigation records that were in the collection and storage of the WRB over a period of 30 years, and which were representative of each of the seven main groundwater systems present in this country, were examined to ascertain the extent to which aquifer boundaries as such had been identified and demarcated. It was, however, finally observed that most such field studies were mainly confined to drilling bores and pumping tests for yield rates of groundwater. In the case of these latter aquifers, only a qualitative picture could be depicted with the available information.

### **Database of State Agencies – WRB and NWS & DB**

At present, there are two state organizations, namely the WRB and NWSDB that are involved in groundwater studies, investigations and preparation of consultancy reports. For over the

past 30 years, a few private drilling companies and donor funded projects such as DANIDA, FINIDA and GTZ have, in recent years, also been engaged in the investigation and preparation of consultancy reports pertaining to groundwater.

These organizations collect data, primarily for their own use as well as for some sharing data with other agencies. The WRB and NWSDB are the main institutions in Sri Lanka engaged in the collection of tube well and water quality data. These data are collected and stored in their own databases. These databases represent more than 30 years of collection effort, and they contain information for more than 30,000 well sites, including data on tube wells, water and water quality. Distribution of well sites having geographical co-ordinates from the WRB database, is shown in Figure 2 . 1. This does not represent all tube well sites existing in Sri Lanka, because wells constructed by the NWSDB, private drilling organizations and overseas projects have not been included in this map. The data mentioned above has been collected and entered, for a wide variety of projects and purposes, over a long period of time and the resulting databases vary in quality and detail. The table shown in Appendix 2 gives the number of tube wells constructed by the WRB and NWSDB in the respective districts of Sri Lanka.

## **Thematic Papers on Groundwater**

The first published *Journal of the Geological Society of Sri Lanka* contains a set of seven Thematic Papers on Groundwater in Sri Lanka. These seven papers represent the more important papers presented at the *Symposium on Groundwater in Sri Lanka* held at the Fourth Annual Sessions of the Geological Society of Sri Lanka from 29 to 31 January 1988.

The authors and titles of these seven 'Thematic Papers on Groundwater in Sri Lanka' as they appear in the contents of the Journal is given below :

1. Davies & R. Herbert : The hydrogeology of the Miocene Sedimentary Belt of Sri Lanka.
2. R. Herbert, D. K. Ball, I. C. P. Rodrigo & E. P. Wright : The regolith aquifer of hard-rock areas and its exploitation with particular reference to Sri Lanka.
3. N. Kulatunga : Hydrogeology of a metamorphic terrain – a case study from Hambantota, Sri Lanka.
4. C. B. Dissanayake : Nitrates in the groundwater in Sri Lanka – implications for community health.
5. A. R. Lawrence, P. J. Chilton and D. S. P. Kurupparachchi : Review of the pollution threat to groundwater in Sri Lanka.
6. A. D. N. Fernando : Use of remote sensing for estimating the groundwater potential of Sri Lanka.
7. A. I. K. Adikari & H.A. Dharmagunawardhane : A low-cost defluoridation method for rural water supplies.

Since these seven papers reflect 'state-of-the-art' knowledge on groundwater during that period, it was considered important to reproduce the 'Abstracts' accompanying each of these papers under the reference section of this Chapter.

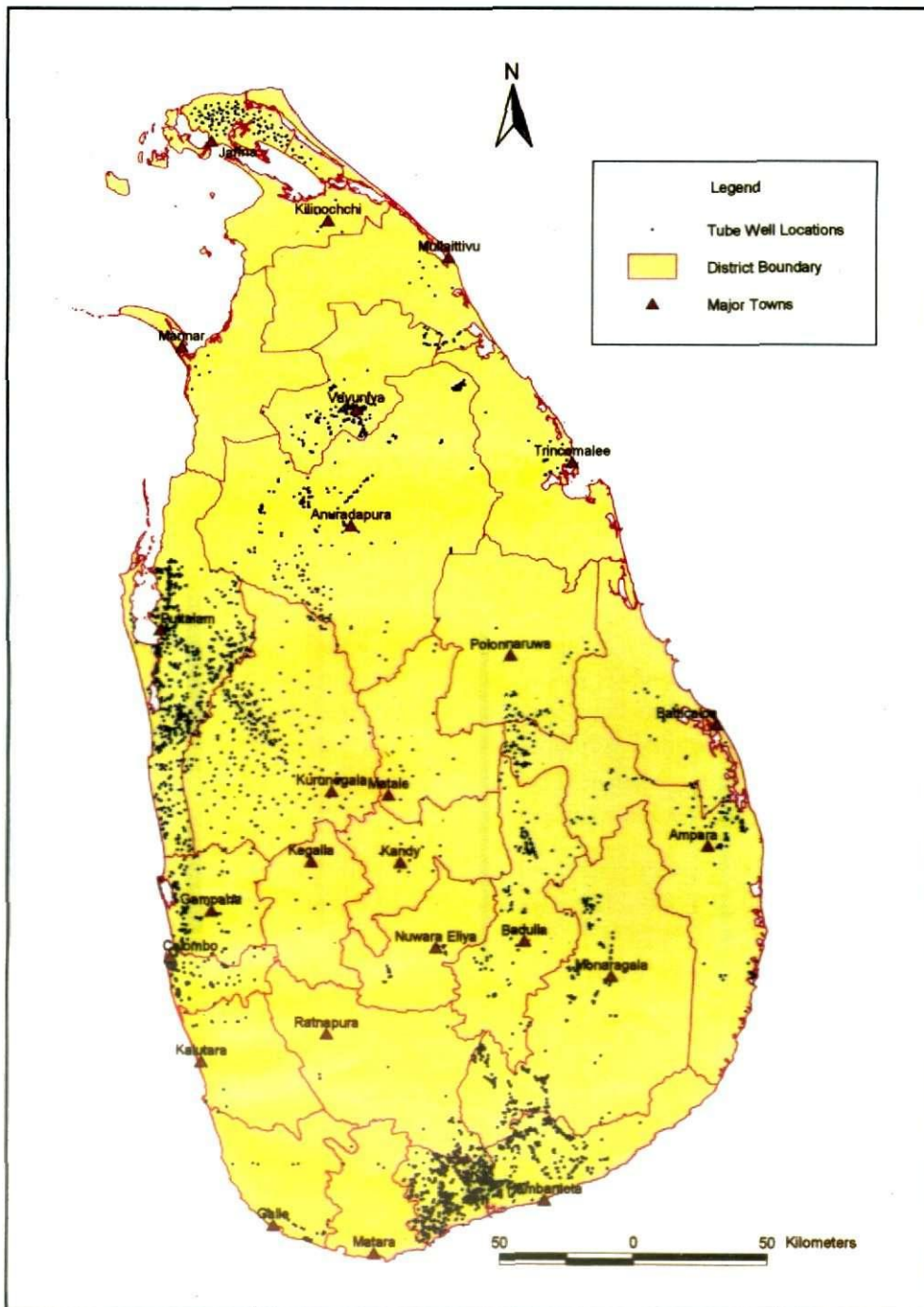


Figure 2.1 Distribution of tube wells

## Groundwater Maps of Sri Lanka

Among the maps on groundwater published, the first scientific map showing the groundwater regions of Sri Lanka was that of A. D. N. Fernando, 1968. It shows three groundwater zones for the sedimentary formation and four zones for the crystalline complex. Figure 2 . 2 shows three of the groundwater zones for the sedimentary formations and the laterite mantle on the crystalline complex.

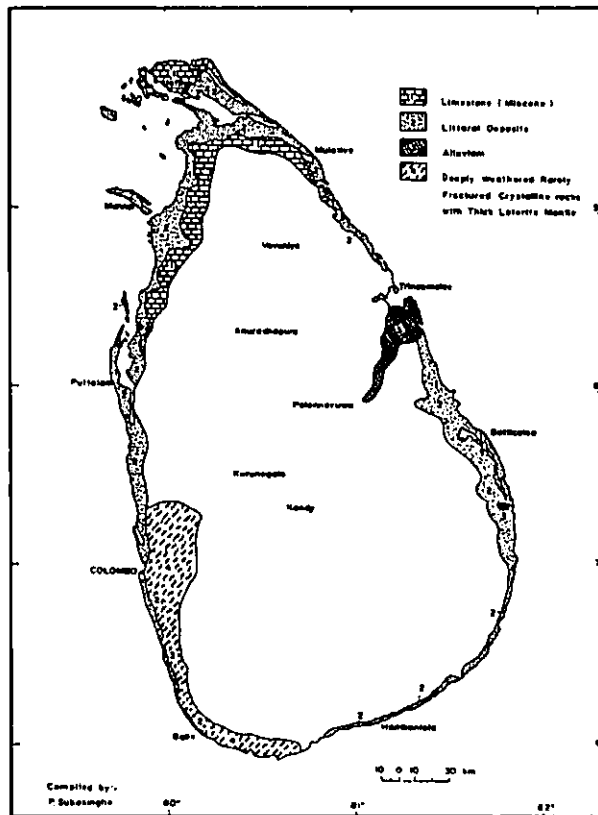


Figure 2 : 2 Groundwater zones (after A. D. N. Fernando, 1968)

The first hydrogeological map of Sri Lanka which shows the principal water bearing formations of the island was by M.W. P. Wijesinghe (1972) and is shown in Figure 2 . 3. This map depicts the main water bearing formations identified to date in the country. They fall naturally into two main groups, namely (a) the crystalline rocks and their weathered products and (b) the sedimentary formations. A further subdivision can be made on the basis of climate into those of the wet zone (south west sector) and those in the dry zone in the rest of the island.

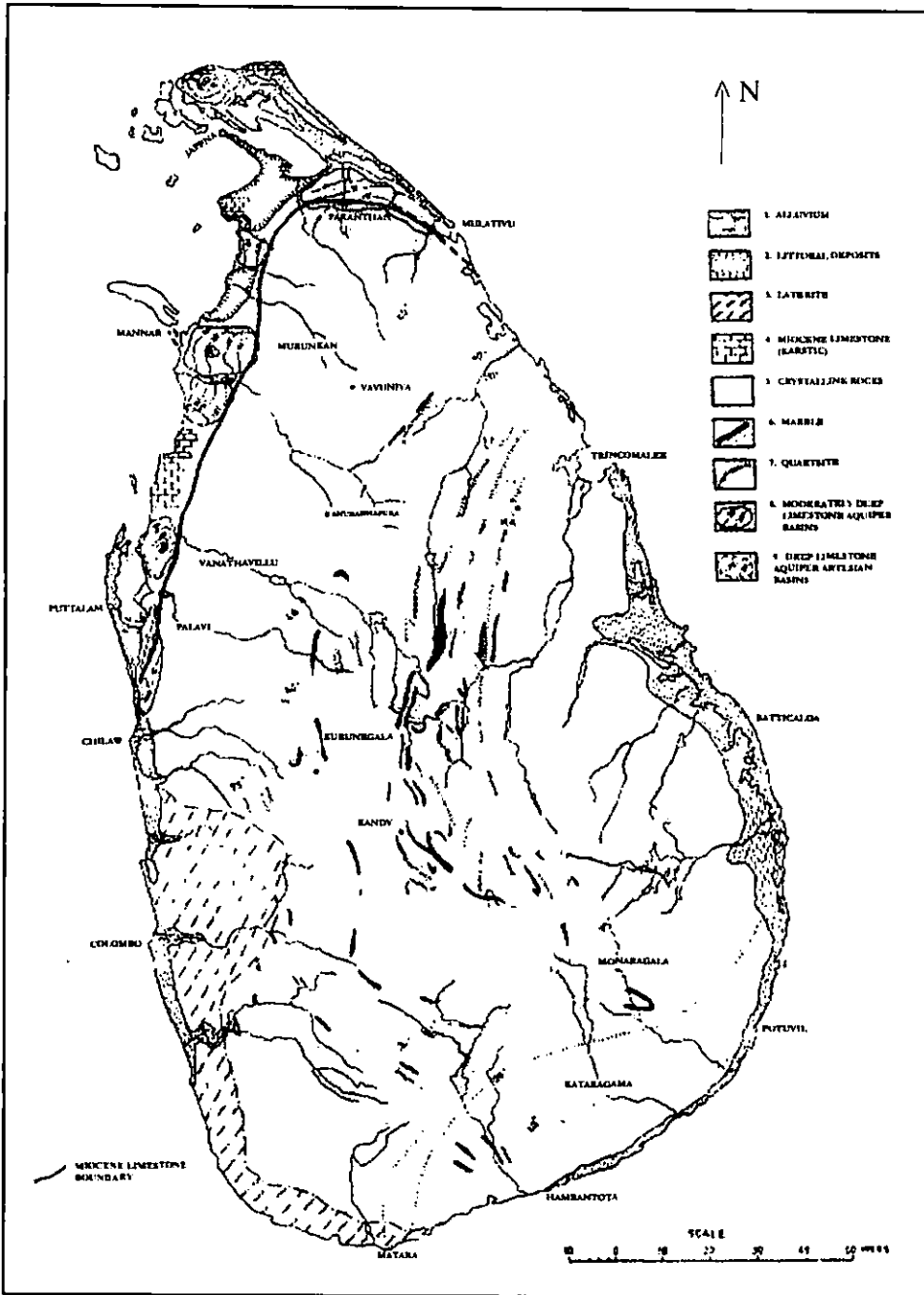


Figure 2.3 Hydrogeological map of Sri Lanka (after M.W.P. Wijesinghe, 1973)

In the National Atlas of Sri Lanka (1988), a groundwater map (scale 1:1,000,000) together with an explanatory text by A. G. N. Wijesekera is shown on pages 40 and 41 of the Atlas. In the legend, the following map units are shown. These are referred to as 'Hydrogeological Features' in the same legend.

- Map Unit 1 : Local or discontinuous productive aquifer in intergranular rock.
- Map Unit 2 : Extensive and highly productive aquifer
- Map Unit 3 : Local or discontinuous productive aquifer in fissured rock.
- Map Unit 4 : Local or discontinuous moderate to low aquifer in fractured rock.
- Map Unit 5 : Rock with local and limited groundwater resources.

In addition, the map and legends show the direction of groundwater flow and the limits of the limestone belt from the sea coast. The location of springs together with groundwater basin boundaries are also shown in this map of scale 1:1,000,000.

Hapugaskumbura's, groundwater map proper of Sri Lanka published in Arjuna's Atlas of 1997, contains the most upto date information that could be included in a map of scale 1:1,650,000 for that period, and could be considered a good reference source.

## **Recent Publications**

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Among the more recent publications that merit consideration, special mention should be made of two symposia held in 1997 and 2002 respectively. The first, held on 2 December 1997 on *Groundwater Utilization for Crop Production in the Dry Zone of Sri Lanka* and the second, held on 30 September 2002 on *Use of Groundwater for Agriculture in Sri Lanka* contain the most recent knowledge and understandings of the nature and behaviour of the groundwater types present in the dry zone of this country and their proper utilization. In view of the limited accessibility to readers of the contents of these two symposia, the page of contents as well as the policy guidelines for groundwater use and extraction outlined in these two symposia are reproduced in Appendix 3 (a) and (b) respectively.

Manchanayake and Madduma Bandara (1999), in their publication titled *Water Resources of Sri Lanka*, have a sub-chapter of four pages on groundwater resources. They report that the total groundwater availability in the country is estimated at around 7250 million cubic metres (mcm) per year (Fernando, 1985). This is around 15 percent of the country's water resources according to them.

Under the auspices of the World Water Assessment Programme (WWAP) supported by UNESCO, a preparatory Workshop was held in October 2004 on the Nature of Sri Lanka's Water Resources and Its Demands and Management Challenges. The present status of the groundwater resources was presented by C. R. Panabokke and Lasantha Perera, and groundwater and ecosystems by R. N. Karunaratne, General Manager, WRB. Also, in press is the latest version of the National Atlas of Sri Lanka to be published by the Survey Department in which the chapter on groundwater is written by R. N. Karunaratne of the WRB.

A 28 page publication titled "*Groundwater Resources of Sri Lanka*" by C. R. Panabokke and Lasantha Perera was published by the Water Resources Board in January 2005.

Its chapter content is as follows:

<u>Chapter No.</u>	<u>Chapter title</u>	<u>Pages</u>
1	Groundwater Types in Relation to Physical Features	1 - 10
2.	Groundwater Resources-Variation in Time and Space	11-13
3.	Human Impacts on Groundwater Resources	14-16
4.	Data and Information on Groundwater Resources	17-21
5.	Present Groundwater Uses and Needs	21-24
6.	Future Needs	25-29

## **Abstracts of Thematic Papers**

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### **1. The hydrogeology of the Miocene Sedimentary Belt of Sri Lanka**

**J. Davies and R. Herbert**

**British Geological Survey, Hydrogeology Group, Wallingford, U.K.**

A study of the aquifers of the Miocene Sedimentary Belt of north-western Sri Lanka has revealed the presence of the major source of potable groundwater within the island.

The large volume of hydrogeological and related data, collected during a twenty-year period of investigation and development of groundwater resources, was used as the basis of the compilation of a series of geological and hydrogeological reconnaissance maps of the component parts of the Belt.

The reconnaissance mapping highlighted the existence of two contemporaneous areas of sedimentation within the Belt during the post-Jurassic period. Predominantly arenaceous sediments were deposited adjacent to an unfaulted area in the north-eastern sector, whereas shallow, marine carbonates were deposited along the margin of a subsiding trough in the north-western part of the Belt. These different modes of sediment deposition and hence aquifer type are explained by possible tectonic controls.

The economic benefits of groundwater resource development have been proved in several areas within the Belt. Reconnaissance hydrogeological mapping indicates the presence of significant, still undeveloped, groundwater resources within the Miocene aquifer system. If the economy of the country is to benefit fully from the development of this valuable natural resource, a programme of detailed investigation must be undertaken so that the full development potential of the resource can be realized.

### **2. The regolith aquifer of hard-rock areas and its exploitation with particular reference to Sri Lanka**

**R. Herbert, D.K. Ball**

**British Geological Survey, Hydrogeology Group, Wallingford, U.K.**

**I.C.P. Rodrigo**

**Water Resources Board, Gregory's Avenue, Colombo 7,  
and**

**E.P. Wright**

**Consultant Hydrogeologist, Aston Tirrold, Oxfordshire, U.K.**

The British Geological Survey and the Water Resources Board have been studying aspects of the hydrogeology of the shallow-weathered zone of the hard-rock areas of Sri Lanka for the last five years. The key findings include the following:

- There is a water-table at the regolith-hard rock interface over most of Sri Lanka.
- The most permeable zone is in the top of the interface, in the Sap Rock.
- Even during long droughts, low points on the interface retain exploitable water.

Drilling rigs have been designed which can drill out horizontal screens from dug wells, converting them into collector wells. About twenty collector wells have been constructed to date in Sri Lanka, Malawi and Zimbabwe. Those collector wells have yields about three times the dug well, are more economical and will give sustained yields throughout the dry season. The safe yields calculated, assuming there may be a 3-6 month dry period, were largely in the range 1.4 litres per second.

### 3. Hydrology of a metamorphic terrain : a case study from Hambantota, Sri Lanka

N. Kulatunga

Water Resources Board, Gregory's Avenue, Colombo 07.

An attempt is made to understand the hydrogeological characteristics of a metamorphic terrain in the district of Hambantota. The rocks are massive and there is no intergranular porosity, but a secondary porosity has been created by the processes of weathering and fracturing which depend mainly on geology, tectonics and meteorological factors. The vertical and lateral inhomogeneity of the subsurface is inevitable. Different stages of weathering and degree of fracturing are important in determining aquifer properties. A moderately weathered zone and / or fractured zone make up an aquifer, providing that they are in hydraulic continuity with a recharging zone either vertically or laterally. The weathered and fractured zones together may form a hydraulically continuous water-table aquifer. On the other hand, any individual fractured zone may not necessarily be in direct vertical hydraulic continuity with the surface and the potentiometric surface may lie well above the fractured zone; that can, therefore, be considered as confined at that point. Transmissivity is very low where there is poor development of fractured / weathered zones.

The groundwater chemistry of this hydrogeological regime reflects the importance of the local groundwater movement, but regionally the groundwater shows a smooth flow from higher potential areas inland to lower potential coastal areas. There are pockets of good quality groundwater within the general bad quality areas, and vice versa. The electrical conductivity of groundwater has more or less the same pattern as the distribution of chloride. More hydrogeological studies should be carried out to determine the origin of high fluoride which has made the occurrence of groundwater more complex.

### 4. Nitrates in the groundwater in Sri Lanka – Implications for community health

C.B. Dissanayake

Department of Geology, University of Peradeniya, Peradeniya

Pollution of groundwater by nitrates is receiving increasing attention in Sri Lanka in view of the fact that nitrogenous fertilizers as well as human waste matter from septic tanks enter the groundwater. A survey of nitrates in the groundwater of Sri Lanka has shown that nitrates tend to accumulate in groundwater in regions of high population density. The Wet Zone of Sri Lanka has higher nitrate levels, possibly due to the shallow water-table into which nitrates percolate easily from the surface. It has also been revealed from tracer experiments that there is a risk to groundwater supplies from pit latrine soakaways in Sri Lanka. Nitrates which could be converted into carcinogenic substances such as nitrosamines within the body are of importance in the incidence of oesophageal cancer in Sri Lanka.

### 5. Review of the pollution threat to groundwater in Sri Lanka

A. R. Lawrence, P. J. Chilton

Hydrogeology Group, British Geological Survey, Wallingford, United Kingdom,  
and

D. S. Kurupparachchi

Department of Agriculture, Peradeniya

Groundwater is an important source of potable water in Sri Lanka. However, little attention has been given to the pollution risk to the supplies despite the increasing threat posed by both modern intensive agriculture and the disposal to ground of industrial and domestic wastes. This paper attempts to review the vulnerability to pollution of the coastal sand, limestone and crystalline basement aquifers of Sri Lanka and the activities likely to generate contaminants.

Monitoring of groundwater quality has shown that some aquifers in Sri Lanka are already contaminated by agrochemicals leached from intensively cultivated soils and by domestic wastes discharged via pit-latrines soakaways.

## 6. Use of remote sensing methods for estimating the groundwater potential of Sri Lanka

A. Denis N. Fernando

Ministry of Mahaweli Development, 500, T.B. Jayah Mawatha, Colombo 10.

The groundwater potential or safe yield was determined first by delineating the hydrogeology using remote-sensing methods. Thereafter these hydrogeological units were subject to their rainfall/infiltration relationships to determine the mean annual gross groundwater infiltration. Losses due to evapotranspiration and subsurface flow were estimated and deducted from the gross groundwater infiltration to determine the net groundwater recharge or safe yield, which is the annual groundwater potential.

Satellite images are suitable for reconnaissance-level mapping whereas aerial photographs are suited for both reconnaissance as well as semi-detailed mapping. In any development planning exercise, detailed surveys should be preceded by semi-detailed mapping.

The 1<sup>st</sup> Approximation of the groundwater potential of Sri Lanka that was determined in 1973 was a very conservative estimate of 5.9 million acre-feet per annum, using reconnaissance-level hydrogeology maps. The 2<sup>nd</sup> Approximation, using semi-detailed hydrogeological maps was determined in 1983, and gave a safe yield of 10 million acre-feet per annum; this included not only the natural recharge through rainfall, but also recharge from artificial means such as irrigation issues, and this 2<sup>nd</sup> Approximation is a more realistic figure.

## 7. A note on a low-cost defluoridation method for rural water supplies

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It has been observed by many geoscientists that the mineral serpentine (magnesium hydroxyl silicate) has the remarkable property of removing fluoride in water. In the areas of high fluoride (in groundwater) in the Mutale and Polonnaruwa districts, the tube wells drilled in marble and granulite contain very low fluoride concentrations. This appears to be due to a fluoride-uptaking property in these rock types. Based on these results, a sample of marble containing serpentine was introduced in a UNICEF-type iron-removal plant and installed in a tube well with high fluoride.

In the filtered water samples from the plant, an increase of pH, electrical conductivity and alkalinity and a remarkable decrease in fluoride concentration were observed. It was also noted that the final concentration of fluoride varied with the flow rate and the contact time of the water with the serpentine marble. With the aim of further development of the plant and implementing it on village level, investigations are now in progress.

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### 3

## GEOMORPHIC SETTING AND GENERAL DISTRIBUTION OF THE MAIN AQUIFER TYPES

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This Chapter discusses the geomorphic setting and the pattern of distribution of the main aquifer types found within the country. All six types of aquifers identified and studied to date, will be considered in the context of their position in the landscape, and their geographic spread across the country.

In the subsequent Chapters 4 to 9, the nature and behaviour of the individual aquifers, as well as their present state of utilization, will be discussed in the context of reported studies carried out on them to date.

### Some Basic Considerations

It is now recognized that the more rewarding approach to the study of the various aquifer types in this country, is from the standpoint of their geomorphic setting in the regional landscapes, together with the hydrology of the landscape on which it occurs. In his several publications on groundwater in this country, C. H. L. Sirimanne was able to clearly bring out the overall geomorphic setting of the various types of aquifers that he studied, and to relate their behaviour to the overall hydrology of the landscapes.

Around the same time, it was apposite that the National Soil Survey of Ceylon, which commenced in 1960, had from its commencement, given special emphasis to the study of the soil in the landscape. This was best exemplified in its groundbreaking study of the landforms and soils of the area between the Malwathu Oya and Kelani Ganga river basins, an area of approximately 19,500 km<sup>2</sup>. This study was carried out in collaboration with the Hunting Survey Corporation of Canada, as a Colombo Plan assisted project. The main landforms together with the *soil catena* were the basic mapping units employed in this study. This made it possible to bring out clearly the geomorphic position as well as the space occupied in the landscape by each of the soil mapping units. A total of 17 soil catenas were identified and mapped at a scale

of 1:63,360 (1 inch to the mile) on topo sheets of the Survey Department. The results of this survey were published in two volumes together with a soil map of 1:250,000 scale in 1963. (see Kelani – Aruvi Report in reference).

A close equivalence between the soil map units of the coastal plain and the main aquifer types present within this survey area, was clearly evident in the main outcome of this study. This was particularly so in the case of the soil map unit of red-yellow latosols (Gambura and Wilpattu catenas) which were found to be co-terminus with the deep confined and semi-confined groundwater aquifers later identified in the north-western sedimentary formations.

On similar lines were the outcomes from the National Soil Survey Project, which mapped the whole extent of the dry and intermediate zones of the country, at a 'great soil group' level. The special merit of the great soil group is that it occupies a specific space and position in the landscape, and the close equivalence between a great soil group region and a hydrogeological domain could be used to advantage in demarcating recognized groundwater regions.

By 1969 the first Great Soil Group Map of Ceylon at a scale of 1:500,000 was published by the Land Use Division of the Irrigation Department. A close equivalence among four of A. D. N. Fernando's (1968) groundwater zones, and four great soil group regions of the dry zone was clearly observed.

By 1971, an updated Soil Map of Sri Lanka was published by the Land Use Division; and the *soil landscapes* or *soilscales* were characterized and described by Panabokke (1996). The first hydrogeological map for the country was published by Wijesinghe 1973 (see Figure 2 . 1 of previous Chapter) which shows the principal water bearing formations as well as the sedimentary limestone aquifers. Of the nine hydrogeological map units shown in Wijesinghe's 1973 map, six could be co-related with corresponding soil landscape units as follows :

<b>Hydrogeological Map (1973)</b>	<b>Soilscape (1996)</b>
1. Miocene limestone (Karst)	Calcic red latosols (shallow)
2. Deep limestone aquifer basin	Deep red latosols (Flat terrain)
3. Littoral deposits	Regosols on beach sands(Flat terrain)
4. Laterite	RYP with laterite(Undulating terrain)
5. Alluvium	Alluvial soils (Floodplains)
6. Crystalline rocks	RBE-LHG on hard rocks (Undulating terrain)

Based on the foregoing relationship, a map on scale 1:2,000,000 showing the main aquifer types present in the country together with a supporting Schematic Table 3 . 1 which indicates the location - distribution of these aquifers was prepared by Panabokke (1998). This master map and supporting Table 3 . 1 are shown here, which shows the main aquifer types and is designated as Figure 3 . 1 ; and its companion map which shows the equivalent soilscales is shown in Figure 3 . 2.

Table 3 . 1

**Schematic table showing the main aquifer types and their equivalence with the corresponding soilscape unit**

<i>Aquifer Type</i>	<i>Location – Distribution</i>
1. <u>Shallow Karstic aquifer</u> (Weathered Karstic Miocene Limestone)	<ul style="list-style-type: none"> <li>• Jaffna peninsula, only and</li> <li>• some outer islands.</li> <li>• <u>Co-terminus with calcic red latosols</u></li> </ul>
2. <u>Deep Confined Aquifer</u> (Vanathavilju – Mulankavil – Mannar – Paranthan Basins)	<ul style="list-style-type: none"> <li>• Sedimentary Miocene limestone basement of North-West region</li> <li>• <u>Co-terminus with latosols of soil map*</u></li> <li>• Puttalam, Mannar, Mullaitivu districts coastal plain</li> </ul>
3. <u>Dry zone Metamorphic Hard Rock</u> a. <u>Shallow</u> Groundwater of Small Tank Cascade System (STCs) and Inland Valleys  b. <u>Deep</u> Groundwater of Joints, Fracture zones and Fissures of Basement Rocks (Bore-hole type)	<ul style="list-style-type: none"> <li>• NCP and NWP – Type locations. Some in NP and SP.</li> <li>• <u>Co-terminus with RBE – LHG and NCB-LHG of soil map*</u></li> <li>• Sporadic</li> <li>• Tube wells of NWS &amp; DB</li> <li>• Mainly Urban and few rural areas of dry zone</li> </ul>
4. <u>Shallow to Moderately Deep Aquifers on Unconsolidated Coastal Sands</u> a. <u>Shallow</u> aquifers on coastal spits - Kalpitiya type  b. <u>Shallow</u> aquifers on coastal sands - raised beaches  c. <u>Moderately Deep</u> aquifers of North-west coastal plain – Pleistocene deposits	<ul style="list-style-type: none"> <li>• Kalpitiya, Mannar Island</li> <li>• Co-terminus with sandy regosols of soil map*</li> <li>• South and south west lower coastal plain</li> <li>• Raised beaches of eastern coastal plain – Kalkudah, Batticaloa, Pottuvil, Nilaweli etc.</li> <li>• <u>Co-terminus with regosols of soil map</u></li> <li>• Chilaw, Negombo, Puttalam, Katunayake</li> <li>• <u>Co-terminus with regosols and latosols on old red and yellow sands.</u></li> </ul>
5. <u>Laterite Region Aquifer of South West Mid-coastal Plain (Cabook Region)</u>	<ul style="list-style-type: none"> <li>• Gampaha, Colombo, Kalutara and part of Galle-Matara</li> <li>• <u>Co-terminus with RYP on soft or hard laterite</u></li> </ul>
6. <u>Alluvial Aquifer</u> Medium, Deep and High Yielding	<ul style="list-style-type: none"> <li>• Kelani, Deduru, Mahaweli, Walawe, Kirindi Oya Alluvial</li> <li>• Buried river beds – high yield</li> <li>• <u>Co-terminus with alluvial soils of soil map*</u></li> </ul>

### 7. Wet zone Metamorphic Hard Rock

#### Water Tables of Variable Depth

a. Low Ridge and Broad valley Land -  
form of Lower Peneplain.  
Shallow open dug wells (domestic)

- Low country wet and semi-wet zone

b. Inland valleys of Dissected Middle  
Peneplain Shallow open dug wells  
(domestic)

- Mid country wet zone

### 8. Miscellaneous Types

a. Springs of high discharge

- Bandarapola – Matale
- Keppitigollewa – Anuradhapura

b. Springs of low to medium discharge

- Ubiquitous
- 225
- 120 – Central Highlands

c. Hot (Thermal) Springs

- Maha Oya, Kanniyai, Mahapellessa

\* 'Soil map' refers to soil map of the National Atlas 1992.

Two other groundwater conditions which provide an unfailing source of domestic water supply in the low-country and mid-country areas of the wet zone of the country, could not be accommodated in this map and schematic table, because of the present uncertainty of their hydrogeological boundaries. Instead, schematic cross sections of the nature of their occurrence in the landscape is shown within the text of Chapter 10, together with schematic figures.

In the rest of this Chapter, a brief description is given on the geomorphic setting and the nature of distribution of the main aquifer types present in the country.

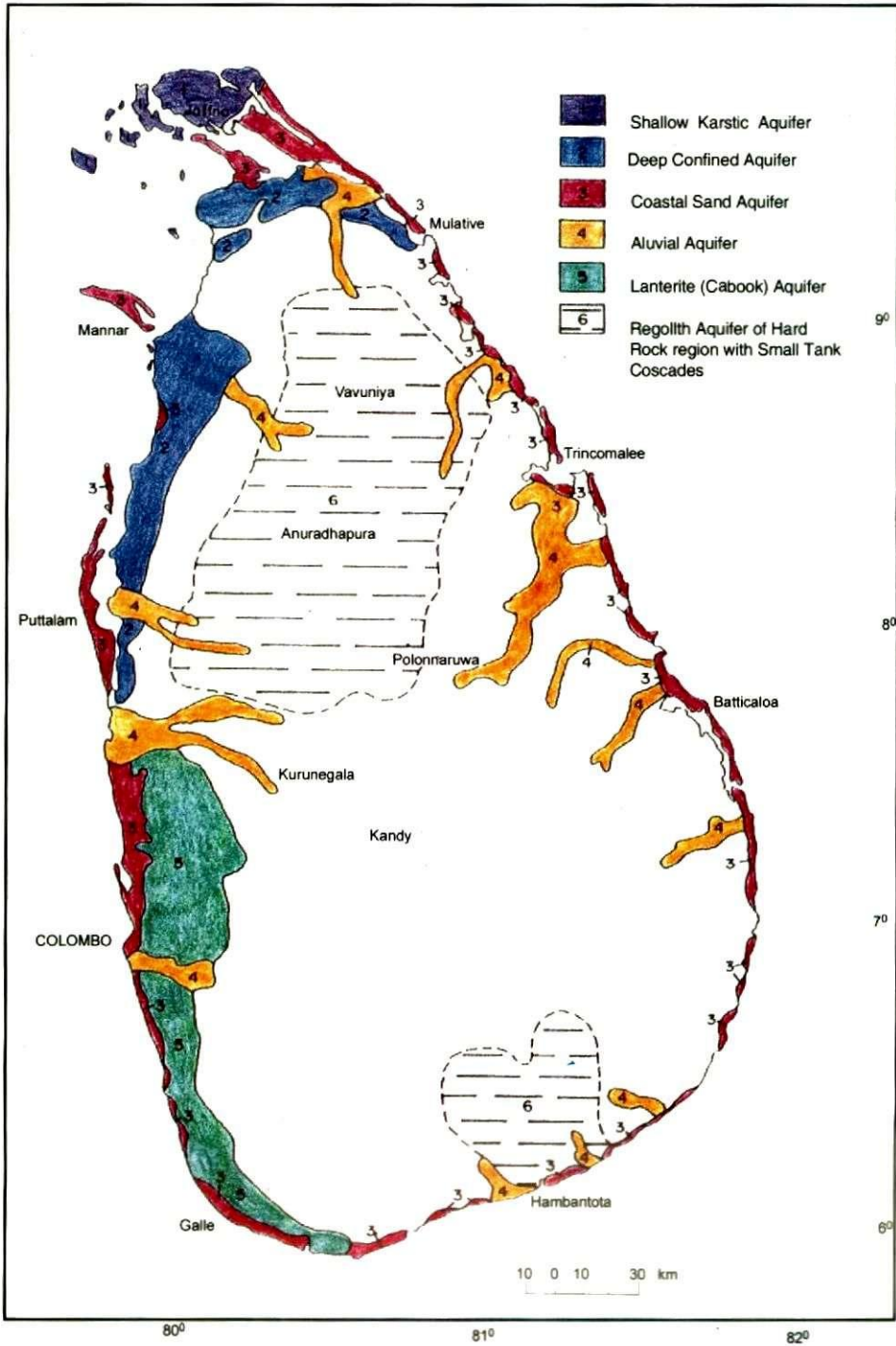


Figure 3. 1 Main aquifer types in Sri Lanka

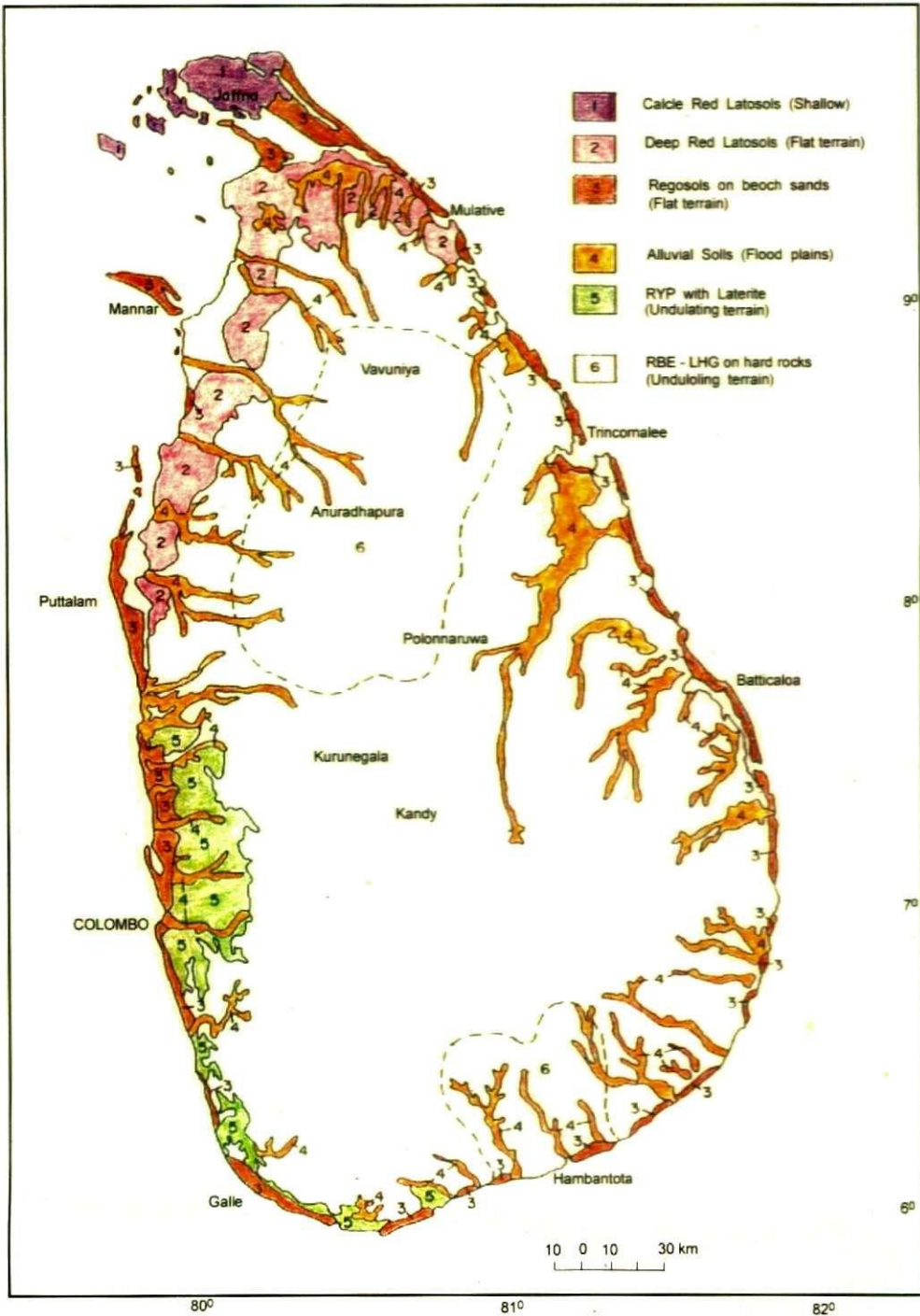


Figure 3. 2 Soil landscape (soilscape) map of Sri Lanka

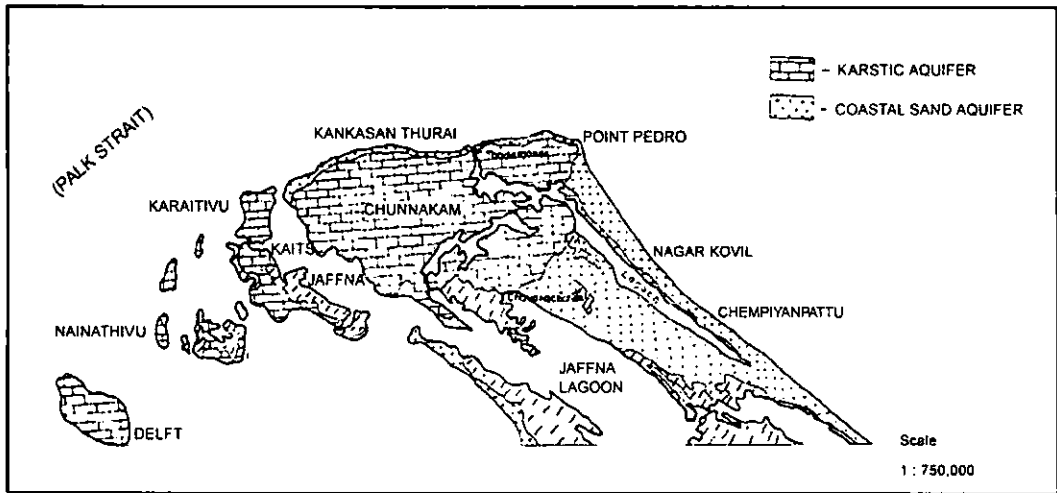


Figure 3.3 Karstic aquifer - Jaffna peninsula

### Shallow Karstic Aquifer

When comparing this master map, Figure 3.1, with the soil map of Sri Lanka (National Atlas Survey Department, 1991), it could be seen that the shallow karstic aquifer is co-terminus with the soil map unit 7, which is termed *Calcic red yellow latosol*. Hence, this soil map unit could be taken as the area occupied by the shallow karstic aquifer (see also the schematic table number 3.1). According to Hapugaskumbura's Groundwater Map of 1997, this groundwater type extends to the outer islands of Karainagar, Kayts, Delft, Punkuditivu and Nainativu as well.

The location and distribution pattern of the Karstic aquifer across the Jaffna peninsula, are shown in Figure 3.3. The peninsula itself forms the northern extremity of the country and has the sea (Palk strait) on its western, northern and eastern sides, and the Jaffna lagoon on the south. An internal lagoon divides the eastern half of the peninsula into two segments, with a northern outlet at Thondaimannar and a southern outlet at Ariyalai.

It could be seen from Figure 3.3 that the Karstic aquifer is mainly distributed across the western half of the peninsula and its outer islands. The eastern half of the peninsula beyond Point Pedro and Chavakachcheri is mainly made up of sandy regosols on recent beach and dune sands, and this supports a different type of aquifer. Although the general soil map of Sri Lanka (1991) shows the soils of the outer islands as 'soils on recent calcareous sediments', these are also underlain by the Jaffna limestone, and the groundwater conditions in these soils are the same as in the Karstic aquifer.

The Jaffna peninsula is underlain by Miocene limestone formations which are generally 100 to 150 m thick, and which are distinctly bedded and well jointed, and are highly karstified.

The special conditions governing the occurrence of groundwater in the Jaffna peninsula according to Sirimanne (1952) "are due to joint planes, fissures, cavities, solution chambers and channels, some of considerable size, which are present in this karstic limestone. Most of these openings are being constantly enlarged by solution by the slightly acid waters which circulate in them".

According to Arumugam (1970), "the presence of groundwater in sedimentary rocks such as limestone cause the formation of sink holes which, with time, enlarge becoming underground caves or solution caverns. Thus, sink holes, caverns and stream passages are commonly found in limestone formations. The term 'Karstic' which originally referred to the Yugoslavian plateau, has now become of wide application to the foregoing conditions".

The terrain throughout the peninsula is flat and it reaches the highest elevation of 10.5 m in the area around Tellippalai. From here it slopes gently towards the south and the east, but towards the north the elevation tends to drop abruptly as the sea is reached, giving rise to a series of low cliffs. The well known seepage channels could be seen along the northern beach from Keerimalai towards Kankasanturai, where during the month of January many of these springs are seen flowing out.

## **Deep Confined Aquifer**

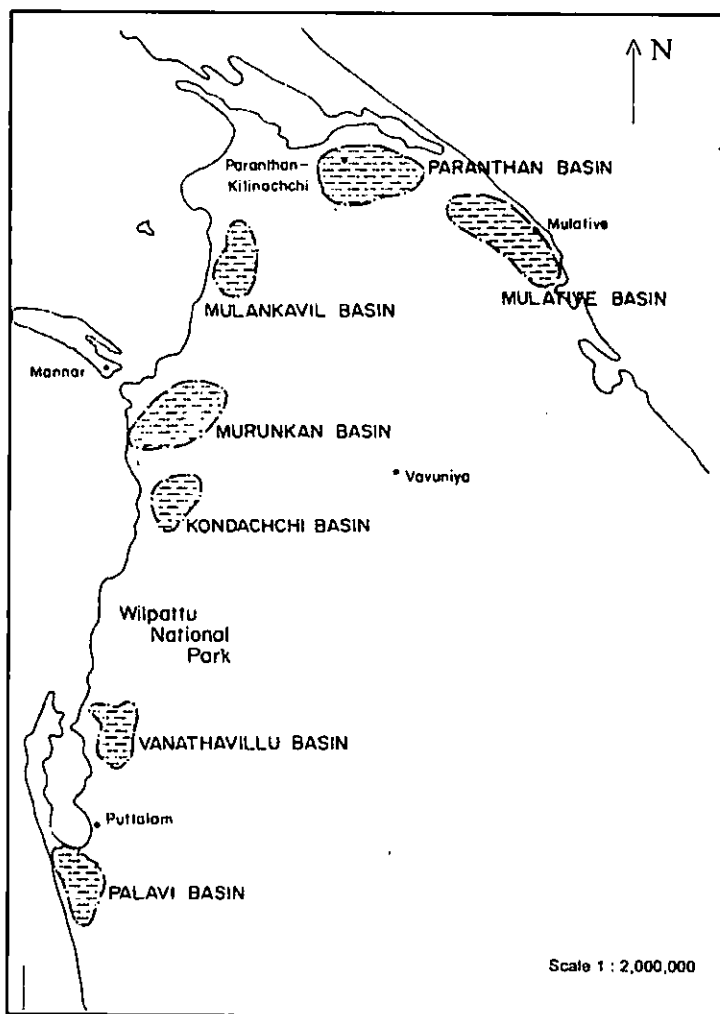
The Miocene age sedimentary strata that underlie the north-western and northern coastal plains of Sri Lanka form the largest sedimentary aquifer system in the island. Although it is one of the very well studied aquifer systems in the country, it is at present the least utilized in respect of its proven potential.

When comparing the master map Figure 3 . 1 with the Soil Map of Sri Lanka (National Atlas 1992) it could be seen that the area occupied by this deep confined aquifer is co-terminus with soil map unit 6 which is termed *red-yellow latosol*. Even on a larger scale map the relationship is so close that the type location for this deep aquifer could be taken as this same soil map unit. (See also supporting schematic Table 3 . 1)

The north western and northern coastal plain are mainly underlain by Miocene and Quaternary sedimentary formations, which extend from Puttalam to Jaffna peninsula, and then towards Mullaitivu. The Miocene limestone in this area is highly karstic and carries most of the flow in thin bands.

The sedimentary limestone in this area is highly faulted, and it separates the aquifers into a series of isolated blocks, which form a number of separate groundwater basins. Seven distinct aquifer basins have been identified, studied and mapped at different scales of detail over a period extending from late 1960's to the early 1980's . From south to north these seven semi confined aquifers are shown in Figure 3 . 4.

- |    |                    |    |                  |
|----|--------------------|----|------------------|
| 1. | Palavi basin       | 4. | Murunkan basin   |
| 2. | Vanathavillu basin | 5. | Mulankavil basin |
| 3. | Kondachchi basin   | 6. | Paranthan basin  |
|    |                    | 7. | Mullativu basin  |



**Figure 3.4** Semi - confined aquifers of the Miocene Belt

Aquifer boundaries have been approximately demarcated in respect of the Vanathavillu, Murunkan and Mulankavil aquifer basins.

## **Metamorphic Hard Rock Region of the Dry Zone**

### *Shallow Regolith Aquifer*

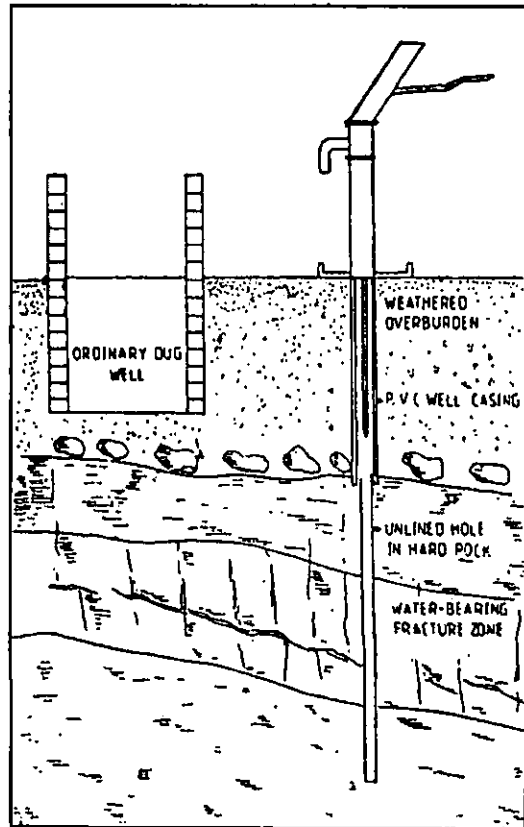
The crystalline basement complex, which is also referred to as the hard rock region of Sri Lanka, covers around 80 percent of the island and nearly two thirds of this falls within the dry zone of the country. The unweathered crystalline rocks, by their very nature are relatively impervious and non-porous. Although these rocks do not show any primary porosity, a secondary porosity could develop by the process of weathering and fracturing. Limited quantities of groundwater could be held within this fractured and weathered zone. However, because of the low groundwater storage capacity and low transmissivity of the underlying basement rocks, geologists have recognized that the groundwater potential in the hard rock regions of this country is limited.

The foregoing assertion has been further affirmed by L. J. D. Fernando (1950), a former Director of the GSD who states:

“ The surface and sub-surface geology of the Island is unfavourable to the retention of large volumes of underground water. With the exceptions of the north-west coastal belt extending from the Jaffna peninsula to Puttalam, and the narrow coastal tracts in other parts, the bulk of the Island is composed of a complex of ancient crystalline rocks that have no capacity to hold or transmit water except where they are decomposed or disintegrated to appreciable depths. The system of joint planes and fissures traversing this complex are too fitfully and sporadically developed to support any active circulation, and the rocks are hydrologically inert. These adverse factors rule out possibilities of tapping large underground reserves of water in the compact crystalline rocks, except under very rare circumstances by the chance meeting of a system of wide fissures connecting with the surface.”

However, the work of the British Geological Survey in recent years on the ‘blanket’ that overlies the granites, gneisses, schists and other crystalline bedrock formations in Asia, Africa and the Americas (Brazil) have helped to modify some of the earlier held pessimistic views of the groundwater potential of the so called ‘hard rock’ basements. Groundwater flowing through weathered rock, sometimes referred to as ‘regolith’ or ‘saprolite’ is able to provide a modest but significant well yield and, in many places, is the only source of potable water supply that is available to rural communities.

For several years the British Geological Survey had also been investigating the nature of the aquifer within the regolith of the hard rock areas in tropical Africa and South Asia, a large part of which is underlain by crystalline basement rocks. Their investigations have shown that groundwater in these areas occur in two main forms, namely (1) *the shallow regolith aquifer* and (2) *the deeper fracture zone aquifer*. Development of the regolith aquifer component is normally carried out by digging wells (dug wells), whereas development of the fractured bedrock component is typically carried out by drilling deeper boreholes. (see Figure 3 . 5)



**Figure 3.5** Shallow dug wells in overburden and deep bore wells in fracture zone  
(after Dissanayake, 1989)

In the course of studies conducted on the shallow weathered zone of the hard rock areas of Sri Lanka, Herbert et al. (1988) have observed that the groundwater in these areas occur both in the regolith (weathered and residual overburden) and in the fractured bed rock. In many places the uppermost section of the basement complex has been altered by weathering processes, to form a distinct horizon termed 'regolith'. The regolith as shown in Figure 3.6 is made up of three main subdivisions namely (a) *collapsed zone* extending up to 3 m in thickness and lying above the water table; (b) *saprolite*, which is commonly termed highly weathered rock; and (c) *saprock*, which is slightly weathered rock where the fractures are likely to be more open than in the fresh bedrock, and in the absence of illuviated clay, permeability could therefore be high.

Mostly the water table is found within the saprolite, which provides substantial storage for extraction. The water holding and transmissivity capabilities of these regolith aquifers are

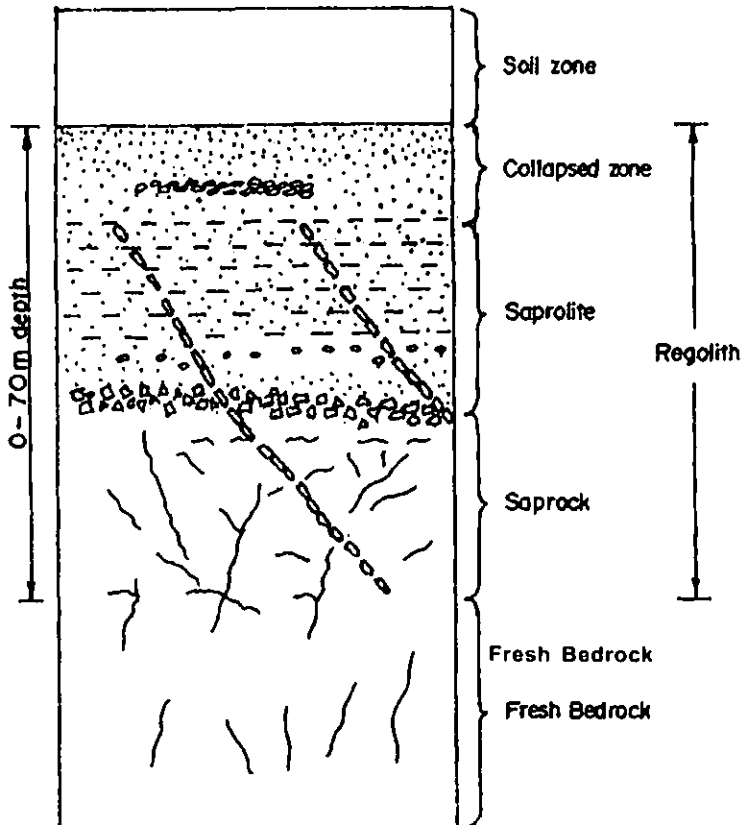


Figure 3.6 Typical regolith profile above crystalline basement rocks

limited, and they are also very shallow in nature, extending up to a maximum depth of 10 to 12 m. Large diameter agrowells, as well as domestic wells, are located mainly within this regolith aquifer.

### *Deep Fracture Zone Aquifer*

In contrast to the shallow regolith aquifer, the deep fracture zone aquifer occurs at depths of around or beyond 30 to 40 m in the hard metamorphic rock regions, wherever the deeper tectonic forces have caused some degree of jointing or fracturing of the underlying basement complex. The groundwater occurring in this zone of jointing or fracturing is referred to as the *deep fracture zone aquifer*. A schematic profile showing the sequence from soil – saprock – bedrock – fissures – joints is shown in Figure 6.3 in Chapter 6.

The occurrence of these fracture zones is more sporadic or random, and is related to the lineaments that occur in this hard rock region. Drilled boreholes or bore wells abstract the groundwater from these deep fracture zone aquifers. The average depth of bore wells in Sri Lanka is around 40 m and in some instances, a few could go down to 70 m. In a recent

hydrogeological study carried out in the Hambantota and Moneragala districts by the JICA and WRB (2003), the fractured aquifer in the study area was categorized into three parts, namely the upper fractured aquifer, the lower fractured aquifer, and the deeper fractured aquifer. This was the first groundwater study that confirmed the occurrence of a productive aquifer below 100 m. These were at Bodagama, Badalkumbura and Yalabowa in the Moneragala district.

Electrical resistivity methods are one of the important tools employed in groundwater exploration, and in the location of suitable sites for constructing bore wells. The method enjoys wide popularity due to its simple field, as well as interpretational technology and its relatively high success rate. In recent decades, satellite image data has also been extensively used to identify potential zones, particularly in hard rock areas. Basically, this involves identifying lineaments which are assumed to be fracture zones, and thus supposedly, potential groundwater zones. In most of the present day investigations, lineament maps are prepared, before resistivity investigations are carried out for locating well sites.

In neighbouring Tamil Nadu, the depth of bore wells drilled in the area, has been steadily increasing over the years. The average depth was about 60 m for all bore wells drilled up to 1982, while in 1992 it has reached 192 m. If continued, the average depth is likely to be over 270 m by the year 2020, by when it is doubtful that recharge could take place at such depths. This is fortunately not the case in Sri Lanka, where the average depth of bore wells or deep tube wells show no increasing trend over the years.

Yield measurements carried out on the bore wells or tube wells in Sri Lanka indicate that it varies over a wide range from 0.1 to 2.0 l/sec, with a median value of 0.35 l/sec.

### *Distribution Patterns*

At present it could be stated that the shallow regolith aquifer occurs in association with the small tank cascade systems, as shown in Figure 3.1.

It will also be shown in Chapter 6 that this shallow regolith aquifer occurs in some definite form along the numerous inland valleys that dissect this hard rock landscape.

In contrast, the deep fracture zone aquifer occurs at random according to the presence of lineaments in the basement rocks.

## **Shallow Aquifers on Unconsolidated Coastal Sands (Coastal Sand Aquifers)**

According to our present knowledge and understanding, three main types of coastal sand aquifers have been recognized and characterized in Sri Lanka. These are;

1. Shallow aquifers on coastal \*spits and bars i.e. Kalpitiya, Pooneryn, Mannar Island.
2. Shallow aquifers on coastal sands - † Raised beaches, i.e. Pulmuddai, Nilaveli, Kalkuda and Low sand dunes i.e. Hambantota.
3. Moderately deep aquifers on old red and yellow sands of Prior beach plains i.e. Katunayake, Chilaw.

Type 1 is located on the Kalpitiya and Pooneryn peninsulas and on the Mannar Island as shown in Figure 7 . 2 (See Chapter 7)

The Kalpitiya peninsula is what geomorphologists describe as a 'compound spit' and it is shaped like a beckoning finger. Its landforms include beach and dune formations together with salt marsh mangroves and saline flats. The Pooneryn peninsula has been built up in response to tidal currents and the small waves associated with the dry south west monsoon. The Mannar Island consists of multiple sand barriers of recent age that have been thrown up by waves of the south west monsoon and Indian Ocean swell and covers the Miocene limestone beneath.

Each of the foregoing geomorphic settings is highly conducive to the build up of the typical Gyben-Herzberg lens of fresh water floating on the underlying denser salt water (see Appendix 4). This fresh water lens is recharged only during the north-east monsoon *Maha* rainfall. Since these landforms are exposed to the sea on all sides, this thin fresh water lens is prone to leak out to the sea on all sides when it acquires a certain depth.

Type 2 as seen in Figure 7 . 2 (see Chapter 7) occurs all around the coastline of the island and is mostly located as narrow bands of raised beaches. Over three-fourths of the coastline in this country is beach fringed, and most beaches in the island are sandy. The beaches of Sri Lanka are usually narrow because of the small tidal range around the country, and also the relatively low wave energy. Where wave energy is perennially low, the beach is often only 10m across in width, and where the wave energy is higher the beaches can be more than 50 m across in width. The raised beaches that are widely distributed along the coastline lie well above the present sea level and are usually 3.0 to 3.5 m above m.s.l. These raised beaches, wherever they occur, are a moderately wide, usually more than 100 m in width, and in the well developed area they can be more than two kilometres in length. There are also 'pocket beaches' that occur along the bedrock coasts of southern Sri Lanka between Dondra and Tangalle. In all these raised beaches, the falling rainwater infiltrates into the ground and collects in the form of a fresh water lens of varying thickness, dependent on the dimension of the beach. As in the case of the previous type, any over extraction of this fresh water lens results in the 'coning' or entry of the underlying brackish or salt water into the lens of fresh water. This is particularly significant in the dry zone where the recharge of fresh water takes place only during a part of the year.

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\* Spits - Unconsolidated material or a narrow shoal projecting into the sea from the shore

† Raised Beach - A beach whose elevation is above the reach of waves of present times.

Sand dunes occur along about a fifth of the country's coastline in both the dry and wet zones, and in both seasonally high and perennially low wave energy sectors. Their best development is along parts of the northern coast, along the northwest coast intermittently and also along the southeast coast. There is an absence of prominent dunes along the southwest coast due to poor sand delivery and lack of a stable base for dune formation. Restricted supplies of groundwater occur within the various dune formations. In the Hambantota sand dunes, this fresh water occurs at a depth of around 12 m.

Type 3 as seen in Figure 7. 2 (see chapter 7), is mainly confined to the old beach plain that covers the area from Chilaw southwards to Negombo – Katunayake – Seeduwa where it is best expressed. This formation is believed to be of Pleistocene age, and once formed a part of a more extensive beach plain than is now present. On its western flank it is now protected by the Negombo lagoon, and on its eastern flank by the residual, rock floored, lower peneplain of the country. A special feature of this formation is its hydrogeological enrichment by the third-order rivers of Attanagalu Oya and Dandugam Oya which cut across this formation and thereby augment its groundwater reserve. The Negombo lagoon on its western flank also helps to prevent leakage of the aquifer to the sea. This aquifer has been subjected to more intensive studies in recent years by the WRB.

As seen in figure 7. 2 (see Chapter 7), aquifer Type 1 occurs exclusively within the dry zone, while Type 2 occurs more extensively along the coast line of both the dry and wet zones as well as the intermediate zone ; and Type 3 occurs mainly within the old coastal plain of the north west depositional plain situated in both intermediate and dry zones.

The total extent of aquifers of Types 1 and 2 is estimated at around 140,000 ha; and Type 3 at around 40,000 ha. Although this is not a very big extent for this Island Nation, it constitutes a limited but very precious resource of a highly renewable groundwater supply that supports intensive agriculture.

## Alluvial Aquifers

As could be seen by comparing figure 3 . 1 with figure 3 . 2, there is a close correspondence between the areas of the alluvial aquifers and the areas shown as alluvial soils in figure 3 . 2. On a map of scale (1:2,000,000) it is only possible to depict a generalized picture of the distribution of this aquifer and this, therefore, shows only the higher order rivers such as the Mahaweli Ganga and Deduru Oya and does not include the lower order rivers and streams. Hapugaskumbura's groundwater map of 1997 depicts most of the important alluvial aquifers of the major river systems.

The alluvial deposits of this country occur over several diversified alluvial land forms such as coastal plains, inland river flood plains, dissected and depositional river valleys, buried river channels, small rivulets and stream beds with shallow alluvial deposits, and inland valleys of varying shape, form and size with fine and coarse depositional in-fill materials.

The deeper and larger alluvial aquifers occur along the lower reaches of the major rivers that cut across the various coastal plains surrounding the low country regions. Rivers such as the Mahaweli Ganga, Kelani Ganga, Deduru Oya, Mi Oya, Kirindi Oya and Malwatu Oya have broad and deep alluvial beds of variable texture and gravel content. Cooray (1988) considers that one of the largest carriers of groundwater in this country is the alluvium, which in the major river valleys may vary from 10 to 35 m in thickness. Wadia (1940) has suggested that in the deltaic portions, the alluvial deposits would be of a greater thickness than in the valley section of the river and, therefore, one could expect semi-artesian conditions in the deltaic portions.

The minor rivers and Oyas, according to Coates (1929), have shallow valleys with irregular floors and varying in width from 70 to 150 m. These shallow valleys are usually filled with sandy clay or sand, with a basal gravel layer resting on the bedrock. These bottom gravels are important water bearing horizons and re-charge of groundwater takes place through these gravel horizons.

In the dry zone, the water table within the minor streams are mainly recharged during the wet season, while in the wet zone they contain sufficient groundwater year round.

In the narrow inland valleys of the wet zone, wells located in the lower and bottom aspects of the inland valleys have a water table through most of the year, and domestic water supplies are obtained from these throughout the year. These are all shallow aquifers which overlie the decomposing bedrock and their locations and its behaviour is well understood by local settlers from traditional times.

### **Laterite (Cabook) Aquifers of South West Sri Lanka**

It could be seen from Figures 3.1 and 3.2 that there is a very close correspondence between the laterite (cabook) aquifer and the soil map unit Red Yellow Podzolic (RYP) soil with soft or hard laterite. Hapugaskumbura's Groundwater Map (1997) clearly demarcates the laterite formation which he considers a "good carrier of groundwater depending on the texture and thickness of the laterite profile". He also observes that "water from the laterite is acidic and water level fluctuation is in the range of 3.0 to 6.0 m depending on the terrain condition".

Sirimanne (1952) considers the laterite of the south-west of Sri Lanka to be of the Malabar coast type of Kerala with a high silica / alumina ratio. The Malabar type laterite, however, occurs on a larger landscape than in Sri Lanka, and shows a deeper mantle of laterite with a very high storage capacity for groundwater. Several workers have described laterite profiles in this country and it is well documented that it is the middle zone of the profile which has a vesicular honey-comb structure of high porosity and permeability that is the main carrier of groundwater in the laterite formations. The lower kaolintic layer, which may be saturated with water, yields water very slowly and it has a tendency to 'cave in', and wells in general are not sunk below this kaolintic layer.

The middle zone is frequently tapped for groundwater with considerable success, for example, the town of Ragama derived its former supply of 16,000 gallons per day from five wells drilled in the laterite.

The vesicular nature of the typical laterite gives it a high porosity and permeability, and this accounts for the absence of permanent streams on it. When the laterite covers low lying hills, the water beneath the higher parts of the hill will fluctuate considerably throughout the year. Near the foot of the hill the fluctuation is small but the laterite is often thinner and hence will yield less.

The laterite formations (called "cabook") of south-western Sri Lanka have considerable water holding capacity, depending on the depth of the cabook formation. The aquifer found within this vesicular laterite responds very rapidly to the initial rains following the usual dry season of February-March, and then keeps filling with the monsoon rains.

When compared with the Malabar landscape of Kerala, which is very large and extensive, the south-west laterite region of Sri Lanka is highly dissected. As a result, the water table of the aquifer in south-west Sri Lanka is essentially fragmented into a member of discreet low mounds within the residual landscape which is separated from each other by intervening valley floors. As such, one could demarcate and map out a mosaic of interconnected aquifers in this landscape rather than a single continuous aquifer as in the Malabar coast.

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## 4

# SHALLOW KARSTIC AQUIFER OF JAFFNA PENINSULA

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### Previous Studies

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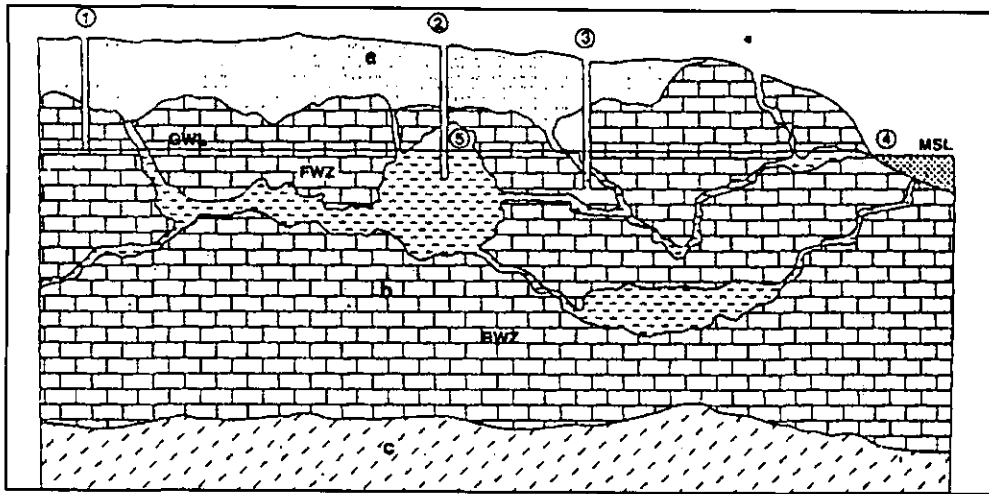
This is the most intensively utilized aquifer in the country. It is also the most adequately studied, where scientific studies have been conducted by several professionals over a period of 70 years.

The groundwater conditions in the Jaffna peninsula were initially studied by Mahadeva (1938) who was then Director, Public Works Department, and who presented his findings before the Engineering Association of Ceylon (1938). The title of his paper was *The Hydrology of Jaffna* with particular reference to the Jaffna water supply. Wadia (1940), the then Government Mineralogist and subsequent Director of the Geological Survey of Ceylon, agreed with Mahadeva's conclusions in regard to general principles after he had toured and studied the ground conditions in the peninsula.

Mahadeva's studies were based mainly on pumping tests carried out on the Putur deep well, results of which furnished, according to him, the data regarding the hydrogeological conditions on which groundwater could be recovered in Jaffna.

In 1952, Sirimanne was to subsequently observe, that, "for a proper understanding of groundwater conditions, detailed geological information is a necessary preliminary. Such information, in the case of Jaffna peninsula is very meagre, and owing to this lack of information there is a danger of over simplifying the actual conditions under which groundwater exists." Based on his field geological studies, Sirimanne was able to show that "although the Jaffna limestone itself is of very low primary porosity, it is traversed by joint planes, fissures, and cavities and in several instances, caverns or solution chambers of considerable size, forming efficient reservoirs of fresh groundwater, at accessible depth below the ground"

Based on the foregoing considerations, Sirimanne was able to develop the excellent master schematic figure 4 . 1 (1952), which clearly demarcates the various inter-relationships between the underlying geology, the hydrogeology and the hydrology of the karstic landscape. This schematic Figure (4 . 1) shown here helps to understand the general behaviour of the main aquifer together with the Putur well, the Keerimalai springs and the solution caverns.



**Figure 4 : 1** Groundwater Conditions in the Jaffna peninsula (after C. H. L. Sirimanne, 1952)

a - calcic red latosol b - Jaffna limestone c - granite gneiss GWL - groundwater level, FWZ - zone of freshwater saturation, BWZ - probable zone of brackish water

(1) dry well; (2) well of Puttur type; (3) ordinary successful well; (4) spring of Keerimalai type; (5) solution cavern

A publication titled *Ground Water in Jaffna* (1968) by Balendran, Sirimanne and Arumugam discusses in depth the geology, groundwater exploitation, salinity studies, water balance and groundwater evaluation.

A comprehensive and analytical study on the *Development of Groundwater and its Exploitation in the Jaffna Peninsula* was made by S. Arumugam (1970) who made his presentation to the Institute of Engineers. This brief publication of 62 pages covers the main aspects of the Jaffna aquifer.

A three part report of the salt water, fresh water interface in the Jaffna peninsula has been prepared by Balendran (1966, 1968, 1969.)

Consequent to a visit to the Jaffna peninsula, Goldberg (1974) concludes that "there appears to be no economic means of controlling or reducing this loss (groundwater discharge to the sea) because optimum utilization of the available resources has already been passed"

Wijesinghe (1975) has published a brief report on the underground water resources of the Jaffna peninsula from the perspective of knowledge of that period.

## **Main Properties of Aquifer**

### *Geology*

The Jaffna peninsula is underlain by Jaffna limestone of early Miocene age. The limestone is typically a compact, hard, partly crystalline rock. It is massive in places but some layers are fossiliferous and weathered into a honeycombed mass (Cooray, 1984). The formation is almost flat bedded, but may have a slight regional dip to the west, and consequently it thickens to the west. It has a vertical thickness of at least several hundred feet, and at one drilling site in the southeastern part of the peninsula at Pallai it was found to be (270 ft) 90 m thick, and underlain by a thick sandstone formation overlying the Precambrian Basement.

In places the limestone is well jointed, and aerial photographs indicate a rectangular fracture pattern with the principal directions being NW-SE, and NW-SW (Cooray, 1984). A typical red soil (calcic red latosol) overlies the limestone nearly everywhere in the peninsula and is generally 0.6 to 2.1 m thick. Sand and dune deposits as much as 20 m thick overlie the limestone along the eastern edge of the peninsula especially between Nagar Kovil and Chempiyanpattu.

Coralline limestones appear to be abundant along the north west of the peninsula, and some of these are of Quaternary age. A coral reef extends along part of the northern shore about 60 to 90 m from the shore.

### *Hydrology*

Rainfall is the only source of all groundwater in the Jaffna peninsula. Rainfall records are available for Jaffna town for an unbroken period of 100 years. The seasonal rainfall exhibits a definite rhythm, with the north east monsoonal rainfall from October to January making up around 82 percent of the mean annual rainfall of 1,250 mm. February to March and June to August are dry months, and annual evaporation amounts to 2000 mm. The year-to-year variation for the peninsula is high, with a low of 625 mm recorded in the years 1875 and 1963, and a high of 1750 mm recorded in the years 1885 and 1932 respectively.

The rainfall infiltrates into the thin, well drained soil (calcic red-latosols) and moves down into the rock openings and then into the zone of saturation. Recharge to the aquifer occurs mainly during the north-east monsoon season in October – January. Water table levels rise from a low in August to a high in January.

The Jaffna limestone is the principal source of water supply in the Jaffna peninsula. The water generally occurs within secondary openings along bedding planes and fractures that have been enlarged by solution of the limestone. Visible karst features include sink holes and solution caverns. Freshwater occurs as a complex of lenses or mounds overlying salt water. These water mounds reach their peak during November – December, and reach an elevation of around 5 m above m.s.l. in certain areas. These lenses of fresh water reach as deep as 35 m below m.s.l. in the central portion of the peninsula.

The thickness and shape of these freshwater lenses in the Jaffna peninsula have yet to be adequately defined. During rainy days, rain water percolates downwards into the soil to join the freshwater that is supported by the heavier sea water, forming a shape like a lens. This underground fresh water lens becomes thicker in rainy weather and flattens out as the fresh water gets drawn out by pumps or other devices. The thickness of the lens of freshwater at any instant in a locality is dependent on the height of the water table above sea level as the height of the column of fresh water must balance the salt water pressure of the bottom of the lens according to the Gyben-Herzberg relationship.

In the southernwestern part of the peninsula and at Thondamannar in the north-central part, the location of the top of the zone of diffusion accords reasonably well with the Gyben-Herzberg prediction. In the southwest, the interface is at a below 21 m (70 ft) below m.s.l. and the water table ranged from 0.3 to 0.6 m (1 to 2 ft) above m.s.l. At Thondamannar the interface is located at 10 m (33 ft) below m.s.l. and the water table altitude was 0.2 m (0.7 ft) above m.s.l.

### *Groundwater Recharge and Discharge*

A very generalized and tentative water balance was prepared by Balendran and others in 1968, in which they estimate that the annual consumption of water for domestic and agricultural use was around 40,000 acre feet per annum. The re-charge from rainfall during a normal year such as 1966 is 90,000 acre feet, while in a lean year as in 1965, the recharge available from rainfall was only 50,000 acre feet.

A later estimate of withdrawal from wells by T. Gunasegaram (1983) gives a figure of 45,000 acre feet in 1976. Visible springs and seeps are located mainly along a four mile stretch of the north shore between Keerimalai and two miles east of Kankasanturai. Total amount flow of these visible springs and seeps is estimated at 7,500 acre feet by Gunasegaram (1983).

Subsequent estimates made in 1977 indicate an annual discharge of 1,500 acre feet from the spring at Keerimalai, and that the probable drainage area contributing to the Keerimalai springs is about 2.5 km<sup>2</sup> or 1 sq. mile. The water table map for August shows that a water table mound persists throughout the dry period immediately south of the springs, and this explains why Keerimalai continues to flow when all other springs and seeps are dry. These other springs and seeps flow only during few months of the year and their total outflow has been estimated at around 6,000 acre feet / yr by Ganeshalingam (personal communication, 1977)

In sum it could be stated that recharge to the aquifer is from monsoonal rains during October-December. This freshwater forms a complex of lenses upto 25 m (80 ft) thick overlying saline water. Discharge through springs and seeps which take place primarily during the monsoon rains appears to be small.

## **Special Hydrological Conditions**

The Puttur well is situated almost in the centre of the peninsula and is on a rocky waste, the well site being about 17 feet above m.s.l. It is popularly referred to as the "bottomless well" because it never seems to run dry. The well is in the mouth of a large underground cavern in the limestone the floor of which is 145 feet below the surface as seen in Figure 4. 1. It has been investigated by various engineering bodies from time to time, during the past 120 years. Yield tests were carried out in 1890, 1894 and 1896.

As reported by Sirimanne (1952) the thickness of the fresh water zone here is about 80 feet and this rests on a brackish water zone nearly 50 feet thick; salt water is present below 130 feet. Test pumping in 1946 yielded 150,000 gallons of water per day for one week. The level of the water surface remained the same after the test as before it; but the relative thickness of the fresh and brackish water had changed to 50 feet and 60 feet respectively, and the salt water level had risen 200 feet above its normal level.

## **Present Utilization and Management Issues**

Human settlement has been taking place in the Jaffna peninsula from the early to middle Historic periods. Over this early period an intensive system of land use based on a frugal use of the underlying groundwater resources had been perfected. This intensive small scale irrigated farming was carried out using traditional methods of lifting the groundwater by the use of mhotes and well sweeps. By the late 1960's the overall picture indicated an almost full development of the available groundwater resource by use of mechanized pumps. The annual replenishment in a normal period of rainfall was matched by the total consumption of groundwater, for both domestic and agricultural use.

With the increase in suburban housing, together with rapid increase in use of water pumps for lifting water, a serious imbalance between consumption rate and replenishment rate has taken place, as reported by Balendran (1969). The shallow aquifer is now stressed both in its quality as well as in its quantity.

Monitoring studies conducted by the WRB from the 1970's have confirmed the significant imbalance between the draw-off and the recharge ratio. These studies also show that the intensity of recycling of water from the shallow dug wells, used in small scale irrigation, has also increased over the recent decades.

Approximately 80 percent of the groundwater of the Jaffna peninsula is used for high value agriculture and the remaining 20 percent is used for domestic requirements, including septic tank flushing demands. Water quality studies carried out from the early 1980's have shown enhanced levels of nitrate pollution as demonstrated by Nagarajah et al. (1988), where the nitrate levels recorded exceed the WHO standard limits for potable water in the more densely settled areas of the peninsula.

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## 5

# CONFINED AND SEMI-CONFINED DEEP AQUIFERS OF THE NORTH WESTERN SEDIMENTARY FORMATIONS

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### Previous Investigations and Studies

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The sedimentary formations in the north west coastal plain of the country, stretching from Puttalam northwards to Jaffna, had always been expected to have in store appreciable amounts of fresh water, which could be exploited for agricultural purposes.

In 1963, Kurt Mendel, an Israeli expert on citrus identified the red latosol area around Vanathavillu as the most suitable environment for irrigated citrus cultivation. A drilling exploration programme was consequently drawn up in 1965 to investigate the groundwater resources of the area. At the same time proposals for the large scale cultivation of citrus, to be irrigated by groundwater, were also being made.

As a result of the exploratory drilling programme, carried out by the Irrigation Department with the assistance of Israeli experts, deep groundwater was raised for the first time in this country, in July 1966. Over 23 drill holes were done in an area of 20 sq. miles by officers of the Irrigation Department, with whom were associated Israeli experts. The Vanathavillu aquifer was thereby properly identified and characterized. A 20 to 50 ft depth of red latosol soil overlies a layer of sand, silt and clay extending to 200 feet to 300 feet depth. This latter layer has been named the *Moongil Aru formation*, in view of the presence of the Moongil Aru stream in the area. This formation confines the water found in the lower formation.

The limestone found below this Moongil Aru formation, which is 30 to 80 ft thick, has been described as hard, fine grained, and has been designated as the Vanathavillu limestone, to distinguish it from the Jaffna Miocene limestone type. The Vanathavillu limestone is permeable and it contains water.

The Mannar sandstone formation is found below this, from about 300 feet below sea level down to basement rock at about 600 ft and is the most interesting, from the point of view of water bearing. It is composed of sandy limestone and calcareous sand-stones, which are very porous and have a sponge like appearance. This sandstone formation is the main source of

groundwater supply in this area. The basement rock was reached at 580 ft ; and the basement was noted to be sloping westwards at about 200 ft in a mile.

The Vanathavillu limestone and the Mannar sandstone formation are very good aquifers, and it has been computed that between these there is likely to be as much as 600,000 acre feet of groundwater in storage. This was the first time in this country that a deep groundwater aquifer was identified and proved in terms of its depth and amount of exploitable groundwater.

In the course of the drilling operations two artesian wells were also encountered; the Karaitivu flowing well and the Elavankulam flowing well, which still function in this area.

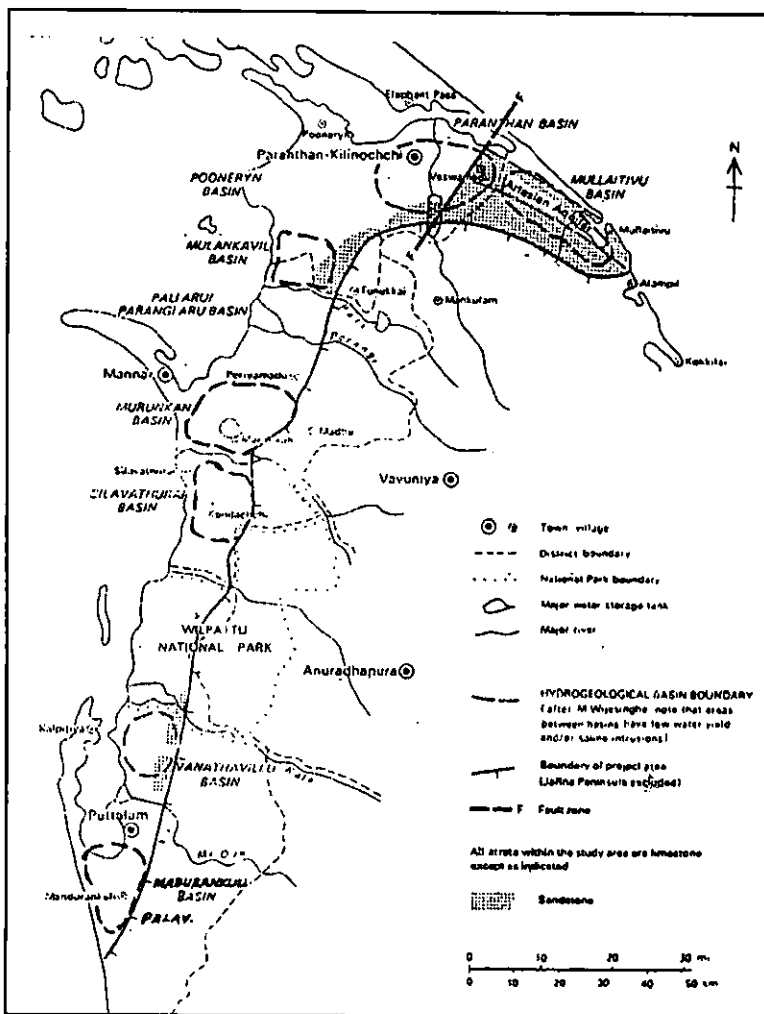


Figure 5.1 Map of seven semi-confined aquifers excluding Jaffna (after Wijesinghe, 1973)

The foregoing investigations have been reported by Sirimanne (1968), Wijesinghe (1973), Lawrence and Dharmagunawardena (1981), Morris and Wijesekera (1981), Davies (1983), and Davies and Herbert (1988). These studies have helped to develop a much closer understanding of the nature of the confined and semi-confined aquifers of the north western region.

A number of distinct and confined aquifers occur within the sedimentary limestone-sandstone formations along the northwestern and northern coastal plains. Intermittent tectonic activity, has given rise to faulting, followed by slow and continuous uplift. The sedimentary limestone-sandstone formation is highly faulted, and it separates the aquifer into a series of isolated blocks, thus forming a number of separate groundwater basins.

Seven distinct aquifer basins have been identified, studied and mapped at different scales over the period extending from the late 1960's to the mid-1980's. From south to north these seven semi-confined aquifers are shown in Figure 5.1

Hapugaskumbura (1997) has categorized these aquifers as follows :

Palavi Madurankuli Aquifer	- Semi Confined (SCA)	Mulankavil aquifer	- Unconfined (UA)
Vanathavillu Aquifer	- Semi Confined (SCA)	Paranthan Aquifer	- Unconfined (UA)
Kondachchi Aquifer	- Semi Confined (SCA)	Mullaitivu Aquifer	- Unconfined (UA)
Murunkan Aquifer	- Semi Confined (SCA)		

## Hydrogeology of the Aquifers

The hydrogeology of two of the larger and more important groundwater basins are discussed in detail in this section, and a general discussion of two others are also included.

(a) **Vanathavillu Basin** In the preceding subsection of this Chapter some of the more relevant features of the Vanathavillu limestone, the Moongil Aru formation and the Mannar sandstone have been described. The Miocene limestone has been uplifted along a major geological fault in the northwest, through Aruwakkalu rising to about 67 metres near the coast. The occurrence of vili in this area is an indication of collapsed caverns and sink holes in the underlying formations.

In the Vanathavillu area, the westerly dipping Precambrian Basement complex, is unconformably overlain by the Mannar sandstone. The sandstone has a gradational contact with the overlying Miocene limestone referred to as the Vanathavillu limestone, within the basin.

The upper part of the limestone is highly karstic, and the limestone sequence wedges out to the east, and the Mannar sandstone is directly overlain by the Moongil Aru formation. The Miocene strata is confined over the whole basin beneath a thick sequence of clays and sands of the Moongil Aru formation. The karstic horizons of the upper limestone exhibit dominantly fissure flow, and the basal members including the calcareous sandstones exhibit granular flow. Flowing artesian conditions exist in the western and northern areas of the basin.

A conceptual sketch of the main limestone aquifer and its relationship to the sandstones and the basement hard rock is shown in Figure 5 . 2.

The piezometric map of the limestone shows groundwater flowing to the north and the water level map of the Moongil Aru formation shows the groundwater flowing to the south and west. The Moongil Aru aquifer shows a rapid response to rainfall with a peak water level being reached in December / January indicating the unconfined nature of the aquifer. The confined limestone aquifer reaches its peak water levels in April / May.

Measured transmissivities show a low value in the margins of the basin. Moderate to high transmissivity values ( $500 \text{ m}^2/\text{d}$ ) are recorded in a narrow belt in the central part of the basin. The annual recharge to the limestone aquifer has been estimated at 7.3 mcm and of this 4 mcm is available for safe extraction, and 1.2 mcm is being currently extracted for agriculture.

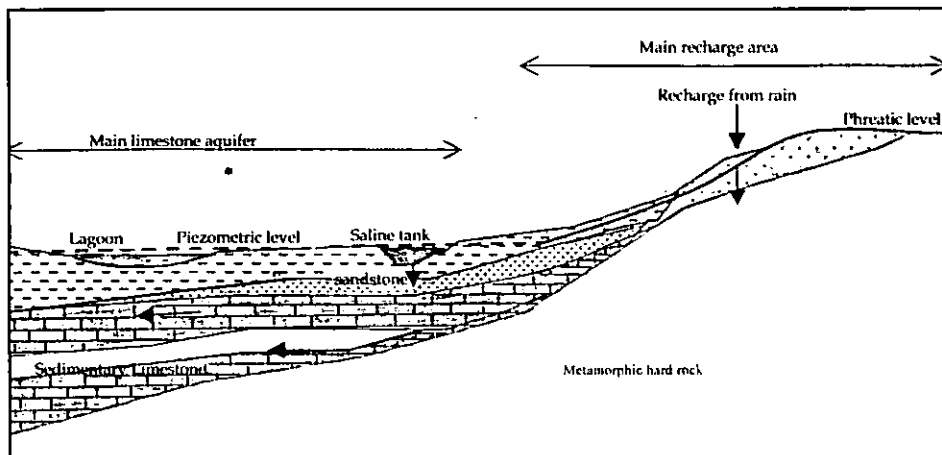


Figure 5. 2 Conceptual model of the Vanathavillu aquifer

(b) **Murunkan Basin** This groundwater basin has been systematically investigated and studied, initially by the Groundwater Division of the Irrigation Department and subsequently by the WRB. The findings and publications of Wijesinghe 1977 are of special significance in this regard.

The Murunkan basin is located inland of Mannar, and is bounded by the Aruvi Aru (Malwathu Oya) to the south, the coast to the west, the Nay Aru to the north and Madhu road to the Madhu on the east. The eastern segment of this basin is jungle covered and comprises of highly permeable red latosol soils, while the western segment is mostly cultivated and is covered by heavy clay montomorrillonitic soils (Grumusols).

Within the Murunkan basin, the Precambrian basement complex is unconformably overlain by Mannar sandstone which is composed of a series of conglomerates and sandstones. The sandstone sequence conformably passes upwards into nodular cherty limestone and sandy

limestone. A ten metre thick sequence of soft yellow fossiliferous limestone containing corals and gastropods overlies a hard cherty limestone.

A detailed study made by Wijesinghe (1977) shows that the highly karstic limestone, lying at a depth of 45 feet below m.s.l., is covered by Pleistocene clay deposits, with an average thickness of 60 feet, as shown in Figure 5.3. Owing to its impermeable nature, the clay cover has resulted in a confined or semi-confined aquifer being present in the limestone. According to Wijesinghe (1977) "the thickness of the limestone aquifer ranges from 300 to over 1,000 feet. Systematic investigations carried out on this basin since 1971 has shown that it has a prolific storage and a very high transmissivity values ranging from 310,000 to 1,595,000 gpd. There is little or no direct discharge to the sea, and excessive pumping tests have resulted in negligible drawdown".

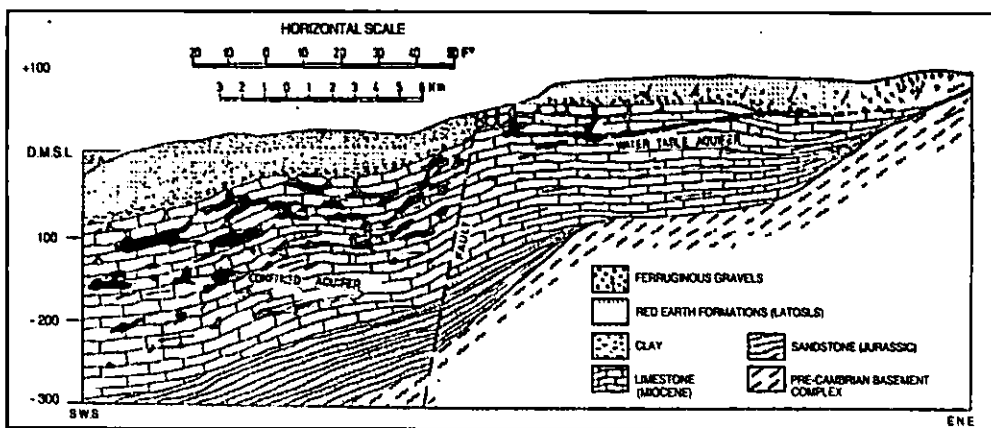


Figure 5.3 Geological cross section across Murunkan basin  
(after M. W. P. Wijesinghe, 1973)

(c) **Silavathurai Basin** is located beyond the Wilpattu National Park, and situated between Kal Aru and Aruvi Aru (Malwathu Oya). A well was driven about 200 feet deep at Kondachchi near Silavathurai in 1966 and this was followed by nineteen bore holes. The typical red latosol surface soil is between 57 to 100 feet in depth in this area, and this is underlain by a thin layer of residual clayey soil followed by the Vanathavillu limestone and Mannar sandstone. Test pumping revealed substantial yield of wells, but the quality of the water was poor, with chloride content of over 1000 ppm. The State Plantations Corporation established a large cashew plantation at that time, and water from these wells were used for watering the young cashew plants, with considerable success.

(d) **Mulankavil Basin** No true geological basin is evident although this is referred to as the Mulankavil basin. Pali Aru in the south, inland limestone boundary in the east, low lying salt flats in the north and the sea in the west defines the boundary of this aquifer. A noteworthy feature of this area is a low, NNW-SSE trending rounded ridge extending from Vellankulam to

the sea at Nachi Kuda, and having a maximum elevation of over 75 feet (25 m) above m.s.l. The soil cover here is dominantly red and yellow latosols. The tilted crystalline basement complex is directly overlain by a sequence of friable sandstones, calcareous sandstones and sandy limestones above. The entire sedimentary sequence thickens, and dips gently to the west. Karstic weathering of the limestone is predominantly in the western part. Hydrogeologically, this sedimentary aquifer system can be divided into a western part and an eastern part.

Water levels were systematically monitored during the 1979/1980 period. Most wells in the western part respond rapidly to onset of *Maha* rains, which indicates the unconfined nature of the aquifer. The distribution of transmissivity in the basin shows a dominant karstic limestone fissure flow in the western part, and a dominant non-karstic inter granular flow in the eastern part.

Based on recharge and through flow studies, it is estimated that 1.5 mcm of groundwater is available annually for safe extraction.

(e) **Mullaitivu Basin** Although the hydrogeology of this basin is yet to be adequately studied and characterized, two artesian well conditions located within this basin is briefly described. Puthukudiyiruppu is a village ten miles west of Mullaitivu and around five miles inland from the sea. It is located within the deep red latosol region which is underlain by sedimentary rocks. An exploratory bore hole was drilled to a depth of 25 m. Artesian flow developed and water commenced flowing at the rate of about half a gallon per minute. Water quality was very good with chloride content around 350 ppm.

Tanniyuttu is an old natural spring flow condition as its name implies, and an old village has been in existence at this site since early times.

## **Present Utilization and Potential Threats**

The safe abstraction rates have been studied and estimated for three of these seven aquifer basins. These safe rates range from 3.0 mcm per year for the Vanathavillu aquifer basin to 9.0 mcm per year for the Mulankavil basin.

Up to the mid 1980s there were around 200 functioning tube wells and over 800 open wells using this groundwater for both domestic and agricultural use. The average depth of wells using artesian aquifers in a well defined basin is from 30 to 50 m. Yields of these wells range from 0.5 l/s to 25 l/s. The electrical conductivity of these groundwaters show moderate to high values.

The most intensively and productively used aquifers in recent times were those around Puttalam, such as the Palavi aquifer, which were used by prawn culture farms. Both the quality and the quantity of these deep groundwaters were ideally suited for the requirements of prawn culture farms, which proliferated in this area because of the ready availability of a good supply of groundwater.

In the case of the medium depth tube wells located within the Murunkan basin, there has been an over exploitation of the aquifer by farmers who used this water for irrigating paddy.

Because almost all these users had owned and operated their individual tube wells, no control could be exercised over their use.

The groundwater of the Vanathavillu basin has been the first source of deep groundwater to be exploited both for human settlement and agriculture from the early 1970's. Kurupparachchi (1995) reports that a 20 percent increase in the electrical conductivity of the tube well water was observed by 1993. This has been attributed to the leaching of salts from the cultivated soil overburden to the groundwater table.

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## 6

### METAMORPHIC HARD ROCK REGION OF THE DRY ZONE

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- (i) SHALLOW REGOLITH AQUIFER
- (ii) DEEP FRACTURE ZONE AQUIFER

(Both aquifers are considered together in this Chapter)

#### Previous Studies conducted on Groundwater in the Hard Rock Region

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The earliest studies of groundwater in the hard rock region of this country were by Sirimanne (1952) in which he pointed out that the un-weathered crystalline rocks, by their very nature, are relatively impervious and non-porous, and water circulation takes place mainly along joints and fissures and also along planes of foliation and cleavage. As summarized by Cooray (1988), "there is, therefore, no continuous body of groundwater with a single water-table in crystalline rocks, but rather separate pockets of groundwater, each with a distinct water

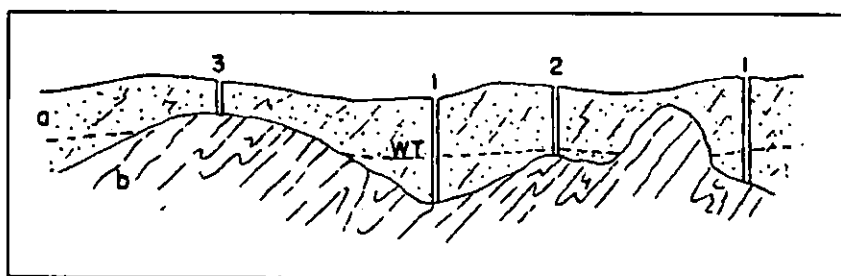


Figure 6. 1 Sketch section showing occurrence of groundwater in pockets in crystalline rocks  
 a - weathered overburden; b - bedrock; WT - water table; 1 - good well in pocket of groundwater; 2 - poor well on margin of pocket; 3 - dry well on bedrock  
 (Sirimanne 1952)

table". A sketch diagram showing the occurrence of groundwater in such pockets in crystalline rocks is shown in Figure 6.1. This Figure shows that the utilization of such water pockets, according to Sirimanne (1952), depends on their exact location in the underlying weathered rock topography, and, therefore, haphazard well sinking in areas of crystalline rock often leads to failure. As could be seen from this Figure, good wells occur only in deeply weathered bedrock, and this indicates the random nature of occurrence of suitable weathered pockets in the underlying rock.

The first reported study of groundwater table behaviour in the hard rock region of the dry zone was by C. R. Panabokke (1959). This study was undertaken at that time to understand the effect of water table behaviour on the soil profile properties. Based on this study, the highest and the lowest positions of the wet season water table recorded over a period of eight years, as well as a typical dry season position of the water table, is shown in Figure 6.2. The conclusions that were drawn from this study were as follows:

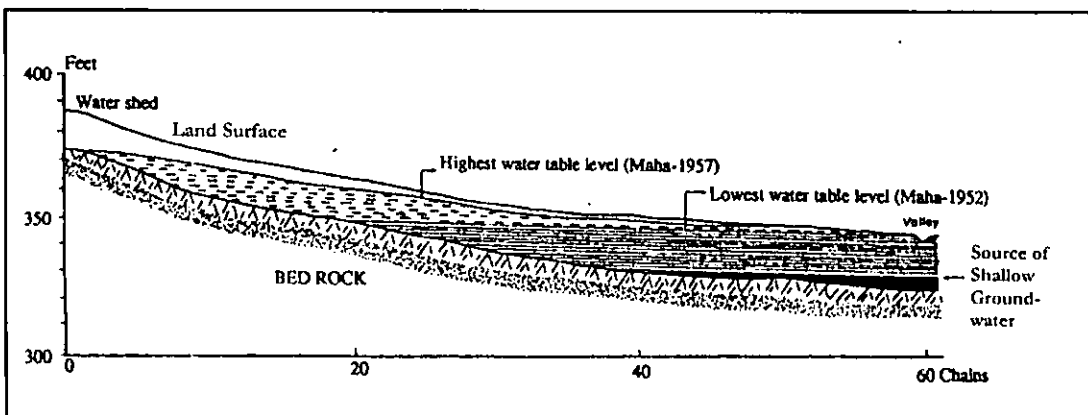


Figure 6.2 Behaviour of groundwater table

- On the ridge and the upper slopes there is no water table evident within the depths to which borings were made (4 to 6 m). While this is so during a normal rainfall season, in a season of unusually excessive rainfall, the water table rises to within 0.9 m of the surface. This land class is, therefore, well drained during the wet season.
- In the middle and upper slopes, the groundwater rises to the surface for a short period but it disappears during the dry season. This land class is, therefore, relatively poorly drained during the wet season.
- The bottom lands are poorly drained during the greater part of the year because the water table rises to the surface for long periods, and falls to within 0.9 m to 2.5 m of the surface during the dry season. This land class is, therefore, poorly drained for most parts of the year.

- During the wet season, in spite of the good internal drainage of the profile, the impervious nature of the underlying rock prevents vertical percolation and the groundwater level rises very rapidly after the onset of the rains.

As shown in Figure 6.2, the landscape position within which groundwater could be tapped during the dry season, is the lower depth in the valley, within which the *Yala* season water table is present.

With the aim of gaining a proper understanding of the groundwater hydrology in the hard rock areas, C. M. Madduma Bandara (1973) made a study of the behaviour of the water table during the dry season in the country around Polonnaruwa. He observed that at the start of the dry season in April 1973, the average depth of the water table was about 3.0 metres below the ground level (b.g.l.). With the progress of the dry season, the water table lowered gradually and reached a depth of around 5.0 meters (b.g.l.) by end of September. In the irrigated areas under Parakrama Samudra, the water table remained stable through the dry season.

The past outlook on groundwater in the hard rock areas of the dry zone has been very pessimistic because of the lack of a clear understanding of the hydrology of both the shallow groundwater and the deeper fracture zone groundwater. This is reflected in Foster et al. (1976), which states "anyone attempting to formulate a national policy on groundwater development for the metamorphic rock regions of Sri Lanka is confronted with enormous deficiencies in hydrological data."

Kulatunge (1988) has described the hydrology of a metamorphic terrain from Southern Sri Lanka. He has shown that a moderately weathered zone as well as a fractured zone constitute a hydraulically continuous water table.

Based on their field studies, Wijesinghe and Kodituwakku (1990) have shown the proper methodology for identifying and safe exploitation of the groundwater resources in this hard rock region, and this has, to a significant extent, helped in a rational location and use of this resource over the past decade.

More recently Panabokke et al. (2006) made a complete study of the dynamics of regolith aquifer in the Malala Oya basin situated in the Southern Province as an IWMI research support activity, the results of which are discussed in Appendix 5. (pp 134, 135)

## **The regolith aquifer of the hard rock region**

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For several years the BGS had been investigating the nature of the aquifer within the regolith of the hard rock areas in tropical Africa and South Asia, a large part of which is underlain by crystalline basement rocks. These investigations have shown that groundwater in these areas occurs in two main forms, namely (1) the shallow regolith aquifer, and (2) the deeper fracture zone aquifer.

In the course of studies conducted on the shallow weathered zone of the hard rock areas of Sri Lanka, Herbert et al. (1988) have observed that the groundwater in these areas occur

both in the regolith (weathered and residual overburden) and in the fractured bed rock. In many places the uppermost section of the basement complex has been altered by weathering processes to form a distinct horizon termed 'regolith'.

Many agro-wells penetrate only to the top of the saprock horizon, as digging becomes more difficult once this material is reached. The collapsed zone, saprolite and saprock together make up the regolith as shown in Figures 3.5 and 3.6 (Chapter 3). The thickness of the regolith in the dry zone of the North Central Province (NCP) of Sri Lanka is variable and is usually not greater than 10 m. The thickness of the saprock, saprolite and collapsed zones can vary greatly in proportion and scale from site to site.

In contrast, the fracture zone occurs at depths of around or beyond 30 to 40 m in this hard metamorphic rock region, wherever the deeper tectonic forces have caused some degree of jointing or fracturing of the underlying basement complex. The groundwater occurring in this zone of jointing or fracturing is referred to as the 'deep fracture zone aquifer' (as shown in Figure 6.3). The occurrence of these fracture zones is more sporadic or random, and is related to the lineaments that occur in this hard rock region. Drilled boreholes or bore wells abstract the groundwater from these deep fracture zone aquifers. The average depth of bore wells in Sri Lanka is around 40 m and in some instances, a few could extend up to 70 m. This is in contrast to the Tamil Nadu situation where the depth of bore wells is between 100 to 160 m, and where the depth of bore wells have increased three-fold in the last 30 years, from an average of 60 m in 1980 to 180 m at present. Yield measurements carried out on the bore wells in Sri Lanka indicate that it varies over a wide range from 0.1 to 2.0 l/sec with a median value of 0.35 l/s, which is just sufficient to meet limited domestic needs.

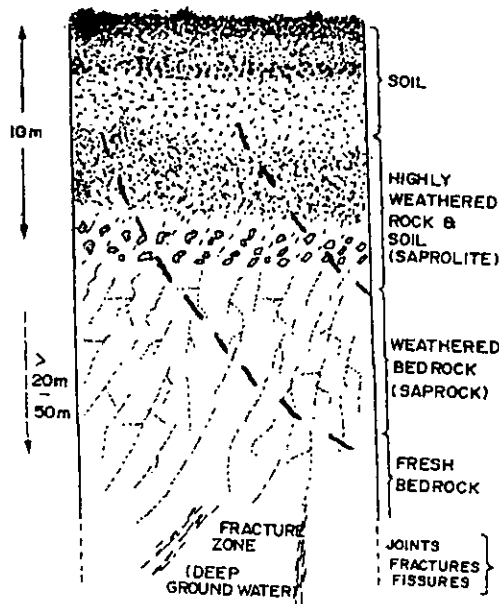


Figure 6.3 Schematic representation of sequence of soil-saprock-bedrock-fissures-joints

## Nature of Occurrence of the Regolith Aquifer

One of the more important advances that have been made over the recent decade has been our improved understanding of the nature of the occurrence, as well as the distribution patterns, of the two types of aquifers, in the undulating landscape of the North Central Dry Zone. It is now evident that the traditional hand-dug domestic wells, located in the village 'gangoda', below the small village tank, draw their water from the shallow regolith aquifer, which also receives some degree of recharge from the hydraulic head of the small village tank, that is situated adjacent to and just above the village settlement.

In this region, these traditional hand-dug wells, have been abstracting water from this basement regolith aquifer for village domestic requirements for several centuries. Despite their relatively low yields and seasonal water level fluctuations, they have provided the basic domestic water needs for the innumerable village human settlements in this rock floored, 'mantled plain', landscape of the ancient Rajarata for over a long period.

In significant contrast to the foregoing, have been the several tubewells, that have proliferated under various donor funded water supply schemes, since the early 1980's, under the auspices of the Water Supply and Drainage Board of the then Ministry of Housing and Urban Development. This countrywide tube well programme was launched by the government, under the National Decade Plans from 1980 to 1990, for water supply and sanitation.

These tube wells exploit the deeper fracture zone aquifer in the fractured bedrock at depths of around 40 to 50 m in this region. In contrast to the hand-dug domestic wells, these borehole tube wells have to be constructed by outside agencies using expensive modern drilling equipment, which can drill to depths of 70 to 80 m in the hard basement rock. As mentioned earlier, the occurrence of these deep aquifers is more sporadic and is closely related to the lineaments that occur in this hard rock region.

With the rapid agro-well development that had taken place in the late 1980's, a very large number of both successful and unsuccessful agro-wells had been constructed all over the Anuradhapura district. It was initially observed that most of these agro-wells were distributed around the small tanks and also in close proximity to the tank village settlement. Indigenous knowledge of the villagers rather than any scientific means of groundwater exploration, was used in the siting of these early agro-wells.

It was only around the mid 1990s, when the IIMI had completed a study of the small tank cascade systems in the Anuradhapura district, under the IFAD supported Participatory Rural Development Project (PRDP), that a clear picture began to emerge on the relationships between the location of the small tank cascade systems and the underlying regolith aquifer. It is in this study that the hydrology of the small tank cascade systems were subjected to a critical analysis, which brought out the position and dynamics of the groundwater regime within these small tanks cascade systems as reported by Sakthivadivel and Panabokke (1996) and Senaratne (1996).

It is now clearly recognized that the large number (more than 15,000) of small tanks that are distributed across the undulating landscape of the dry zone **are not randomly located**

and distributed as commonly perceived; rather they are found to occur in the form of distinct cascades that are positioned within well defined small watersheds or meso-catchment basins.

A cascade is made up of 4 to 10 individual small tanks, all located along the main inland valley or side valleys as shown in Figure 6.4 (a). Each cascade is defined by its (a) watershed boundary or meso-catchment boundary; (b) main central and side valleys along with the main axis of the cascade; and (c) the component small tanks with their own micro-catchments as shown in Figure 6.4(a). A cluster of cascades would form a sub-basin of a river, while a cluster of sub-basins would form the entire river basin. This could be clearly seen in the one inch to one mile topo-sheets of the Survey Department as well as in the master map of the Rajarata in a publication by Panabokke (1999) on the 'Setting and Distribution Patterns' of all the cascade systems in the Rajarata.

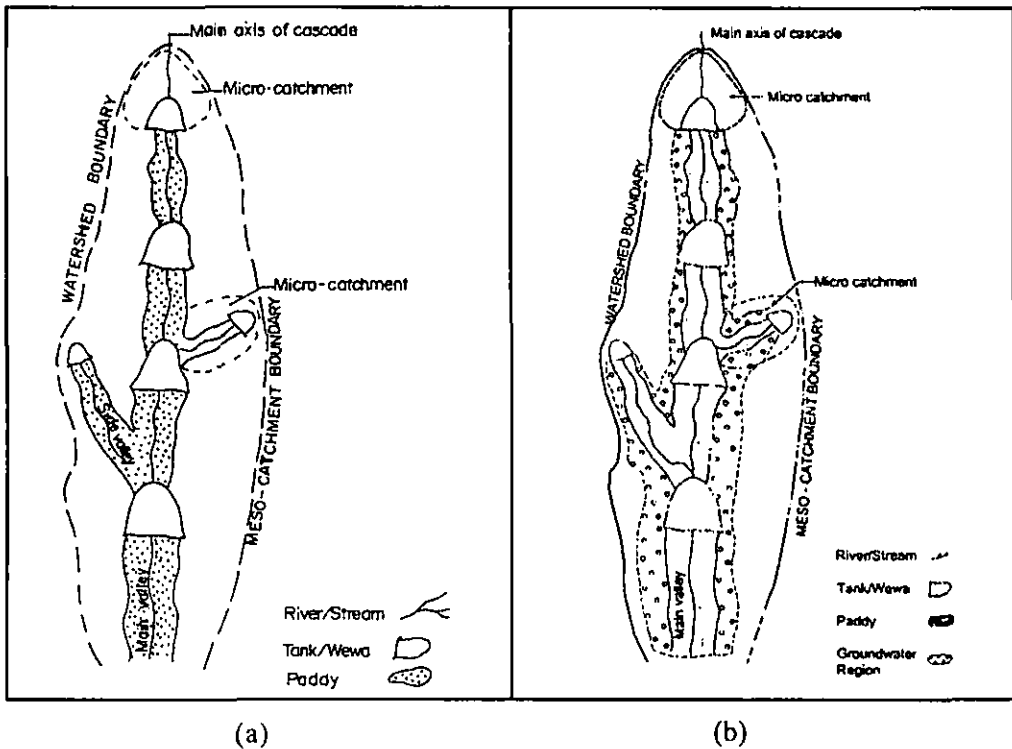


Figure 6.4 Schematic representation of (a) a small tank cascade:  
(b) groundwater area within a cascade

The shallow regolith groundwater within these cascades is mainly confined to a narrow belt along the main valley of each cascade, and to a smaller extent along the side valleys, which are shown in Figure 6.4(b). It could thus be seen that this shallow groundwater occurs between 5 to 10 m depth and as shown in Figure 6.4(b) it is this shallow groundwater in the lower part of the valley that is being tapped by the agro-wells.

Field measurements carried out both in Sri Lanka and South India indicate a very good correlation between tank water levels and groundwater levels in the command area. Therefore, the assumption that agro-wells located in the command area would be able to draw upon the groundwater under the tank spread area, appears to be a valid assumption.

At the same time, both the regolith aquifers and the deeper fracture zone aquifers below it are, in most instances, interconnected, and therefore, any pollution in the regolith aquifer will also adversely affect the drinking water supplies drawn from the fracture zone aquifer.

### **Dynamic Nature of the Regolith Aquifer**

There is no reported data available to date on the dynamic behaviour of the regolith aquifer, both in space and time, over a consecutive wet and dry season.

The first such study was carried out and reported for four selected cascades in the Malala Oya basin located in the southern dry zone of Sri Lanka over a period of 18 months, which included two wet seasons and one dry season. This study was carried out as an IWMI supported field research study from October 2003 to January 2005.

The findings from this study are to be published initially as a working paper and subsequently as a technical paper.

The main findings from this study are presented in Appendix 5 of this publication.

### **Groundwater Recharge**

There are several methods that could be used to estimate the degree of recharge. A fairly simple and straightforward method that is commonly employed for rapid field assessment is the estimate of recharge that is made, based on the rise in the water table during the rainy season. The principle, in calculating recharge of this method, is that recharge causes a rise in groundwater level, which is directly proportional to the recharge and inversely proportional to the specific yield of the water table aquifer. Thus, the recharge is calculated by multiplying the observed rise in water level by the specific yield of the aquifer. For the prevalent rock types in the NCP, specific yields in the range from 2 to 4 percent are considered appropriate (COWI Consult, 1993). Using these figures and groundwater fluctuations given in the same report, the recharge works out to roughly 100 mm for the upland areas and 150 mm for the lowland paddy areas.

Studies conducted by de Silva (1997) have also shown that the key aquifer parameters such as hydraulic conductivity and specific yield, are very poor for most of these regolith aquifers and, as a result, the rate of well recoveries are also very poor. Therefore, the pumping schedule and abstraction rates should match the seasonal recharge rates within an agro-well in order to avoid drying up of the well, during the cropping season. De Silva (2002) has also observed and reported from select studies conducted by her, that the annual average

recharge was only 10 to 15 percent of the annual rainfall, and that a major proportion of this recharge takes place during the rainy season from late October to late December. However, it has also been observed that in some areas where these studies were conducted, this amount of recharge was not sufficient to fully replenish the shallow regolith aquifer. Based on select aquifer parameters and their recharge capacity, a set of nomographs has been developed by de Silva (1997), and these could be effectively used to regulate utilization of this limited groundwater supply on a sustainable basis.

### **Rational Exploitation of the Regolith Aquifer**

Senaratne (1996) has studied the groundwater table in a tank environment as well as in a cascade environment, and developed a methodology for allocation of agro-wells to each cascade area. It is based on a set of assumptions as follows :

- i. Cascade is a closed system;
- ii. Water is contributed to a cascade only through rainfall; and
- iii. Water loss from a cascade is mainly thorough evapotranspiration, surface and underground out-flow from a cascade.

He has also observed that around 20 percent of the agro-wells are located in the upper catchment area of the cascade, around 35 percent in the middle catchment area, 20 percent in the lower reaches of the catchment area, and around 25 percent located below the tanks within the cascade.

In the middle catchment area, the water level in all agro-wells comes up to the ground level during the rainy season and goes down to 4 m below ground level during the dry season. The fluctuation in the lower reaches and below the tanks is much lower and is of the order of 1 to 1.3 m.

In a study conducted on 50 cascades within the Anuradhapura district, Senaratne (1996) has shown that the optimum number of agro-wells that could be safely accommodated within these 50 cascades is not more than 3,600; and that already within 5 of these 50 cascades, the number of agro-wells had already exceeded the upper limit.

Dharmasena (2000) has shown that since the regolith aquifers have very limited reserves of groundwater, at least 25 percent of the potential groundwater storage in an aquifer should be reserved in order to meet environmental concerns. It is recommended that the imperfectly drained area is the most suitable area for agro-wells construction. This is found to be in line with recent experiences reported in the Anuradhapura PRDP project.

In a two year monitoring study carried out by the Water Resources Board (WRB) on 94 agro-wells under the same PRDP project, it was observed that Dharmasena's recommendation of a minimum water depth of 2 m during the dry period and 5 m during the wet period for an agro-well is a valid proposition.

## Present Utilization and Potential Threats

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It was reported four years ago that there were as many as 10,000 agro-wells operating in the Anuradhapura district alone (Shanthi de Silva, 1997). This development of agro-wells had taken place in an unorganized manner without a proper assessment of the hydrogeological properties of the basement rocks, spacing between agro-wells, safe yield, and recharge potential. It was only after a symposium held in December 1997 on *Groundwater Utilization for Crop Production in the Dry Zone of Sri Lanka*, under the auspices of the Food and Agricultural Organization (FAO) and Department of Agriculture (DOA), where all research findings to date were presented, that policy guidelines for groundwater use were enunciated for the first time in this country (see Appendix 3 a). Policy guidelines for groundwater extraction and for groundwater use for irrigation were also developed (Policy guidelines for groundwater use, 1998). In the absence of such guidelines, the indiscriminate expansion of agro-well farming under state sponsorship of the NCP Government, would have led to severe environmental degradation in this Province.

It is now recognized that this shallow groundwater benefits from the presence of several small tanks cascades that are situated within these inland valleys. The average thickness of the regolith is not more than 10 m in this region, and the traditional hand-dug wells have been abstracting water from this basement regolith aquifer, for village domestic requirements, for more than 2000 years in the ancient Rajarata landscape. Despite the relatively low yields of these aquifers they have provided the basic water needs for innumerable human settlements over several centuries.

Hand-dug wells or agro-wells are shallow, large diameter wells that effectively make use of the high storage but low permeability of the weathered overburden. Abstraction from hand-dug wells typically occurs twice a day with a recovery time of 12 hours generally sufficient for renewed abstraction.

In a series of publications by Sakthivadivel, Panabokke *et al.* (1994, 1996, 1997), they have demonstrated the methodology of assessing the safe extractable amounts from these shallow aquifers, through the agrowell irrigation period from February to September. By this approach it has been possible to properly characterize the nature and extent of this aquifer, and to reliably estimate the volume of extractable groundwater without adversely affecting the hydrological environment.

The **deep groundwater** bodies that occur in a discontinuous and highly fragmented manner within the joints, fracture zones, and fissures of the underlying hard basement metamorphic rocks have been exploited through deep tube wells or bore wells installed by the NWSDB since the early 1980s. The quality of this deep groundwater is generally good with little or no fecal contamination, but several areas report a high level of fluoride and iron content in this deep water.

These bore wells or 'tube wells' which draw from the fissured bedrock could, at times, be prone to water level decline. A significant number of tube wells are found to be abandoned, especially in the Anuradhapura district because of the unacceptable quality of the bore well water.

Dissanayake (1989), reported that around 15,000 deep tube wells have been drilled by many foreign agencies such as DANIDA, FINNIDA, UNICEF and GTZ during the implementation of various water supply schemes. He reports that a problem of growing concern is the excessive concentration of fluorides found in many deep wells in the Anuradhapura and Polonnaruwa districts. Similarly excessive quantities of manganese, iron and nitrates have also been observed in several locations.

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## 07

# SHALLOW AQUIFERS ON UNCONSOLIDATED COASTAL SANDS OR COASTAL SAND AQUIFERS

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## Previous Studies

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One of the earliest studies on groundwater in the island is found in H.F. Tomalin's Presidential Address to the Engineering Association in 1921, titled 'Underground Water Resources of Ceylon'. The author refers to the possible sources of underground water available for drawing 'when occasion and necessity arises', and he discusses in some detail the prevailing use of dune water in the island, which he considers more wholesome than river water.

Tomalin recognizes the value of this dune water in the following terms "sand dunes along the seaboard of the south-east coast, especially those beyond Tangalle in the direction of Hambantota, those on the east coast where they frequently form elevated and undulating sand ridges, often shifting and of considerable height due to the prevailing winds, are a source of water supply of utmost value, and are locally used". He also states "it is a common occurrence to see fisherman camping on the sand bars across the mouths to lagoon as these always yield fresh water".

The groundwater conditions in the sand dunes of Hambantota have been described and discussed in more detail by Sirimanne (1952). His sketch section of the geological sequence in the dune sand area is shown in Figure 7.1. His description of the nature of occurrence of the ground water in these dune sand formations is reproduced in full as follows.

"Overlying the crystalline rock which occurs at about 30 ft below m.s.l., is a bed of porous beach sands, which are capped by dune sands which may rise 20-30 ft above m.s.l. Intercalated in the sands, mostly in the lagoon-ward side, is a layer of tough clay. This relatively hard and impervious layer prevents the downward percolation of any large quantity of fresh water, which could depress the sea water to good depths. Hence, conditions for the storage of large bodies of fresh water in the sandy beds with these thick clay intercalations are not favourable. The only possible locality would be in the porous beach sands, lying away from the lagoon, but between it and the sea, provided adequate facilities for replenishment are available in order that large fresh water bodies, capable of depressing the sea water, could exist. The dunes are narrowest at the windward (western) and widen as they approach the headland on the east. The town of Hambantota is situated on such a headland."

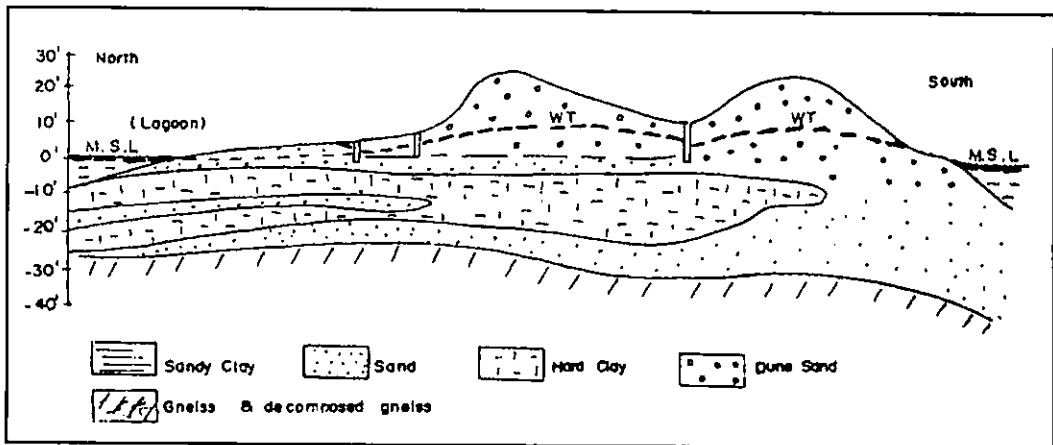


Figure 7.1 Groundwater in dune sand area - Hambantota  
(after C. H. L. Sirimanne, 1952)

“Two belts of dune occur in this area and the wells are sunk in the valley between them. Those wells sunk of the margin of the dunes towards the lagoon turn brackish during the dry season. There are in all about 15 wells in the dune area of which only a few can maintain supplies of fresh water during the dry season.”

In respect of dune sand, Sirimanne (1952) observes that they are found around most of the island's coasts except in the south-western portion. They may be from 20 to 50 ft in height along the south and eastern coasts. The north-western coastal dunes have a lower general elevation. The dunes along the south-east coasts form wider belts than those in the north-west coast, and dune sands may extend as far inland as two miles. Small supplies of water are obtained from the dunes along the coast by the several fishing village settlements.

An excellent description of the different coastal and shoreline types that are present in this country, as well as the different types of beaches and dunes could be had in Bernard Swan's Coastal Geomorphology of Sri Lanka 1983. Fresh water resting on salty water in permeable coastal formations, and the Gyben-Hezberg theory on this phenomenon is described in Appendix 4.

Groundwater conditions in Kallady from where Batticaloa town draws its water supply, from a battery of wells sunk in an area of 160 acres, has been properly characterized and described by Sirimanne (1952). The wells are located on a northward pointing sand spit which consists of loose unconsolidated sands, underlying which, at a depth of around 45 feet, is a calcareous sandstone layer. The estimated safe yield from these wells is around 250,000 gallons per day.

In a similar manner the groundwater conditions at Pulmoddai have been characterized by Sirimanne (1952), and a sketch map and section illustrates the extent and depth of the fresh water body on this coastal sand formation.

Hapugaskumbura's *Groundwater Map of Sri Lanka* (1997) shows the principal Hydrogeological Domains, and it states that the main coastal sand aquifers range from 10 to

20 m in thickness. The water table is in the range of 3 to 5 m and the yield from wells constructed in these aquifers varies from 6 l/s to 4 l/s.

## **Four Examples of Different Types of Coastal Sand Aquifers**

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Four principal types of coastal sand aquifers will be discussed in the rest of this section.

### *Kalpitiya Coastal Sand Aquifer*

The Kalpitiya aquifer is located on what geomorphologists refer to as a *Coastal Spit*, and it is best expressed in the Kalpitiya peninsula located on the western coast of Sri Lanka, as seen in the accompanying Figure 7.2. As could be seen in the Figure 7.2, a somewhat similar formation is found further north in the Mannar Island, and also in the Pooneryn meso-peninsula which is located close to the main Jaffna peninsula.

A schematic section across this Kalpitiya aquifer is shown in Figure 7.3. As seen in this Figure, this aquifer is bounded by the sea on both western and eastern flanks, and it mainly comprises coarse grain sands.

The geological succession in the Kalpitiya peninsula consists of sandy regosols (quartzipsamment according to Soil Taxonomy, USDA) overlying 15-20 m of coarse sand, underlain by clays and Miocene limestone as shown in Figure 7.4. A thin fresh water lens occurs in the sand, and is present at depths of 1-3 m over most of the peninsula, as shown in the same Figure. Groundwater occurs in the limestone also, but it is more saline than in the sand aquifer and it is, therefore, not presently utilized.

This phreatic aquifer is extensively pumped for both irrigation and domestic water supply. Recharge is by direct infiltration from both rainfall and return irrigation flow. The highly permeable sands permit an excess of 50 percent of the water applied to the surface to reach the water table.

According to Lawrence et al. (1989), the groundwater system can be visualized as a series of cells as shown in Figure 7.5, and "within each cell groundwater is drawn from the irrigation well and spread over the cropped area where most of the applied water returns to the water table. The return irrigation flows, on reaching the water table, are unlikely to migrate beyond the cropped area, except possibly, for short periods during the *Maha* season when irrigation reduces". This circulation of groundwater within these cells has important implications for groundwater quality. The electrical conductivity of this shallow groundwater varies from 400 to 1,500  $\mu\text{S}/\text{cm}$  over most of the peninsula.

The results of monitoring of agro-wells had shown that most agro-wells had nitrate concentrations in excess of the WHO guideline of 11.3mg N/l, which shows the build up of nitrate over the period 1987 to 1991, as reported by Kurupparachchi (1995).

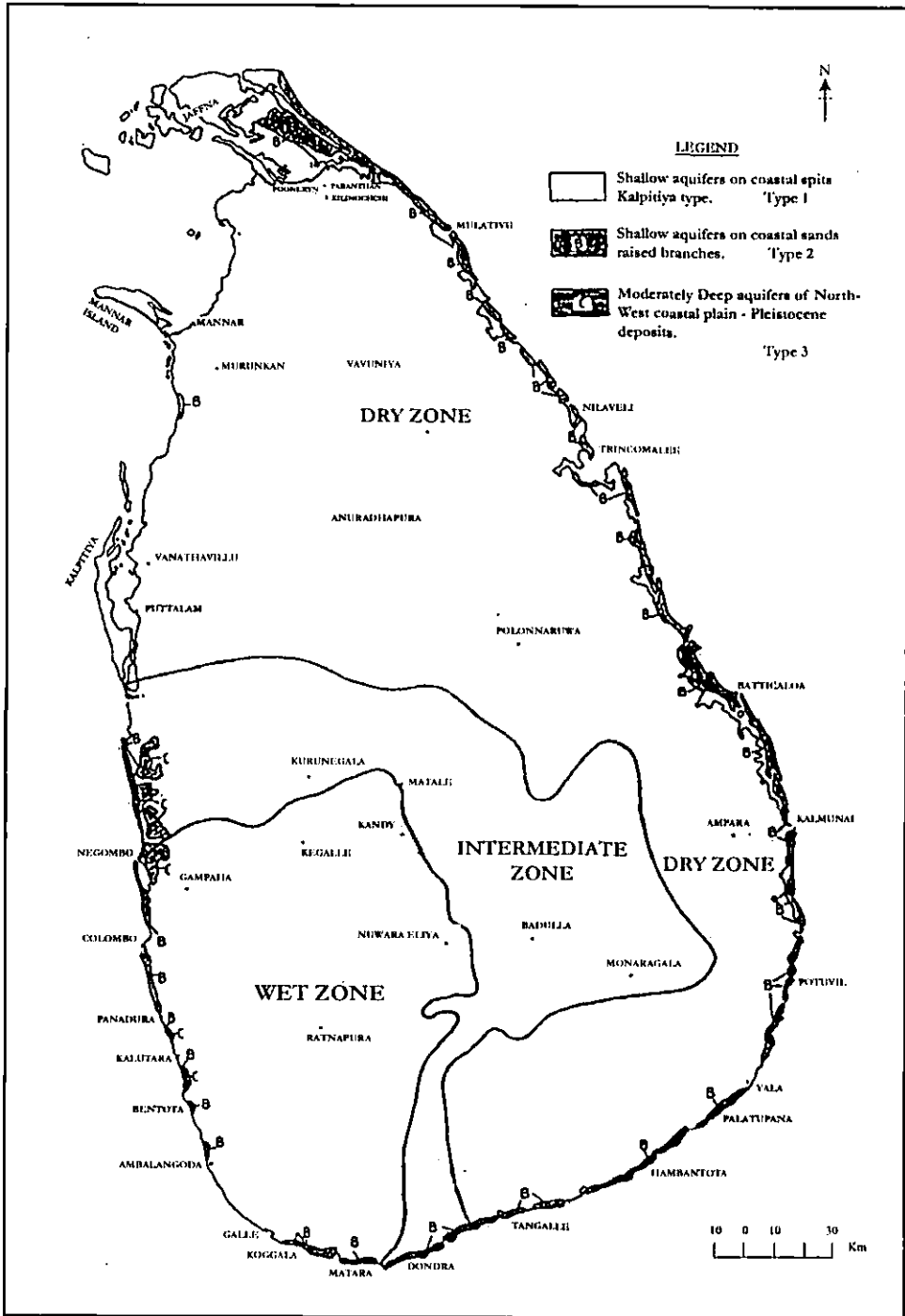


Figure 7.2 Coastal sand aquifers of Sri Lanka

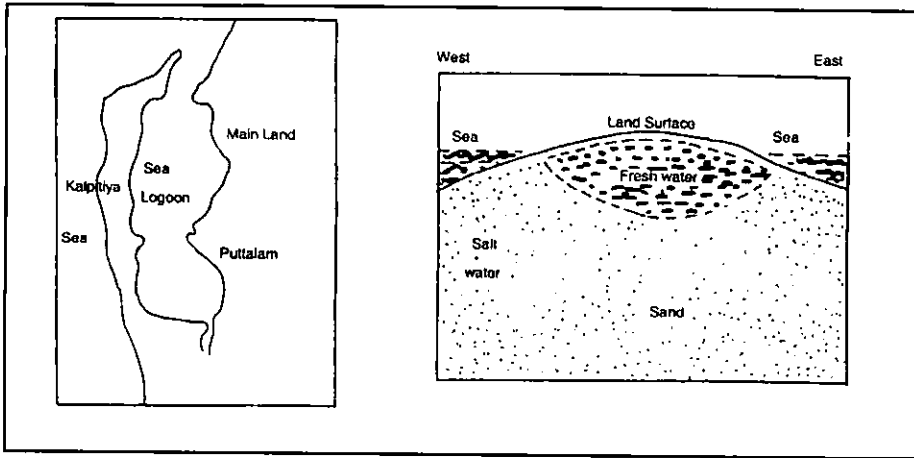


Figure 7.3 Schematic section across Kalpitiya peninsula

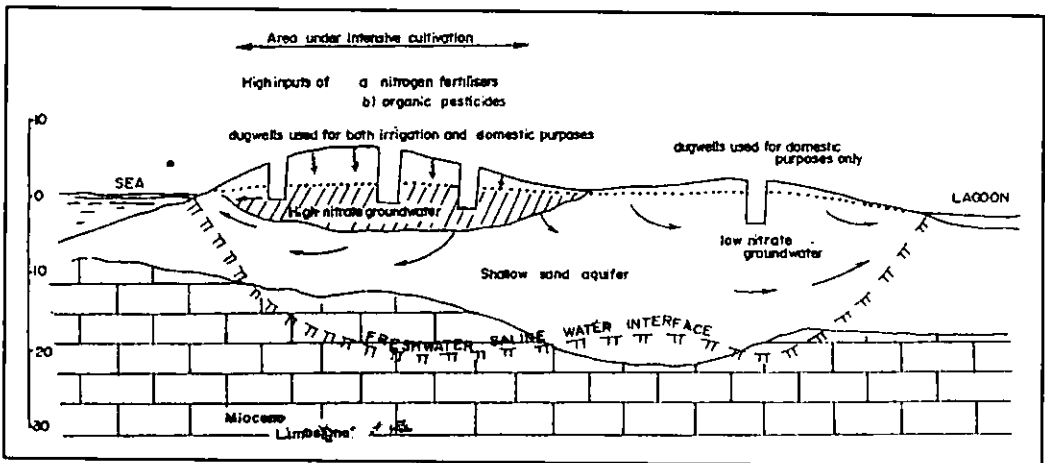


Figure 7.4 Hydrogeological section of Kalpitiya aquifer

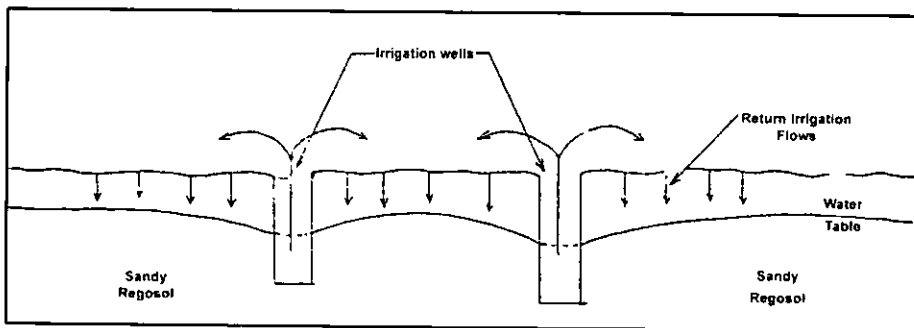


Figure 7.5 Groundwater flow dominated by abstraction from irrigation wells

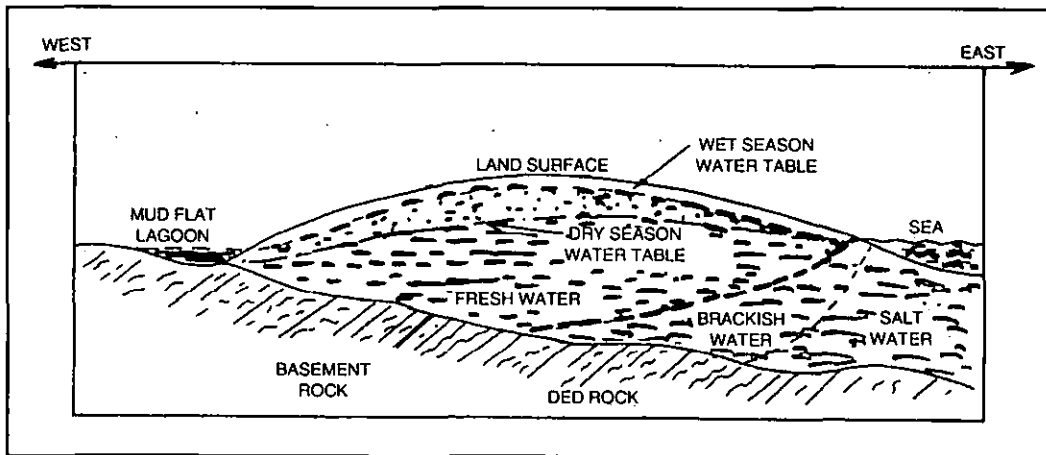


Figure 7.6 Schematic cross section of Nilaveli coastal sand aquifer

### *Nilaveli Coastal Sand Aquifer*

The Nilaveli coastal sand aquifer is located on what geomorphologists describe as a 'raised beach' of unconsolidated coastal sands. These raised beaches are best expressed along the eastern coastline of this country as shown in Figure 7.2, with smaller extents also found in the southern and southwestern coastline. Those located in the Batticaloa coastal plain, especially between Kalkudah and Pottuvil, make up for a major proportion of this formation in the eastern seaboard. The town water supply to Batticaloa is yet drawn from a very productive aquifer at Kalladi, which lies adjacent to the Batticaloa lagoon.

The raised beaches located between Trincomalee and Mullaitivu have been intensively utilized in recent times, and are also considered to have very productive aquifers within them according to local experience.

The major coastal mineral sand deposit of the island is located at Pulmoddai, adjacent to the Arisamalai headland.

A schematic section across the Nilaveli Coastal Sand aquifer is shown in Figure 7.6. As seen in this Figure, this aquifer is bounded by the sea on its eastern flank and by the lagoon and mud flat on its western flank. As a result, this aquifer can hold up the groundwater for a longer period than in the case of the Kalpitiya aquifer which is bounded by the sea on both sides.

This sandy regosol of the Nilaveli aquifer has more 'body' than the Kalpitiya sands because of the presence of a small amount of clay in the soil body. It also receives a higher rainfall during the north east monsoon season, and it can thus store more water in its groundwater lens which is also larger in volume than the Kalpitiya aquifer.

This aquifer has been studied by the WRB in collaboration with the GTZ which has been funding these studies since August 1999. Three component studies have been in progress since 1999/2000. These are as follows :

- i. Agro-well Inventory
- ii. Agro-well Monitoring
- iii. Hydrogeological and Water Balance

The more important results from each of the foregoing studies is given below :

Across an extent of approximately 1,600 ha, a total of 958 wells were identified and demarcated on maps of scale 1:6,250. It was found that this total of 958 wells was made up of 400 agro-wells, 394 domestic wells, and 164 abandoned wells.

Also, of these 958 wells, there were 739 that were more than 10 years old and the rest were less than 10 years old.

The water level of wells at the end of the rainy season is close to the surface, and at the end of the dry season there is a 2 to 4 m depth of well water. The electrical conductivity of well waters is within the normal range, except in areas close to the sea.

Using the geophysical resistivity method, the thickness and dimensions of the water lens in three selected transects of the aquifer was estimated.

The total groundwater flow in the southern (Nilaveli) and northern (Kumburuppiddi) segments of the aquifer was estimated. The calculated average recharge of this aquifer shows a value of 4.05 mcm for the Nilaveli segment, an 2.36 mcm for the Kumburuppiddi segment.

The safe yield for the Nilaveli segment is 2.43 mcm, while that for the Kumburuppiddi segment is 1.42 mcm. For the Kumburuppiddi segment, an additional 0.54 mcm of groundwater is further available for exploitation.

### *Koggala Coastal Sand Barrier Beach and Incipient Dune*

Investigations on this aquifer have been conducted by the WRB on behalf of the Board of Investment (BOI), for the southern industrial park during the period 1990. The location of the project area is shown in Figure 7.7.

As shown in this Figure, this barrier beach is bounded by the Koggala lake in the north, and the sea in the south. This beach is also protected on its seaward side by a shallow fringing reef. The Koggala lake itself receives the runoff from its own catchment which is around 60 sq. km, and its outfall to the sea is at Kataluwa, as shown in figure 7.7.

This barrier beach is made up of coastal sand, weathered shell and coral fragments, and is little more than 3 m above m.s.l. Incipient dunes, which are typical of the wet zone coast, form a patch of over 50 m width behind the beach. The soils in the coastal lowlands are predominantly recent sands, and in a few places in the offshore area coral reefs are visible.

A south-north cross section across this coastal sand formation is shown in Figure 7.8 and it shows that this coastal sand formation is underlain by weathered basement rock below 12 m depth.

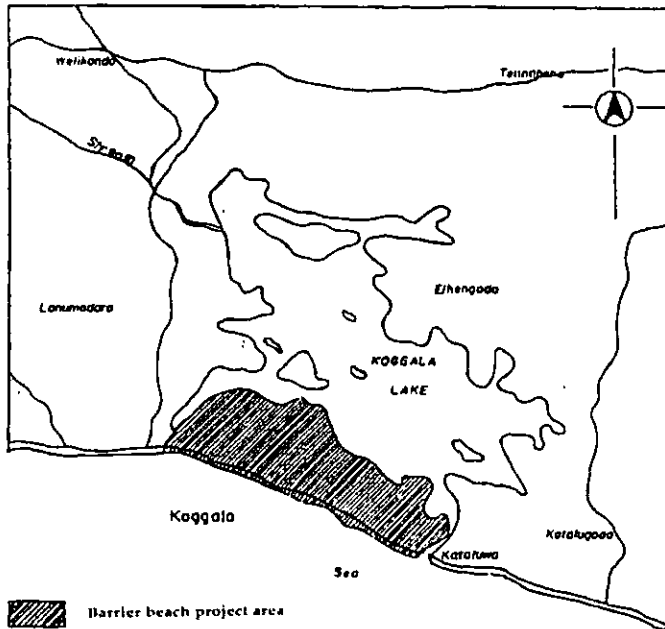


Figure 7.7 Koggala project area location

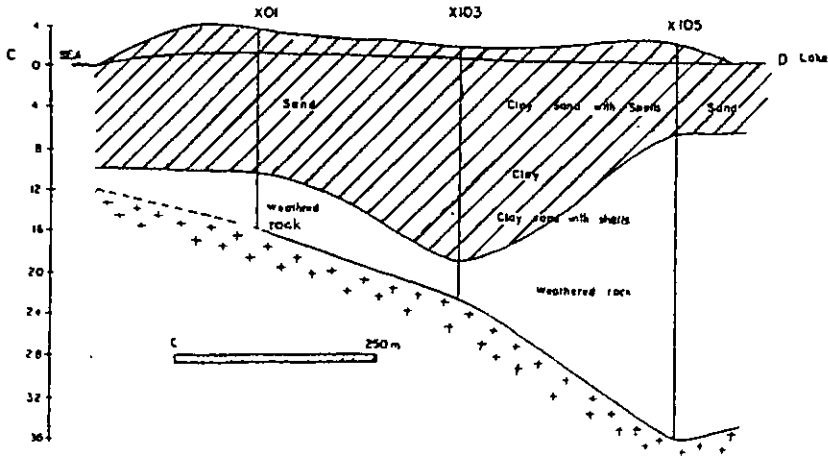
The main aquifer is located within this sand and coral sand admixture. The depth to basement floor in this formation varies within the range of 15-20 m.

Because this formation is located well within the wet zone agro climatic regions as seen in Figure 7.2 , it receives a year round recharge with the mean annual rainfall of more than 2,500 mm, except for a very short period in February – March. The frequently replenished fresh water in the adjacent Koggala lake helps to maintain the regular rainfall recharge to this coastal sand aquifer.

The several small islands within the Koggala lake are on the outcropping basement charnokitic rocks, and so is the northern fringe of the lake shoreline.

Around 35 bore holes of 20 cm diameter were drilled to depths varying from 8 to 15 m. Test bore holes reveal that fresh water in this aquifer occurs down to a depth of 10 m, beyond which saline water is encountered. In general, the electrical conductivity (EC) of the water in the test bore holes showed values of less than 750  $\mu\text{S}/\text{cm}$  up to depth of 10-12 m. Hardness and chlorides were found to be well within permissible levels as for drinking water standards. However, water with a high iron content was reported from the central portion of the BOI project area.

At present, ten production wells are being operated for the BOI requirements, and around 19 million litres of water is being pumped per month. In addition, 24 wells have been monitored for water level variation, but to date no significant variation in water levels has been observed.



**Figure 7.8 North - South section of Koggala aquifer**  
 (Main aquifer consists of sand clay and thickness of this aquifer is ranging from 10-20m)

### *Katunayake Free Trade Zone – Coastal Sands on Old (Prior) Beach Plain*

Investigations on this aquifer have been conducted by the WRB on behalf of both the Free Trade Zone (FTZ) and Board of Investment (BOI) from 1978. The location of the project area is shown in Figure 7.10.

As shown in this Figure 7.9, this formation is situated on an old (prior) beach plain stretching from Kochchikade through Negombo – Katunayake – Seeduwa – Ja-Ela – Kandana in a belt of varying width of around 4 miles in its northern aspects around Kochchikade – Negombo; and 2 miles in its southern aspects around Katunayake – Seeduwa and again widening towards Ekala to around a 3 mile width.

The WRB initiated its studies on this aquifer during 1978-1979, where 50 wells were drilled around the Katunayake International Airport (KIA) area. This investigation was undertaken to provide the water requirements of the KIA. Production wells yielding between 20-50 gal/min. were successfully prospected. Even with the rapidly increasing demand, the total water requirement of this whole airport complex is met from wells. The water level is around 5 to 8 m below ground level. Average groundwater abstraction is around 10,000 – 12,000 m<sup>3</sup>/day.

The main aquifer consists of sand and sandy clay and this formation has a thickness ranging from 10 to 15 m; and this is underlain by another aquifer whose thickness ranges between 8 to 15 m.

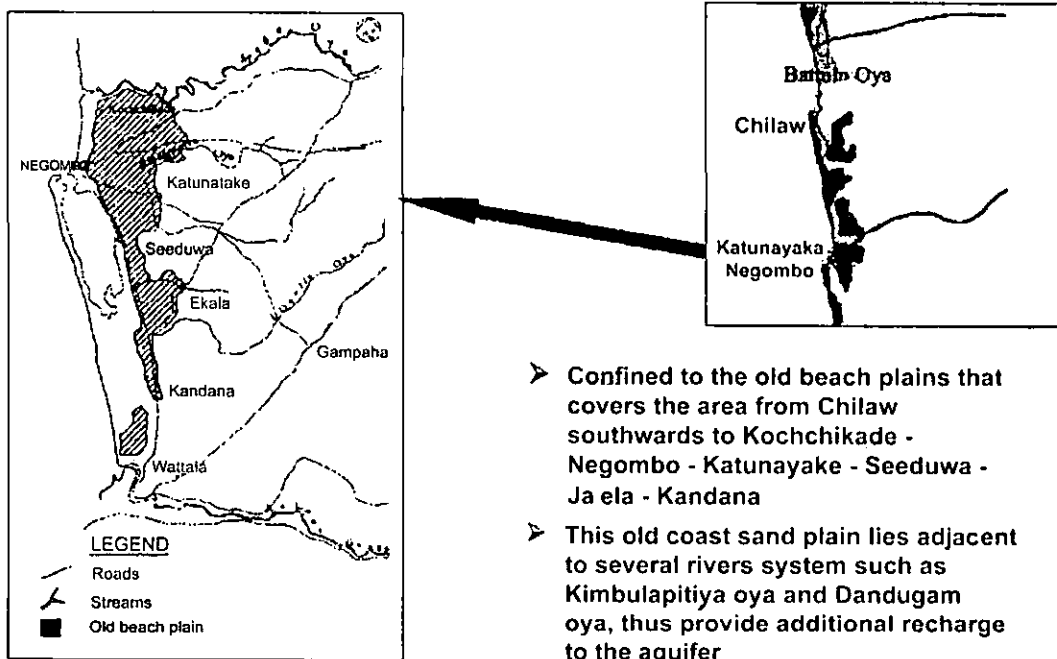


Figure 7.9 Old beach plain from Chilaw to Kandana

From 1980 onwards, a further 140 wells were drilled from Negombo to Ja-Ela including the BOI and Katunayake areas. Because of the very good recharge from rainfall in this wet-intermediate zone region, both the yield and quality of this groundwater is highly satisfactory.

More recently, a total of 15 test wells were drilled between Ja-Ela and Negombo, through this old beach plain, within a 100 to 150 m coastal strip. The depth of these wells was limited to 15 m in order to prevent any saline water intrusion. It was found that wells located more than 150 m from the coastline had an EC value of less than 500  $\mu\text{S}/\text{cm}$ , while these that were within 100 m from the coastline had an EC between 500 to 1,000  $\mu\text{S}/\text{cm}$ .

As could be seen in Figure 7.10, there is a likelihood of both the Kimbulapitiya Oya and the Dandugam Oya augmenting the aquifer recharge in addition to the rainfall recharge, thus enriching this aquifer.

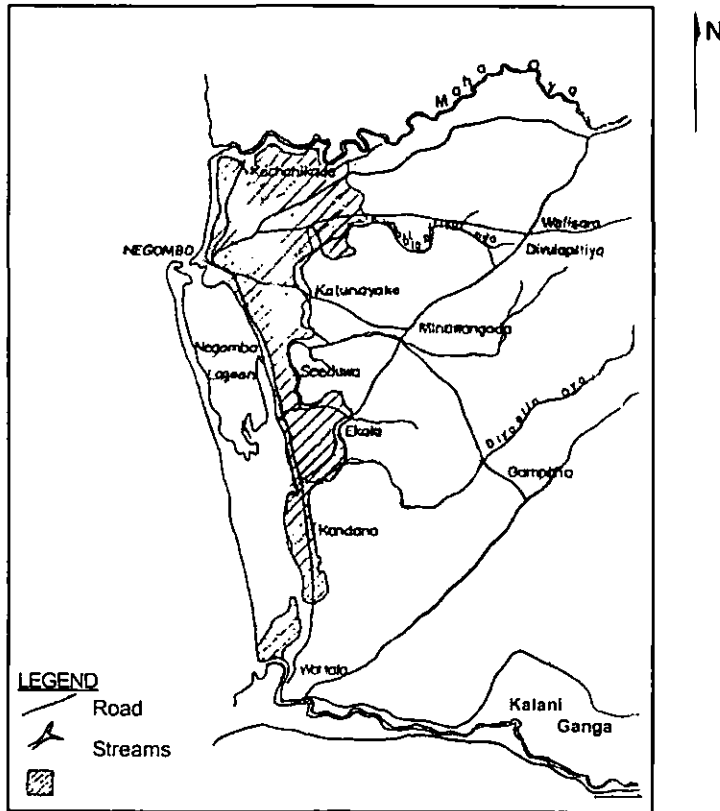


Figure 7. 10 Location of Katunayake Free Trade Zone

## Present Utilization and Potential Threats

The Kalpitiya peninsula could be considered as one of the best examples of a Shallow Coastal Sand Aquifer which has, over the past 17 years, been subject to extreme exploitation for intensive agriculture. Kurupparachchi (1995) reports that there has been a gradual build up of salinity and high rates of leaching due to intensive agricultural practices in the Kalpitiya peninsula. The nitrate concentration in well water has exceeded the WHO recommended values, making it unsuitable for human consumption. He also observes that some sections of the peninsula are more prone to saline water intrusion than others; and that exploitation of the groundwater within the peninsula must be done carefully with a proper understanding of the hydrological conditions of the area.

Aside from the Kalpitiya peninsula there has been an increasing exploitation of this very limited fresh groundwater resource wherever it occurs on the sandy regosols along the south and south west coastal areas of the country. This shallow groundwater resource, traditionally

used in a very sparing manner by homestead settlements, has now given way to several tourist resorts and hotels which have started to over-extract this limited supply, thus causing saline water intrusion into the aquifer. Similarly, some of the less shallow but more productive aquifers located in the north west coastal plain around Chilaw, are being exploited beyond their limits to meet the needs of prawn culture ponds, thus causing saline water intrusion into the aquifer.

It would also be necessary to document the present status of the very significant extents of shallow unconfined aquifers of the eastern and north eastern coasts in the Kalmunai, Batticaloa, Kalkudah, Trincomalee, Nilaweli areas which are well known for their typical conditions, since this would provide a suitable control or standard for comparison with those heavily exploited aquifers in Kalpitiya and in the western coast.

The Tsunami of December 2004 hit the Sri Lankan coast with various impacts, especially the eastern, northern and southern coasts. Though the period of flooding caused by the Tsunami was of short duration, the salt water intrusion in these sandy regosols was significant because of their high permeability. It is estimated that a stretch of land between 50 m and more than 1 km from the coast was inundated. The greater inundation was in the eastern seaboard which is made up of north-south trending barrier-beaches of varying width up to 50 km wide. These sandy regosol beaches had to face the full blast of the Tsunami from Komari in the south to Kalkudah further north.

The southern coasts which are predominantly of the 'Bay and Headland' type suffered less damage, especially along the headland portion and the shielded lagoon portion, while the more severe damage was mainly observed within the open bay segments.

The Tsunami affected the groundwater in various ways, the most notable being the salinization of the groundwater of these coastal sand aquifers. The shallow groundwater wells had traditionally provided the main domestic water source to the settlers located on these sandy regosols.

A very recent publication titled *Tsunami Impacts on Shallow Groundwater and Associated Water Supply on the East Coast of Sri Lanka* by K. G. V. Villholth et al. (2005) provides a very good explanation of the processes involved in the Tsunami incursion and it also discusses a proposed rehabilitation based on a monitoring and research strategy.

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## 8

# AQUIFERS OF VARIABLE DEPTH ON ALLUVIUM OR ALLUVIAL AQUIFERS

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### Previous Studies

Alluvium, in its broadest sense, is applied to clay, silt and sand brought down by streams and rivers and deposited in their lower reaches of flood plains.

Despite its widespread occurrence throughout the country and also the many ways that it is being exploited, there are comparatively very few reported studies on the alluvial aquifers of this country.

The only reported study on a higher order river is that by Sirimanne (1957) on the Mi Oya alluvium; and on a lower order river is that by Coates (1929) on the Kirama Oya alluvial formation.

In an investigation carried out by Wadia (1941), he estimates the depth of the alluvium of the Kelani Ganga as being more than 50 ft. A boring made within the flood plain of the river proved the presence of river gravel at 62 ft below m.s.l. and thickness of nearly 72 ft of alluvium.

It is reported that the town of Chilaw is supplied from wells sunk in the flood plain of the Deduru Oya, but that the water in this instance occurs as ordinary groundwater and not as water under artesian conditions.

Cooray (1967) reports that in the Madampe town in the North Western Province, a bed of gravel 5 to 18 feet thick is overlain by 10 to 30 feet of red earth (red latosol) with fine sand. The gravel appears to be the principal aquifer in the area and most of the wells derive their water from it.

There are a several investigation reports on various alluvial formations carried out over the last 25 years, and these are repositied in the library of the WRB.

### Main Properties

As was pointed out in Chapter 3 the set of alluvial aquifers in this country constitute one of the most diversified forms in the tropical region. They occur over several diversified alluvial land forms, such as coastal and inland floodplains, depositional river valleys, buried river channels

and smaller rivers (oyas) with alluvial deposits of varying depth. The minor rivers and oyas have shallow valleys with irregular floors and are of variable width.

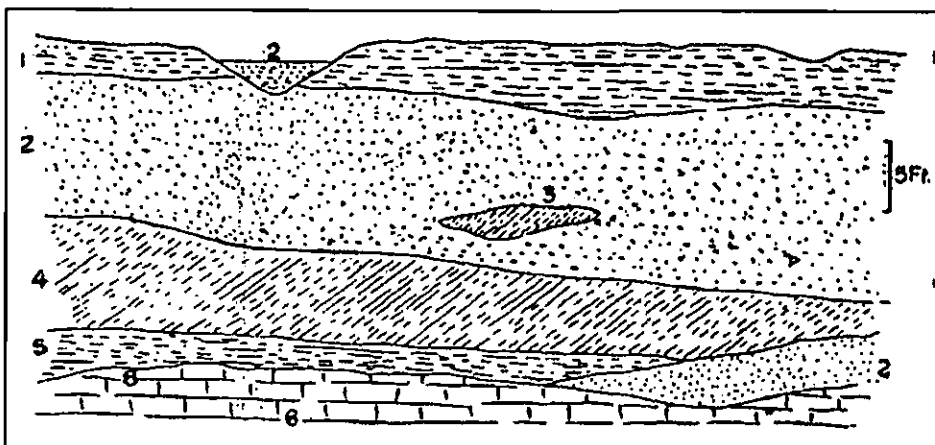
Alluvial deposits cover significant areas of the country, particularly in the lowest peneplain where the rivers overflow their banks during periods of flood. The stretches of alluvium are particularly extensive near the coast, as in the case of the Kelani Ganga, Mahaweli Ganga, Deduru Oya, Mi Oya, Bentota Ganga and Kirindi Oya. These alluvial deposits could be quite thick as in the case of the Kelani Ganga valley near Malwana where it goes down to about 20 ft below sea level.

This great thickness of the alluvium is the result of the gradual subsidence that has taken place during the Quaternary period; as could be seen in the case of the bed of the Kalu Ganga, which is 60 ft below sea level further inland, and where the water can be only a foot or two above sea level.

According to Cooray (1967) "One of the largest carriers of groundwater among the sedimentary formations is alluvium, which in the major river valleys, may vary from 30 to 40 feet to 100 feet in thickness and may extend laterally for hundreds of feet on either side of the river bed."

The Mahaweli Ganga at the railway crossing at Manampitiya is 900 feet wide within the river channel, and the alluvium is over a mile wide with a depth of 60 to 90 feet. A significant amount of underflow of groundwater takes place in such extensive tracts of alluvium.

One of the best examples of a published study on a major alluvial aquifer is that by Sirimanne (1959) of the Mi Oya, from which the Puttalam water supply is drawn; while that of a alluvium of a minor river is by Coates (1929) on the groundwater storage of the Kirama Oya near Tangalle from which the town water supply was drawn. These two studies are described in this section in order to present the main properties of the two types of alluvial aquifers.



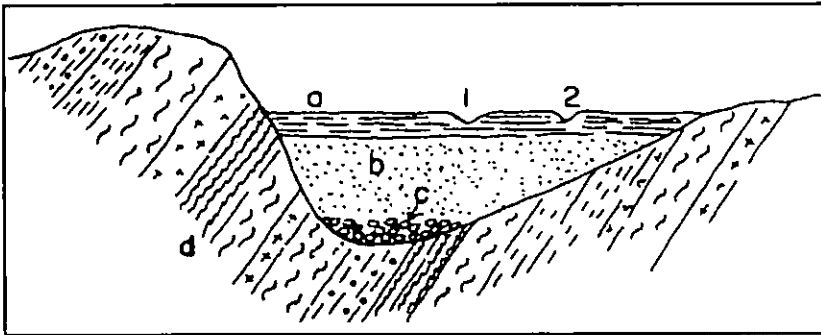
**Figure 8.1** Schematic section Mi Oya aquifer (after C. H. L. Sirimanne, 1957)

1- clay; 2- sand; 3- black, peaty clay; 4- black, impermeable clay; 5 - gray, plastic clay;  
6- bedrock, probably Miocene limestone.

A schematic section of the aquifer of the Mi Oya from which the Puttalam town water supply is drawn is shown in Figure 8 . 1. As seen in this Figure, the aquifer which is situated in the sandy layer which is around five feet in thickness is overlain by a clay layer, and also underlain by black and grey plastic clays. The porosity of the sandy layer is around 25 percent and the total storage capacity of this layer is around 30 million gallons and it provides 300,000 gallons of water per day. What is important about this aquifer is that it gets recharged each year by the seepage of water from the Mi Oya during 150 days of the year when it is in flow. Thus, the amount of recharge of about 90 million gallons is sufficient for the total annual consumption, and it is only in an exceptionally dry year that the ground storage reserves needs to be drawn upon.

A schematic section across the Kirama Oya which shows the groundwater storage in a buried river channel is illustrated in Figure 8 . 2. As seen from this Figure an alluvial clay layer (a) overlies a 30 ft thick layer of sands and sandy clay; (b) which in turn overlies a bed of gravels; (c) these bottom gravels are important water bearing horizons and the recharge of the groundwater takes place within this layer of bottom gravels by replenishment in the upper reaches of the stream.

According to Coates (1929) the existence of 'sub-artesian' springs further upstream is due to the foregoing conditions, with the upper clay layer acting as a confining medium.



**Figure 8 . 2** Schematic section across Kirama Oya aquifer  
(after Coates, 1929)

- a - Alluvial clay 6ft thick; b - Sands and sandy clays 30ft thick  
c - Bed of quartz gravel at bottom of old channel; d - Gneissic bedrock 1 and 2 - Surface streams

In the wet zone, the shallower and smaller aquifers occur within the alluvial deposits of the minor rivers (oyas) and streams. These aquifers are generally shallow and are directly connected to the surface water in streams and rivers. Even in periods of low surface flow, these aquifers get quickly recharged.

The alluvial aquifers of the larger river systems, especially those that flow out to the sea in the southwestern part of the country do not get significantly reduced during extremes of

drought because they are deeper and have a wider alluvial fill as described earlier in this Chapter.

Sirimanne (1964) considers the groundwater potential of the alluvial aquifers of the dry zone in the following terms.

“The alluvium of the major river systems often store considerable amounts of groundwater that drains to the sea slowly as under flow. This water could be conserved for use. The relatively low relief and thin soil cover, generally less than 40 to 50 ft thick in this zone, results in very meagre storage of water underground. A continuous water table occurs only for a short period after the rainy season. As the dry season progresses the water table declines and towards the end of the dry season water is found only in isolated pockets of decomposition in the crystalline rock floor, or in areas where the water table is artificially maintained by means of a tank or irrigation channel”.

## **Rational Utilization**

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A very good example of a sustainable use of an alluvial aquifer could be had from the old Kirindi Oya irrigation project at Tissamaharama, which is situated on the ‘flat alluvial plain’ of the lower Kirindi Oya, between Tissamaharama and Mahagama. As shown in Figure 8.3, water diverted from the old Ellegala anicut (restored in 1897) augments the three irrigation tanks of Wirawila (Right Bank), Tissawewa and Yodawewa (Left Bank). Because of the very flat topography of this alluvial plain, both rainfall and the irrigation waters are easily conserved within this command area, with a minimum loss of ground water to the incised river flow and to surface run-off.

Stable human settlement has been going on since 1897 in this flat plain because of the assured availability of groundwater through the years to the settlers whose homesteads are located within this flat alluvial plain.

During the rainy *Maha* season the aquifer is naturally re-charged; and during the dry *Yala* season the irrigation issues from the three irrigation reservoirs (tanks) help to keep this alluvial aquifer recharged.

A schematic cross section (East-West) orientation shown in Figure 8.4 illustrates the manner of recharge that takes place on this flat alluvial plain.

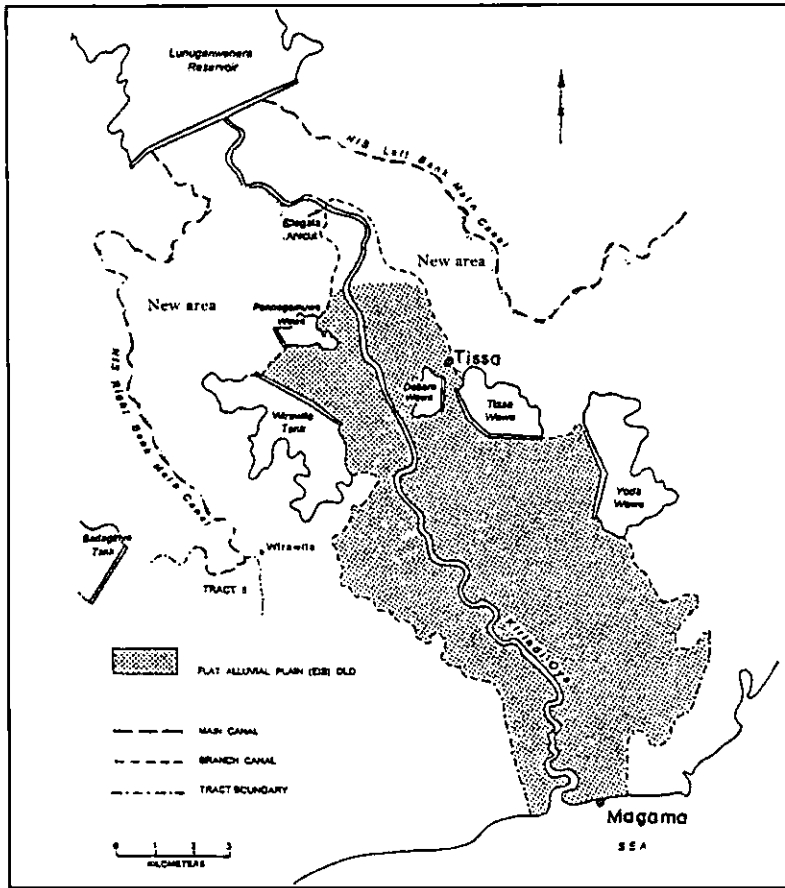


Figure 8.3 Flat alluvial plain of Kirindi Oya Irrigation Project

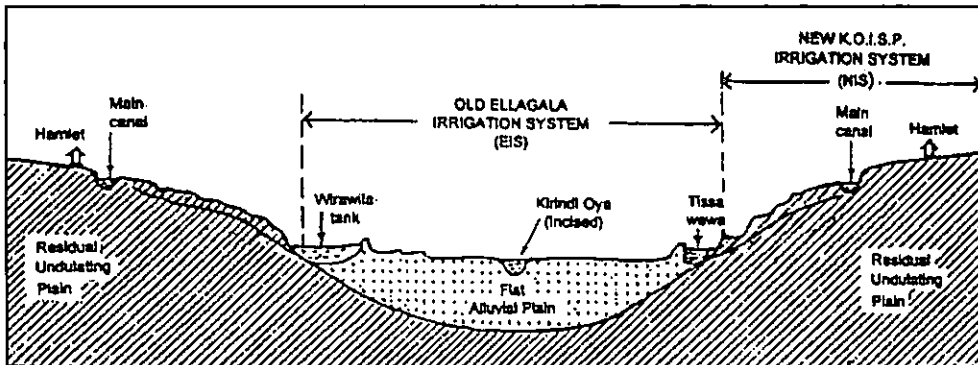


Figure 8.4 Schematic cross section (East-West) orientation showing the manner of recharge from old and new irrigation canals

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## 9

## LATERITE (CABOOK) AQUIFERS OF SOUTH - WEST SRI LANKA

### Previous Studies

The Ragama town area is situated in a typical laterite area. An investigation was carried out by the Public Works Department from March 1929 to March 1932 on the yield of wells located in this area. Results from this study were published by Mahadeva (1934), which serve to illustrate the nature of occurrence and behaviour of the water table conditions in this laterite formation.

The water table was found to oscillate over a range of 20 ft at the top of the landform to about 10 ft on the lower slopes. The rise of the water table was very rapid a few hours after a heavy shower.

Sirimanne (1952) in his well known schematic section of the Ragama laterite reproduced in Figure 9.1, shows the wet and the dry weather water tables. Owing to the high permeability of the laterite, the water table oscillates over a wide range, namely about 25 ft in the higher aspects and less than 10 ft in the lower aspects of the landscape. The best sites for wells are, therefore, at the valley edges where extensive groundwater flow takes place.

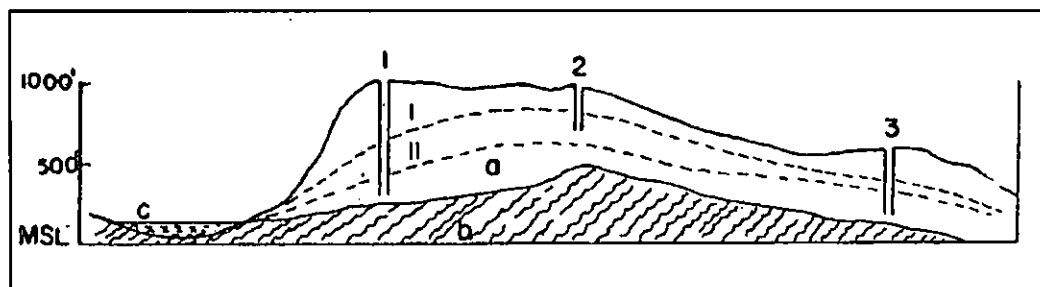


Figure 9.1 Groundwater conditions in typical laterite at Ragama (after C.H.L.Sirimanna, 1952)  
 a - laterite b - gneiss c - alluvium; I - wet - weather water table; II - dry - weather water table; 1 and 3 - permanent wells; 2 seasonal well, runs dry in dry weather

Sirimanne also shows that yields could vary from area to area depending on the permeability of the laterite. In Ragama where the interstices of the laterite are partly filled with kaolin, eleven wells yield 60,000 gallons per day, whereas at Gongitota, where the vesicles are free of clay, a single well yields 80,000 gallons per day. Cooray (1967) states that "true laterite, locally known as cabook, is found only within a well marked coastal belt in the wet zone of Ceylon, and is restricted to the south-western part of the country". Hence the present nomenclature adopted as laterite (cabook) aquifers of south-west Sri Lanka.

It is noted that laterite is best developed in the south-west of the country within a belt extending six or seven miles inland from the coast and up to around 100 feet above sea level. Good examples could be observed at Ragama, Hunupitiya, Hendala, Nawala, Homagama, Beruwela and Ambalangoda where laterite is exposed in quarry faces and in road and railway cuttings.

A vivid description of laterite made in the 19<sup>th</sup> century (1844) by Newbold is worth quoting:

"The laterite, generally speaking is a purplish to brick-red porous rock passing into a liver brown, perforated by numerous sinuous and tortuous tubular cavities either empty, filled, or partially filled with grayish white clay passing into an ochreous, reddish and yellowish brown dust ; or with lilac-tinted lithomargic earth. The sides of the cavities are usually ferruginous and often of a deep brown or chocolate ; though generally not more than a line or two in thickness, their laminar structure may be distinguished by the naked eye ..... The hardest varieties of rock are the darkest coloured and most ferruginous".

Although the exact chemical processes by which laterite is formed are not fully understood, it is well established that an alternation of a wet and dry period during the year is a necessary condition for its formation. Various forms of laterite are present throughout the tropical regions of Asia, Africa, and S.America .

## Main Properties

A schematic cross section through a laterite profile is shown in Figure 9 . 2.

The surface horizon from 0 – 10 cm is usually a friable gravelly loam, and is underlain by a horizon of nodular ironstone gravel which can be loose or compact according to the previous history of land use in the area.

This horizon is underlain by the typical cellular honeycomb structured 'in situ' soft laterite which has a high porosity and permeability. It is this soft laterite which is cut into blocks and when exposed to the air becomes as hard as brick, and highly resistant to the action of air and water. It is this hard material termed 'cabook' that is used as building material. It is this vesicular soft laterite horizon of variable thickness that holds most of the groundwater, and is on the average between 40 to 50 ft in thickness. In some parts of Colombo and Gampaha, wells of over 100 ft depth have been sunk into this laterite zone.

The lowermost kaolinitic layer, which although saturated with water, yields water very slowly and has a tendency to 'cave-in'. This is also referred to as the 'pallid zone' of the

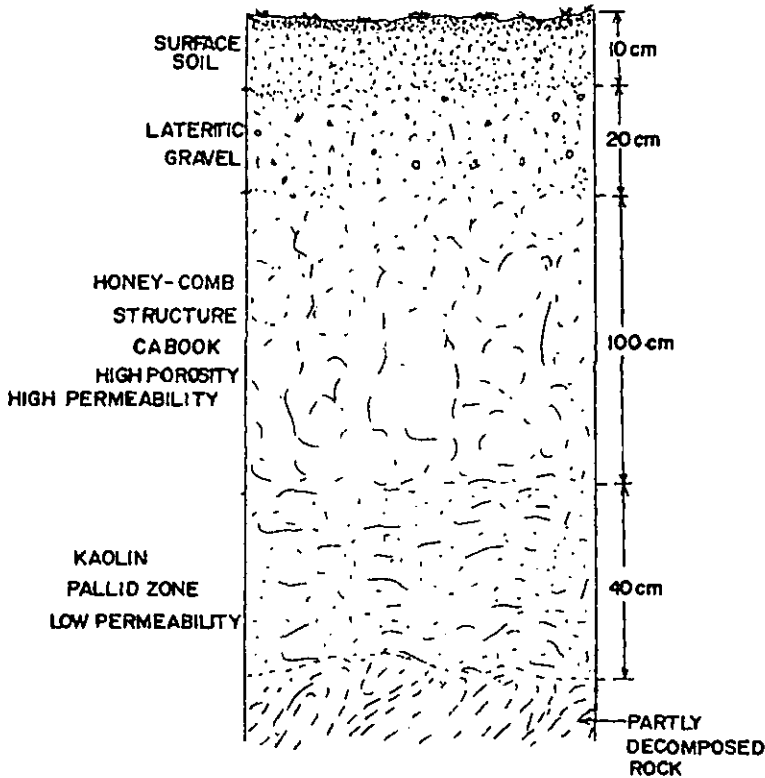


Figure 9.2 Schematic section across laterite profile

laterite profile because of its pale, leached yellow colour. It also shows mottles in a orange yellow matrix closer to the underlying decomposing parent rock. Wells, in general, are not sunk below this layer in this country, because during the low water levels that prevail during the very dry periods, the kaolin tends to disperse and cloud the clear water.

Despite several studies and investigations that have been conducted within this laterite region of south-west Sri Lanka, no serious attempt has been made as yet to properly demarcate and map out the aquifer boundaries. In fact, in terms of the intensity of investigational drillings done per sq. km of country, this laterite region has been covered very intensively over the last 15 years by both state and private agencies. However, all these studies and investigations have been carried out at point sources and no attempts have been made to incorporate the findings from these investigations into aquifer boundary demarcations.

Furthermore, because of the highly dissected nature of this region, the water table or the aquifer itself is highly fragmented into a number of discreet low mounds within the residual laterite landscape and these mounds are separated from each other by intervening valley floors. As such, one should consider this aquifer in terms of a complex mosaic of meso-aquifers rather than a single macro-aquifer as it occurs, in the case of the semi-confined aquifers of the north-western Miocene Belt of the country.

## **Present Utilization and Potential Threats**

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A greater part of the homestead settlements of the Western Province, together with the smaller scale industries, are located within this aquifer landscape, where severe stress is experienced during the dry season. Pollution levels are also reportedly high. Although there has been a very high amount of drilling cum pumping investigations that have been carried out throughout this aquifer landscape, all the results of these investigations have not been properly collated and documented in a manner that would help us to visualize the extent of the drawdown and replenishment that is taking place throughout the course of the year.

In view of the critical position that this aquifer occupies in the Western Province, there is a pressing need to map out and demarcate the extent and boundaries of these aquifers, as well as their current patterns of utilization over the year. As a first step, some selected modal sample areas should be studied intensively in order to obtain a good ground level understanding, and these could then be extrapolated to the rest of the areas. Since this constitutes a great gap in our present knowledge, this should be given very high priority ranking.

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## 10

# METAMORPHIC HARD ROCK REGION OF THE WET ZONE

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## General Background

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A groundwater aquifer in its true sense is not present within the metamorphic hard rocks of the wet zone. Rather, what is found is a fragmented series of water tables that randomly occur within the underlying weathered zone of the basement. These get charged during the rainy periods and this helps to build up a water table within this weathered zone. It should be borne in mind that the weathered zone of the basement rocks of the wet zone is deeper and more extensive than that in the dry zone. The weathered zone of the basement rocks in the wet zone reach depths of between 20 to 30 m, as compared with that of the dry zone which is usually between 8 to 10 m in depth. As a result it could hold more water in its weathered basement than in the dry zone. Furthermore, the bimonsoon nature of the wet zone rainfall also helps to maintain an enhanced recharge.

As was pointed out in Chapter 3, the groundwater in this metamorphic hard rock region of the wet zone has been providing an unfailing source of domestic supply to the settlers who have lived in these regions since medieval times. The supply from these domestic dug wells have provided the cooking, washing and bathing needs of the population over the centuries.

The contours of the water table in this weathered overburden closely follow the morphology of the landform in which it is situated. In the low country or the lower peneplain region, the most common landform that is present is that of a generally rounded upland of medium relief and an adjacent broad flat valley with a very gentle gradient. In the mid-country or the middle peneplain region the most common landform that is present is that of a 'hill and valley' landform of moderate relief with narrow valleys.

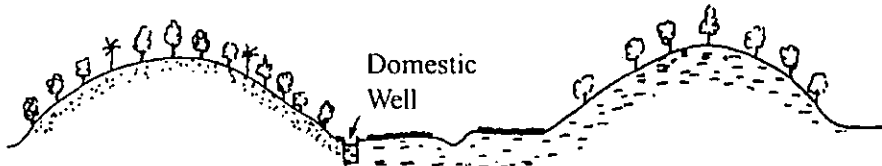
## Groundwater Conditions in the Respective Landforms

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### *Groundwater Conditions in the Lower Peneplain*

Groundwater conditions in this lower peneplain region are best understood by reference to the morphology of the landforms that make up this region. The modal landscape of this region, as

shown in Figure 10.1 below, consists of an undulating to rolling landscape made up of rounded residual uplands of low relief which are usually situated between broad valleys.



**Figure 10.1** Modal landscape of lower peneplain

These valleys are almost flat across the slope, but are gently sloping along the drainage way. The width of these valleys gradually increase as one proceeds downwards along the slope. The area occupied by the upland is slightly more than the lowland which makes up the valley.

The above cross section represents the situation across the higher third order valley. In the first and second order valleys, the ratio of upland to valley bottom-land is higher, and the valleys are narrower and they have a weak gradient.

The position of the water table at the end of the rainy season is shown in Figure 10.2 below. This is typical of the phreatic water table that is present in the weathered overburden.



**Figure 10.2** Phreatic water table at the end of the rainy season

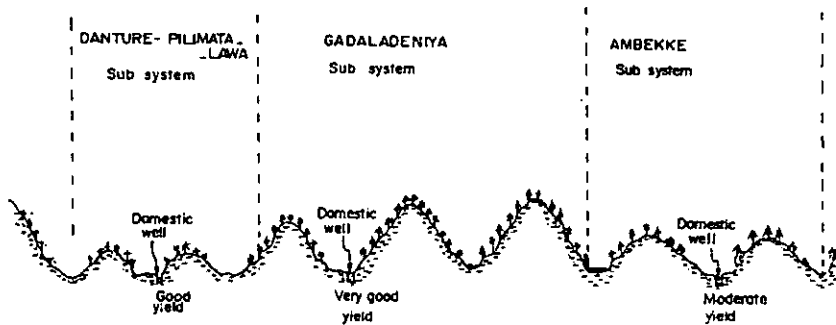
This phreatic water table emerges at the break of slope in the landscape as shown above. The bathing well is located at the footslope of the upland. Even during the dry season this well has sufficient water because of its position in this landscape. As could be seen in the above Figure, the water table replenishes the draw-off from this bathing well.

Because of the bimodal nature of the rainfall distribution pattern that prevails in this wet zone, this phreatic water table or the groundwater is recharged by rainfall for most months of the year except during the normal dry season in February – March. During this short dry season, the water table recedes in the upper aspects of the landscape, but it maintains a sufficient hydraulic head at the foot slopes. This enables a sustainable recharge of the wells located along the lower edge of the landforms that lie adjacent to the valley.

### *Groundwater Conditions in the Middle Penneplain*

The Kandy plateau occupies a significant proportion of the land surface of the middle penneplain and is characterized, for the most part, by a hill and valley landform. A transect of the Uduwara – Yatinuwara land system as shown in Figure 10.3 could be taken as the modal representative of the various land systems that make up this middle penneplain.

As compared with the low rounded hill and broad valley landform which characterizes the lower penneplain, the modal landform of the middle penneplain is made up of hills of medium relief which make up the upland, and these are situated between narrow valleys as shown in Figure 10.3 below.



**Figure 10.3** Transect of Uduwara - Yatinuwara land system of the Kandy plateau

The area occupied by the upland is, on the average, three to five times that of the lowland. This helps to store sufficient water in the upland that gets slowly released to the phreatic water table throughout most of the year. It could be generally stated that the uplands in this landscape virtually function as storage reservoirs, and they slowly release the stored water reserves to the phreatic water table whose position is shown in the schematic sketch. Here too, the weathered zone of this upland has sufficient depth that enables the storage and slow release of appreciable amounts of groundwater through most of the year.

As in the case of the lower penneplain, the bimodal nature of the annual rainfall helps to recharge the phreatic water table for most months of the year. This helps to maintain the phreatic water table which is slowly released to the adjacent valley floor. The domestic wells are usually located at the foot slope as shown in Figure 10.3, and they are augmented by the slow release of the phreatic water table.

### **Present Utilization and Potential Threats**

The shallow open dug wells that are distributed across the entire wet zone metamorphic hard rock regions provide the basic drinking and domestic water requirements to a major proportion

of the rural dwellers in this country. Under the low population density that existed in the past, these open dug wells provided the essential basic domestic needs of water for the rural dwellers, and it was then possible to maintain a balance between supply and demand in these aquifers during that period. With the rapid increase in the rural and semi-urban settlement that has been taking place over the past decades, there has been an increasing stress experienced in both the quantity and quality of water in these aquifers across the entire wet zone. Some fragmentary studies have been carried out in this area by various consultants working with the NWSDB. But no reliable assessment of the present status and urgent needs have been carried out at a national or regional level in this critical needs assessment area.

## 11

### SPRINGS IN SRI LANKA

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Three types of springs could be recognized in this country. These are

- (a) the large perennial springs locally known as *bubulas* which yield around 50,000 gallons per day in the dry season
- (b) the smaller springs locally known as *ulpothas* which have an appreciable flow in the wet rainy season, but could have a very restricted flow in the dry season; and where during a severe dry spell there could be little or no flow; and
- (c) hot springs also known as thermal springs where the temperatures of the water range from 100 °F to 130 °F, and a continuous flow takes place throughout the year.

Springs could also be classified as (i) natural (ii) thermal and (iii) mineral, according to the chemical composition of the water. The term mineral water is loosely applied to various types of bottled water sold in the drinking water markets.

#### Large and Small Springs

A complete volume on the *Springs of Sri Lanka* was compiled in 1974 by S. Arumugam and P. U. Ratnatunga, both senior members of the earlier WRB. This publication is made up of six individual chapters together with an index of the 225 springs that were identified and mapped during the field survey carried out over the period 1970 to 1973. A map of scale 1:2,000,000 showing the distribution of *Springs in Sri Lanka* is also shown in this publication. In Chapter 6 of the publication *Numerical List of Springs of Sri Lanka* shows the name, district and co-ordinates of each of the 225 springs that were visited. In Chapter 3 of the same publication which gives the districtwise list of springs, it could be observed that Badulla district has the highest number of springs, namely 71, followed by Matara 24. The only single copy of this publication is now available for reference at the WRB Library.

A more recent update of the location of 115 normal springs and the eleven hot (thermal) springs is given in Hapugaskumbura's map in 1997 (Arjuna's Atlas). The accompanying Figure (11 : 1) shows the approximate location and distribution of the 115 normal springs and the eleven thermal springs.

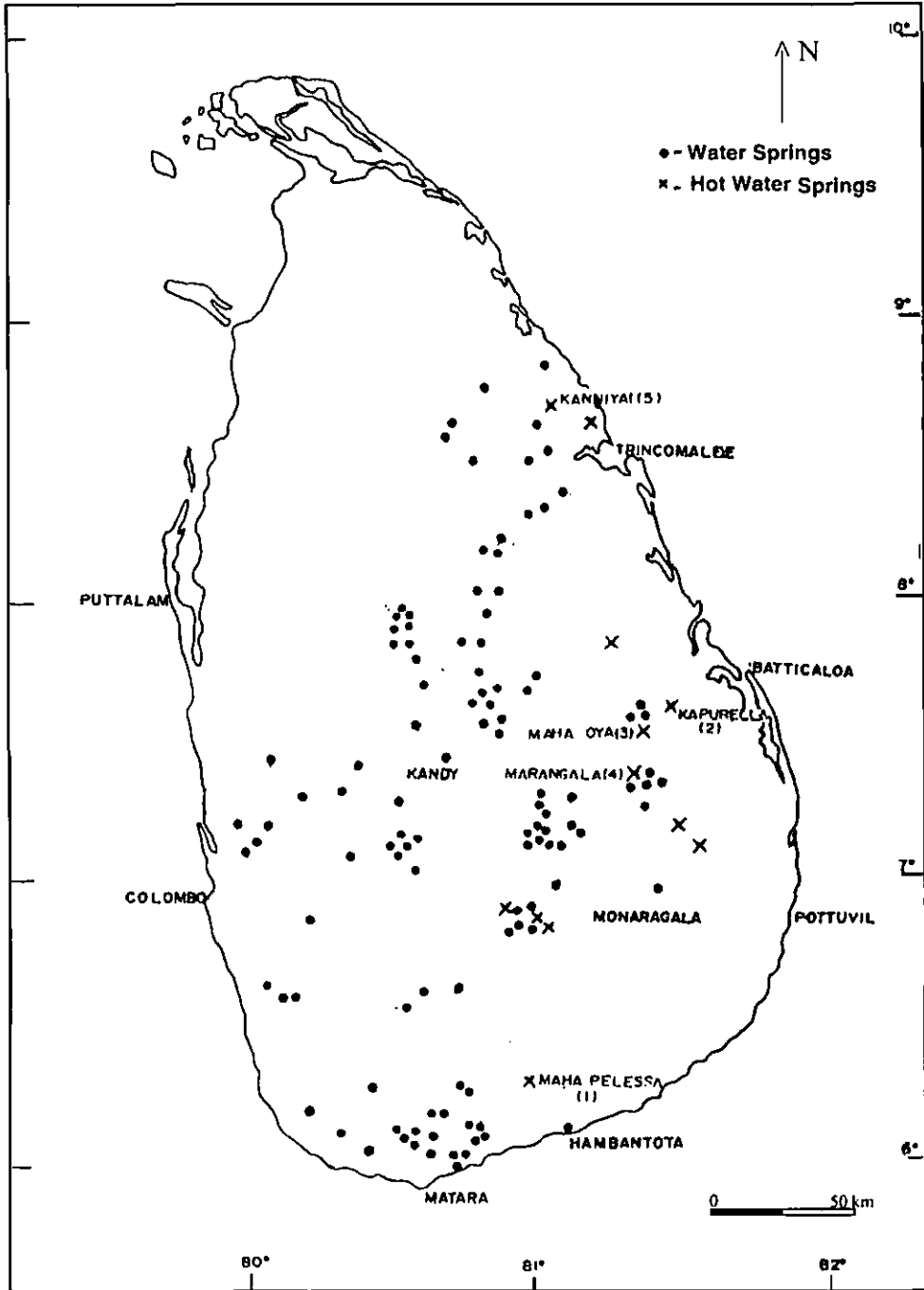


Figure 11 . 1 Approximate location and distribution of normal and thermal springs in Sri Lanka

Most springs in the hill country occur in locations where the planes of bedding and foliation as well as joint planes in the Highland Series of rocks intersect the surface topography, or wherever the ground water table intersects the land surface. It is on such springs that local people install the commonly observed *pihilas* or spouts which are convenient bathing spots, especially for ladies in the neighbourhood.

Individual springs in the quartzites, crystalline limestones and fissured gneisses are capable of yielding between 5,000 and 15,000 gallons per day (g.p.d) in the dry zone.

The larger springs usually occur in places where the land surface has been eroded down to the local water table in a fissured zone, thus causing the water to emerge in the form of springs. Such springs are mostly found in the highly jointed and fissured rocks like quartzites, as for example at Bandarapola in the Matale valley. A section across the Matale valley between Wiltshire Estate (2800 ft elevation) and Bandarapola Estate (1700 ft elevation) is shown in Figure 11 . 2. As could be seen from this Figure 11 . 2 the springs are present in the bands of quartzites and also in the bands of crystalline limestone, and are absent in the bands of gneiss. According to Pattiaratchi (1956), a yield of 50,000 g.p.d. is recorded from the springs in the quartzite bands in the dry season and over 100,000 g.p.d. in the wet season.

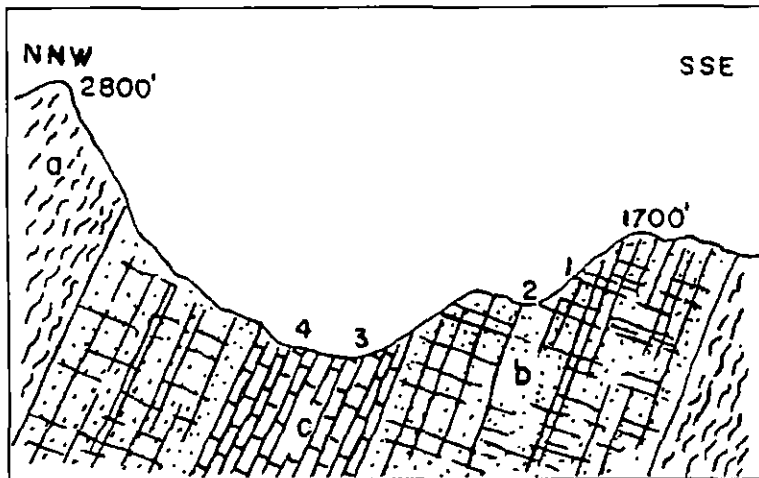


Figure 11 . 2 Section across Matale valley showing position of springs in bands of quartzite(b) and crystalline limestone (c). Note absence of springs in gneiss (a). Position of springs- 4,3,2,1 as shown above (after D. B. Pattiaratchi, 1956)

In the Polonnaruwa area, the quartzites are the principal water bearing strata, being continuous for long distances, as observed by Vitanage (1959). They abound in perennial wells and springs. The several lines of springs seen along these quartzite bands mark the contact interface between the quartzite and the impermeable substrate of granulites below them.

A similar quartzite formation is found around Kebutigollewa cutting halfway across the Horowpothana – Vavuniya road in which perennial springs are present. Several north-east

trending quartzite bands are clearly shown in P. G. Cooray's Geological Map of Sri Lanka (1982). It is these quartzite formations that provide the necessary conditions for the occurrence of these perennial springs.

Similar conditions are found around Gomarankadawela just north of the Anuradhapura-Trincomalee main road, where both a hot and cold spring is shown at Rankihiriya Ulpotha. Five perennial springs are also shown in the quartzite formation in the Adampan and Thampalakamam Pattu of the Trincomalee district. Their locations are shown in the north-west segment of the Horowupathana toposheet; and these were visited by the author in the mid 1960s while conducting the national soil survey of this region.

The several broad bands of dolomitic marble and quartzite that are shown between Matale – Nalanda – Sigiriya – Habarana in Cooray's Geological Map of Sri Lanka contain several springs of varying flow such as those seen off the main road at Madawala Ulpotha, Nalanda, Pallegama and Kibisa. According to Cooray (1982) "some limestone bands, occurring in joints and fissures, which have been enlarged by solution, contain large perennial springs (bubula or ulpotha) which are important sources of water".

The spring at Keerimalai in the karstic limestone of the Jaffna peninsula was previously mentioned in Chapter 4. This spring outlet which is at sea level, is the terminus of a solution channel; and the reasons for its continuous flow was discussed.

## **Hot Springs or Thermal Springs**

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As could be seen in Hapugaskumbura's Groundwater Map (1997), seven of the 11 hot springs are found within the Vijayan Complex of the Precambrian rocks.

The better known and often visited thermal springs are those at (1) Kanniyai (near Trincomalee); (2) Maha Oya just north of Maha Oya town also known as *Unuwaturabubula*; and (3) Mahapellessa (within the Walawe basin just south of Tunkama and Suriyawewa). Others less often visited but equally significant are those at Marangala Wahawe (located two miles north of Maha Oya town), Kapurella (located five miles north of the Maha Oya – Batticaloa road), and Pattipalar on the Uva-Eastern Province boundary.

A description of the hot spring at Maha Oya made by Parsons (1907) almost hundred years ago and is considered yet relevant is reproduced here.

"The water at Maha Oya rises with considerable force by three vents in the sandy bottom of a pond about 30 feet in diameter and 2 feet deep ; it bursts at irregular intervals of about one minute, bubbles of odourless gas rising with the water. Mud at the side of the pool smells strongly of hydrogen sulphide and there is a slight deposit of sulphur on the surface of the mud. This gas is probably due to the decomposition of organic matter. The people of the area occasionally bathe in the pool as cure for itch and other diseases, but fresh elephant tracks by the side of the pool show that the water is not obnoxious to animals".

An unpublished (limited circulation) report on the 'Thermal Springs of Ceylon' by Eng. Hope Todd, and submitted to the Ceylon Tourist Board in November 1968, contains a complete

site description of five of these thermal springs, namely (1) Mahapellessa; (2) Maha Oya; (3) Kapurella; (4) Marangala Wahawe; and (5) Kanniyai. A complete chemical analysis of the waters together with a bacteriological examination of the water samples is provided in this report. Select chemical analysis and chemical classification of five of these thermal springs is given in Table 11.1.

Table 11. 1

**Chemical analysis and chemical classification of waters of five thermal springs \***

<i>Thermal Spring Name</i>	<i>pH</i>	<i>Conductivity <math>\mu\text{S}/\text{cm}^2</math></i>	<i>Bicarbonate (<math>\text{HCO}_3</math>)</i>	<i>Chloride (Cl)</i>	<i>Sulphate (<math>\text{SO}_4</math>)</i>	<i>Sodium (Na)</i>	<i>Chemical Classification*</i>
1 Mahapelessa	7.7	7100	16.1	2630.0	200.0	1157.6	Chloride Type
2 Kapurella Rugam Area	7.6	1600	52.1	286.0	164.0	247.0	Chloride-Sulphate Type
3 Maha Oya	7.6	1500	92.2	75.9	210.0	106.8	Chloride-Sulphate Type
4 Marangala	7.6	900	3.9	4.4	29.9	16.1	Sulphate Type
5 Kanniyai	6.4	250	170.0	16.8	Trace	11.3	Bicarbon-ate Type

\* Classification according to Palmer (1911) and Hill (1941)

\* Also see L.K. Seneviratne and V.S. Balendran (1968) in 'Hot Springs of Ceylon' C.A.A.S; which gives the temperature for Kapurella as 55°C, and Mahapellessa as 44°C

As could be seen from the above table the Mahapellessa thermal spring is high in soluble salts and falls within the Chloride Type. The other two, namely Kapurella and Maha Oya, are moderate in soluble salts; while Kanniyai is low as reflected in an EC value of 250, which is equivalent to Class I potable water.

Cooray (1984), considers that these waters do not qualify for the status of 'spas' which usually have a higher content of soluble salts. As could be seen in Table(11.1), only the Mahapellessa thermal spring comes close to a 'spa' in terms of its content of soluble salts, but unfortunately it is dominated by chlorides rather than by sulphates which thereby lowers its acceptability as 'spa' quality.

In respect of their therapeutic value, people bathe in these as a cure for itch and some skin diseases. The ideal temperature for hot immersion baths is between 96 °F and 106 °F which

obtain in all these thermal springs. The Japanese however, are accustomed to having waters in their baths up to 130 °F.

According to Eng. Hope Todd (1968), “traditionally, these thermal springs have been a source of cure for diseases of the skin and as a mild rheumatic treatment. Although no proper therapeutic values have been worked out, it is possible that further studies would be useful in determining the effects of this water on aging persons, women’s diseases, and also some other illnesses.”

Temperatures of these thermal springs range from 100 °F to 130 °F with very little variation in temperature for any particular spring. The temperature of the Maha Oya thermal spring is reported as 131 °F, while the Kapurella thermal springs have a temperature of 135 °F or more.

As regards the mode of origin of these thermal springs, the current view is that they are normal groundwaters that have traversed great depths along major joints and fissures and thus derived their thermal energy from these great depths and subsequently emerged as springs.

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## 12

# AN APPROACH TOWARDS SUSTAINABLE USE OF GROUNDWATER

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### General Considerations

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Sustainability in groundwater management essentially means limiting the extraction rate to a value below the long term natural replenishment rate. This implies

- (a) The restriction of the groundwater table drawdown to a level which is compatible with vegetation water (mainly the natural forest climax) requirements.
- (b) A guarantee of minimum flow rates in down stream drainage basins.
- (c) The prevention of salt water intrusion and salt water upconing in coastal aquifers.
- (d) The prevention of long-lasting pollution from agro-chemicals and prevention of soil salinization.

In the long term, it is impossible to extract more water from an aquifer than is replenished by seepage from both precipitation or surface water bodies. The pumping or extraction rate will eventually have to adjust to the availability of water within the aquifer. But it is usually more advisable to strike this balance at a high level of groundwater heads than at low levels.

Declining groundwater levels can lead to other serious damages as, for example, a severe lowering of the water table can adversely affect the natural forest climax that is dependant on groundwater for its survival.

Extraction of water from an aquifer can diminish the amount of outflow from a basin and eventually reduce stream flow downstream of the basin.

For human use, as well as for wetlands and ecologically sensitive areas that are situated further downstream, a minimum flow rate has to be ensured.

In coastal areas, over exploitation of groundwater leads to sea water intrusion . Due to the density difference between fresh and saline water, a salt water wedge forms naturally in coastal aquifers. If the fresh water flow is diminished, the wedge may advance further inland, eventually leading to the contamination of wells located inland.

Sustainability not only concerns quantity but also quality. While quality is the more important issue in agriculture, it is of greater importance for drinking water purposes. As a general

guideline, due to its high quality, groundwater should receive a higher priority for drinking water rather than for irrigation, especially in the case of restricted aquifers such as those of the hard rock regions.

Pollution by nitrates and pesticides is common in rural areas, while in industrial regions, petroleum based hydrocarbons and chlorinated hydrocarbon are the main problem. Generally, non-point pollution by nitrates is more widespread than industrial pollutions of groundwater because it is mainly caused by excessive application of nitrogen fertilizers as well as animal waste. This causes increased leaching of nitrates to groundwater and also increased emission of  $N_2O$  and  $NH_3$  into the atmosphere.

The most important parameter for sustainable groundwater management is the recharge of the aquifer. It is a quantity that is difficult to estimate, and indirect methods have therefore to be employed. Measurement of stream flow recession curves is one of the accepted indirect methods, and this is based on the understanding that under low flow conditions that obtain during dry weather all the flow in a stream is supposedly from groundwater. Another method for estimating recharge is by the use of environmental tracers such as tritium.

## Threats to Groundwater Quality

Problems of groundwater quality can arise from two main destructive causes, namely (1) those related to anthropogenic pollution and (2) those related to excessive abstraction. The main causes and concerns that relate to the type of problem is shown in Table (12.1) below.

**Table 12.1**  
**Classification of groundwater quality problems**

<i>S. No.</i>	<i>Type of Problem</i>	<i>Causes</i>	<i>Concerns</i>
1	Anthropogenic Pollution	Inadequate protection of aquifers against manmade pollution.	Pathogens, $NO_3$ , Cl, aromatic hydrocarbon, heavy metals, $SO_4$
2	Excessive Abstraction	Polluted or saline groundwater induced to flow in to fresh water aquifers.	Persistent anthropogenic contaminant and Na, Cl etc.

### *Anthropogenic pollution*

Serious pollution of groundwaters occur when contaminants are leached from the land surface consequent on major changes in land-use practices. The most common pollutants are nitrate, fecal pathogen, and toxic organic compounds. The major concerns relate mainly to

the phreatic aquifers where the vadose zone is thin and the water table is also shallow. In urban areas leakage from water mains and seepage from septic tanks become important factors. More serious contamination can occur where industrial effluents, particularly halogenated solvents, are allowed to infiltrate the ground because of their persistence and non-degradability.

The impact of intensification of agricultural cultivation on groundwater quality is best observed in the industrialized countries, where high rates of leaching of nitrates in soils is taking place, under intensive use of inorganic fertilizers. Similarly, the increasing use of quantities of pesticides, poses additional threats to groundwater quality.

### *Excessive abstraction*

Any degree of groundwater abstraction causes a lowering of aquifer water levels, as well as some external side effects. As a result of the rapid growth of groundwater exploitation that is taking place in some developing countries, it is observed that water is being abstracted from several aquifers at uncontrolled and grossly unsustainable rates.

This uncontrolled abstraction results in quality deterioration of the exploited aquifer caused by the inflow of saline water by upconing or lateral intrusion. In the case of the coastal aquifers ; and an almost irreversible deterioration in the case of those aquifers where the micro-porous matrix is invaded by poor quality water, because it takes a very long time for this poor quality water to be flushed out of this micro-porous matrix.

## **Approach Towards Sustainable Use of Groundwater**

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In order to formulate a rational approach for the sustainable management of any type of aquifer, an acceptable level of knowledge of the setting and hydrological behaviour of the aquifer type is an essential pre-requisite. In the case of the different types of aquifers encountered in this country, such an acceptable level of knowledge is now available in respect of four of the country's main aquifers. These are the shallow Karstic Aquifer of Jaffna, the Deep Semi-confined Aquifers of North-West Sri Lanka, the Regolith Aquifer of the Hard Rock Region, and the Shallow Coastal Sand Aquifers.

Of these four aquifers, although a considerable body of information was available on the Jaffna karstic aquifer prior to 1983, the monitoring studies have been disrupted since then and the continuity of the studies affected. In the case of the deep confined aquifers only preliminary data on the dynamics of the hydrology is available to date. However, an adequate body of data is now available for the Regolith aquifer of the hard rock region and the Coastal sand aquifers, where a set of uninterrupted monitoring studies have been carried out by two principal agencies namely the WRB and the DOA. Hence these two aquifers have been selected for further discussion in this section.

### *Regolith Aquifer of the Hard Rock Region*

The main features of this aquifer has been adequately described and discussed in Chapter 6 of this publication. The recent trends in the utilization of the groundwater resources and potential hazards of over-exploitation are discussed.

The use of shallow groundwater from the regolith aquifer zone in the hard metamorphic rock areas of the north central region has progressed very rapidly during the last 20 years. The former Agricultural Development Authority (ADA) had been promoting the agro-well development programme in the Anuradhapura district from the mid 1980's, in order to help small farmers cultivate high value crops under lift irrigation during the dry *Yala* season. It is estimated that in the Anuradhapura district alone it had assisted nearly 15,000 farmers to construct open dug wells (agro-wells) usually 7 to 10 m in depth and 5 to 7 m in diameter, in order to abstract limited quantities of groundwater for irrigating small plots of 0.5 to 1.0 acre size for the cultivation of chilli, onion and other vegetable crops.

Because of the shallow nature of these regolith aquifers as well as their low specific yield, excessive abstraction could easily lead to a rapid lowering of the existing groundwater levels down to the bedrock. A high density of agro-wells could also lead to a situation where an over extraction of the limited amount of groundwater takes place, which in turn leads to an abandonment of other agro-wells in the vicinity as happened at Paluwa in the Galgamuwa area in the early 1990's. It is suggested that over extraction of the groundwater could also lower the groundwater level to such an extent to adversely affect the natural vegetation in a very dry year, which, in turn, would lead to an irreversible environmental damage.

Overall, it could be concluded that the selective use of this regolith aquifer will continue to remain a good strategy as long as the rate of extraction is less than the average annual recharge of the regolith aquifer.

### *Results of Recent Monitoring Studies*

In respect of the regolith aquifer, results from two exploratory studies, one by Kendaragama (1993), and the other by Ariyabandu (1996) have been reported; while results from a more detailed systematic study carried at on 94 agrowells located within 35 cascades in the Anuradhapura district have been reported by Perera et al. (2001).

Results of the above exploratory studies show that the quality of groundwater in the agro-wells of the Anuradhapura and parts of the Kurunegala districts are suitable for the irrigation of the commonly grown crops; and also that there was no risk from any sodium hazard developing because the SAR values of the tested water samples had a value of less than 10.

Results from Perera's systematic study show that 50 percent of the 94 agro-wells studied have an EC value of between 500 to 1,000  $\mu\text{S}/\text{cm}$ , and that 30 percent of the agrowells have an EC value of between 1000 to 2000  $\mu\text{S}/\text{cm}$ . Values of EC higher than 2000  $\mu\text{S}/\text{cm}$  were reported from only five percent of the agro-wells.

The depth of water columns in the agro-wells showed a gradual increase from September to January, and a steady decline from April to August. At the end of the dry season, wells in the Kebithigollewa, Kahatagasdigiliya and Horowapathana D.S. Divisions had a depth of water columns of more than 1.5 m which indicated their better groundwater status endowment; while wells in the Vilachchiya and Palagala D.S. Divisions had a depth of water column less than 1.0 m which indicated their poorer status of groundwater endowment.

As could be seen from the preceding information, there is an upper limit beyond which the exploitation of the regolith aquifer would result in an irreversible degradation of this precious groundwater resource. In a study conducted on 50 cascades within the Anuradhapura district, Senaratne (1996) has shown that the optimum number of agro-wells that could be safely accommodated within these 50 cascades is not more than 3,600; and that already within five of these 50 cascades, the number of agro-wells has already exceeded the upper limit.

Studies conducted by de Silva (1997) have also shown that the key aquifer parameters, such as hydraulic conductivity and specific yield, are very poor for most of these regolith aquifers and, as a result, the rate of well recoveries are very poor. Therefore, the pumping schedule and abstraction rates should match the seasonal recharge rates within an agro-well in order to avoid drying up of the well during the cropping season. De Silva (2002) has also observed and reported from select studies conducted by her that the annual average recharge was only 10 to 15 percent of the annual rainfall, and that a major proportion of this recharge takes place during the rainy season from late October to late December.

However, it has also been observed that in some areas where these studies were conducted, this amount of recharge was not sufficient to fully replenish the shallow regolith aquifer. Based on select aquifer parameters and their recharge capacity, a set of nomographs has been developed by de Silva (1997) and these could be effectively used to regulate utilization of this limited groundwater supply on a sustainable basis. On the foregoing considerations, it is now possible to limit the future development of agro-wells according to the carrying capacity of the aquifer by use of the above nomographs.

Dharmasena (2000), has very correctly shown that since the regolith aquifers have very limited resources of groundwater, at least 25 percent of the potential groundwater storage in an aquifer should be reserved in order to meet environmental requirements. His recommendation that an agro-well should have a minimum water depth of 1.5 m at the end of the dry season has been supported and confirmed by the monitoring studies carried out over a 24 month period by the WRB in the Anuradhapura district.

### *Coastal Sand Aquifer*

The main features of this aquifer has been adequately described and discussed in Chapter 7 of this publication.

Traditionally, up to around the 1960's both types of these coastal aquifers were very sparsely utilized. Water from these shallow aquifers was lifted manually and mainly used for domestic

purposes by the fishing villages. In the early part of the last century several rainfed coconut plantations were successfully established in the coastal aquifers of the Puttalam district and also along the Eastern sea board around Nilaveli in the Trincomalee district. Chewing tobacco was also grown by small farmers in the Kalpitiya peninsula using simple lift irrigation devices, and these co-existed with the coconut plantations.

Intensification of land use in these coastal sand areas began around the early 1970's with farmers using small diesel pumps to lift water for irrigating chillies and onions, which were becoming quite profitable. Small and medium scale tourist resorts also began to develop, especially around Nilaveli in the north eastern region, which draw their water supplies from these aquifers.

One of the best examples of a rapid change, both in the nature and intensity of land usage, comes from the Kalpitiya peninsula. With the introduction of highly profitable cash crops such as chilli, onion, potato and vegetables, more dug wells were constructed, and mechanical pumps and year round spray irrigation used to supply crop water requirements. The rate of groundwater extraction in some parts of the peninsula has now exceeded the recharge rate. Results of monitoring of water quality now reveal a high build up of nitrate concentration in excess of the stipulated WHO standards, often exceeding 22 mg/l for part of the year.

Monitoring of the agro-wells in the Nilaveli aquifer indicate that despite the high intensity of onion cultivation, there is no build up of soluble salts in the groundwater, and that both nitrate and chloride values in the irrigation water show a sharp rise by the end of the dry season, but decline to a low level after the November – December rains. It is, therefore, reasoned that in this environment the amount of rainfall received during the *Maha* season is sufficient to leach out and dilute the solutes that have built up in the soil during the dry *Yala* season and also as a result of recycling of irrigation water by intensive irrigation.

Several studies have been reported in respect of the coastal sand aquifers both in Kalpitiya and in Nilaweli – Kuchchaweli. The Kalpitiya coastal sand aquifer has been studied over the period 1985 to 1991 by the DOA and the BGS under an ODA assisted programme. The Nilaweli coastal sand aquifer has been studied by the WRB in collaboration with GTZ from 1999 to present.

### *Results of Recent Monitoring Studies*

Results of monitoring of agro-wells in Kalpitiya show that the EC values of the groundwater varied from 400 to 1,500  $\mu\text{S}/\text{cm}$  over most of the peninsula. Lawrence and Kurupparachchi (1989) have reported that while the quality of groundwater over large areas of the peninsula is good, it is observed that within the cultivated areas the concentrations of nitrate, potassium and chloride are exceptionally high. Kurupparachchi and Fernando (1999) also report that the build up of nitrate and chloride is quite dramatic and has been estimated at 1-2 mg  $\text{N}^{-1}$  and 5 mg  $\text{Cl}^{-1}$  per annum, respectively.

Results of monitoring of agro-wells in the Nilaweli – Kuchchaweli area, as reported by Panabokke et al. (2002), show a rise in EC values following the early *Maha* rains followed by a period of stability in February – March, and then a sharp decline after the April rains. The

concentrations of nitrate and chloride also show a rise in initial values in September followed by a decline in values after January – February. In summary, it could be concluded that at present there is no evidence of a build up in the concentration of solutes in these agrowell waters. It could be reasoned that the quantity of *Maha* season rains received is sufficient to leach out solutes that have built up during the dry season. It would, therefore, be concluded that this Nilaweli aquifer is of a more benign and robust nature than the Kalpitiya aquifer.

As previously shown, there is a clear difference in behaviour between the Kalpitiya and Nilaweli coastal sand aquifers. Being located on a 'spit' with the sea and lagoon on both sides, the Kalpitiya aquifer is more fragile and also receives a lower *Maha* season rainfall for recharge. The Nilaweli aquifer in contrast, being located on a raised beach with the sea only on its eastern flank and also experiencing a higher *Maha* season rainfall, is more robust and lends itself to easier management. This is borne out by the results of the monitoring studies reported in respect of the two aquifers.

According to Lawrence et al. (1986), the groundwater system in the Kalpitiya aquifer can be visualized as a series of cells as shown in Figure 7.5, where "within each cell groundwater is drawn to the irrigation well and spread over the cropped area where most of the applied water returns to the water table. The return irrigation flows, on reaching the water table, are unlikely to migrate beyond the cropped area". This statement aptly sums up the cyclic path of the limited irrigation water and its return to the underlying aquifer directly below the cultivated surface area.

Bearing this in mind, one should not be too complacent regarding the sustainability of these aquifers under the present irrigation and water management practices. A systematic and well conceived monitoring programme on both the quality and quantity of the aquifer on a sequential seasonal basis is of prime importance if the sustainable use of these fragile aquifers is to be ensured. Although at present it is observed that the groundwater in wells located outside the intensely cultivated areas is generally of good quality and does not appear to be significantly affected by diffusion of pollution solutes, adequate safeguards should be set in place to ensure their sustainability.

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## Appendix 1 (a)

### *Ten Selected Publications from C.H.L. Sirimanne Memorial Volume*

	<i>Contents</i>	<i>Pages</i>
1.	H.F. Tomalin Underground Water Resources of Ceylon – 1938 Presidential Address 1921 at The Engineering Association of Ceylon	10 - 16
2.	S. Mahadeva The Hydrology of Jaffna – 1938 With particular reference to the Jaffna water supply	17 - 30
3.	C.H.L. Sirimanne Geology for Water Supply – 1952 Presidential Address to Natural Science Section of CAAS Annual Session 1952	31 - 58
4.	C.H.L. Sirimanne and G.D. Vaidya The Occurrence of Ground Water in Ceylon – 1955 Occasional Paper Geological Survey Department	59 - 68
5.	Prof. Abel Wolman Groundwater Exploration – 1956 Problems and Deficiencies W.H.O. Consultancy	69 - 72
6.	John W. Frink, Geological Engineer Groundwater Condition in Ceylon – 1958 and Suggested Programme for Exploration and Development USOM	73 - 89
7.	S.J. Bocks Groundwater Hydrology – 1961 Specialist Officer Irrigation Department	90 - 94
8.	C.H.L. Sirimanne Ceylon's Water Resources And Their Development -1962 Paper read at Symposium of Soil Construction South of Ceylon	95 - 104
9.	C.H.L. Sirimanne Ceylon's Ground Water Resources – 1964 Working Group on Irrigation and Development	105 - 116
10.	C.H.L. Sirimanne Ground Water Resources in the Dry Zone – 1967 Paper read at Annual conference of CAAS Annual Session in 1967	117 - 126

## Appendix 1 (b)

### *Selected References from C.H.L. Sirimanne Presidential Address of 1952 to C.A.A.S. Section D Natural Science*

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## Appendix 2

### *Number of Tube Wells Constructed by the WRB and the NWSDB*

<i>District</i>	<i>No. of Tube Wells Constructed by WRB</i>	<i>No. of Tube Wells Constructed by NWSDB</i>	<i>Total Tube Wells</i>	
01	Ampara	321	716	1037
02	Anuradhapura	329	4693	5022
03	Badulla	114	925	1039
04	Bataloa	136	9	145
05	Colombo	190	152	342
06	Galle	158	239	397
07	Gampaha	272	618	890
08	Hambantota	989	1494	2483
09	Jaffna	260	—	260
10	Kegalle	06	163	169
11	Kilinochchi	14	—	14
12	Kalutara	32	1099	1131
13	Kandy	23	1731	1754
14	Kurunegala	264	3420	3684
15	Mannar	99	34	133
16	Monaragala	371	1961	2332
17	Mulathivu	44	30	74
18	Matale	51	1509	1560
19	Matara	11	398	409
20	Nuwara-Eliya	49	134	183
21	Polonnaruwa	189	1648	1837
22	Puttalam	1563	1705	3268
23	Ratnapura	70	1054	1124
24	Trincomalie	21	248	269
25	Vavuniya	503	498	1001
	<b>Total</b>	<b>6079</b>	<b>24478</b>	<b>30557</b>

*Source : WRB and NWS DB databases*

## Appendix 3 (a)

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### **Groundwater Utilization for Crop Production in the Dry Zone of Sri Lanka**

(Proceedings of a Symposium on Groundwater Utilization in the Dry Zone, 2 December 1997, Kandy, Sri Lanka)

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#### *Policy guidelines for groundwater use*

1. It is recognized that groundwater exists in the hard rock areas of dry and intermediate zones. It is also observed that agro-wells and tanks are hydrologically connected and exists in a cascade system. Tank cascade has to be used as a unit of analysis for planning purposes. As there is a limited amount of available groundwater, there is a limit to the number of agro-wells that can be successfully operated. There is also a delicate balance between the two, which should be preserved. Therefore, agro-wells should be used conjunctively with rainfall and tank water.
2. At present agro-wells are constructed without any concern for the environment. For sustainable groundwater use for irrigation "carrying capacity" of wells (or extraction value) for each cascade system needs to be determined and the number of wells should be maintained within the limit.
3. Further research on groundwater availability and development of groundwater for conjunctive use on a pilot scale needs to be carried out.
4. Awareness among all the groups involved (political, general public, government and non-government officers, and farmers) on the potential dangers of over exploitation of groundwater should be created.
5. It is very clear that the present legislation is not sufficient to guide people to use groundwater in a sustainable manner.
6. There is a lack of coordination among the organizations that promote construction of agro-wells. Various agencies provide support for indiscriminate construction of agro-wells. This approach is self-defeating and destructive. There is a necessity for having a central agency to coordinate all activities related to groundwater use.
7. There is an urgent need to review and revise existing policies, legislation and enforcement concerning agro-well construction and management. The issue is considered serious enough to be taken at the highest political level.
8. There must be a policy to ensure the efficient use of all agro-wells in the country.

*Guidelines for groundwater extraction*

1. The basic land unit that is to be used for analysis and development of groundwater in the dry zone has to be a cascade micro-watershed.
2. Rainfall, land use, geology, water outflow from the watershed (surface and subsurface), groundwater level, water abstraction rates, water use by different land users and influence of water abstraction from deep wells on the shallow wells have to be further studied. Data on the influence of irrigation canals on the water table are also needed for proper assessment of groundwater availability.
3. Environmental impact of agro-well irrigation has to be studied and short-term as well as long-term follow-up actions are needed. In view of the seriousness of damage caused to environment due to over-exploitation of groundwater, immediate steps should be taken to contain the problem by making appropriate recommendations based on the existing information, to limit extraction. These recommendations could be fine-tuned once the gaps in information are filled with further studies. Such recommendations should include guidelines for policymakers, politicians, regulators/institutions, technical and professional staff, and agro-well farmers.
4. In order to prepare guidelines based on existing information on water extraction, it is recommended to set up a national task force. This task force should identify critical areas/regions of groundwater and propose institutional arrangement to implement the guidelines.
5. Following long-term follow-up actions are recommended :  
Development of project proposals and securing of funds for further research. Prioritization of research related to agro-well irrigation by relevant institutions. Continuous monitoring of groundwater level and maintenance of a groundwater inventory.
6. The available information of groundwater availability and extraction related to agro-well irrigation need to be disseminated to groundwater users, potential users, funding organizations, policymakers, planners, and various donors and project personnel. Mass media publications and awareness creation programmes are possible means of achieving this end.

## Appendix 3 (b)

### Proceedings of a Symposium Use of Groundwater for Agriculture in Sri Lanka (30 September 2002 Peradeniya)

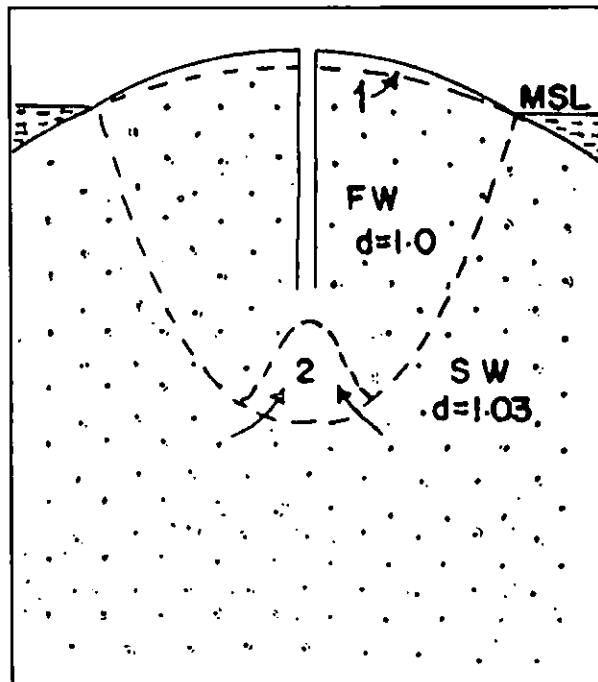
<i>Table of Contents</i>	<i>Page No.</i>
Use of groundwater for agriculture in Sri Lanka ; A synthesis of the Past, present and the future, <i>S. Pathmarajah</i> . (Editor)	01
Nature of occurrence of the regolith aquifer in the hard rock region Of the North Central dry zone, and its rational exploitation for agro-well development, <i>C.R. Panabokke</i> .	10
Groundwater exploration in Sri Lanka – personal experience, <i>Athula Senaratne</i> .	23
Groudwnwater development through introduction of agro-wells and Micro-irrigation in Sri Lanka, <i>A.D.M. Karunaratne and S. Pathmarajah</i> .	29
Regulation of shallow groundwater resources in hard rock areas of Sri Lanka, <i>Shanthi de Silva</i> .	42
Integrated management of surface and groundwater resources in Tank cascade systems, <i>P.B. Dharmasena</i> .	53
Regional groundwater modeling, <i>D.C.H. Senarath</i> .	66
Water quality of agro-wells in the Anuradhapura district, <i>A.P.G.R.L. Perera, D.V.K. Wijekoon, A.A.A.K.K. Seneviratne</i>	74
Water quality of agro wells in the coastal sand aquifer in the Trincomalee district, <i>C.R. Panabokke, S.R.K. Pathirana and Deepthi Wejckoon</i> .	85
Water quality of agro-wells in the coastal area of the Batticaloa District, <i>P. Jeyakumar, P. Premanantharajah, and S. Mahendran</i> .	99
Agro-well and pump in irrigation schemes in the dry zone of Sri Lanka: past diffusion, present status and future prospects, <i>M. Kikuchi, P. Weligamagae, R. Barker, M. Samad, H. Kono and H.M. Somarathna</i> .	108
Socio-economic issues pertinent to agro-well farming in Sri Lanka, <i>M.M.M. Aheeyar and R. de. S. Ariyabandu</i>	119

## Appendix 4

### The Gyben – Herzberg Theory

Around 100 years ago two investigators B.W. Gyben of Holland and B. Herzberg of Germany, working independently along the European coast, found that salt water occurred underground not at sea level but at a depth below sea level of about forty times the height of the fresh water above sea level.

According to this theory – generally known as the Gyben-Herzberg theory – a head of fresh water equal to  $t$  feet above sea level should have a depth  $h = 40 t$  feet of fresh water below it, assuming that the density of sea water is 1.025. If a well at this point is drawn down by a distance equal to  $d$  feet then the column of fresh water is reduced by  $40 d$  ft, by the rise locally of the salt water in the form of a 'cone of infiltration' (Tolman, 1937).  $2f d = t$  then the fresh water column equals 0 ft. and the height of the cone of infiltrations would rise to mean sea level as shown below in Figure 5, Sirimanne (1952).



**Figure** Development of the cone of salt-water intrusion (after Sirimanne, 1952) (2) by Overpumping of the fresh-water lens; FW- resting on salt water; SW - in permeable sandy formation.

## Appendix 5

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### *Characterization and Monitoring of the Regolith Aquifer within Four Selected Cascades (Sub-watersheds) of the Malala Oya Basin (MOB)*

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Up to now no study had been carried out or reported in this country on the dynamic nature of the shallow regolith aquifer.

The Malala Oya basin is located within IWM Ruhuna basin study area, and it is made up of 17 individual sub-watersheds or cascades. The study area included four of these cascades which are located within the upper segment of the Malala Oya basin.

The chief objectives of this study were to a) characterize the mode of occurrence of the regolith aquifer within the study area, and b) monitor and quantify the pattern of depletion as well as the pattern of replenishment of the aquifer through the wet and dry seasons ; and c) to understand the nature of changes in the chemical quality of the aquifer through the dry and wet seasons.

The presently functioning open dug wells that are present within the study area were chosen for monitoring the water table of the regolith aquifer. A total of 25 such dug wells were selected for this study. These dug wells are located within the area bordering the main axis of the natural drainage of landscape and are situated just below the seepage zone of the small village tanks.

The field studies included (a) weekly monitoring of the depth of water table of the 25 dug wells, (b) monthly sampling of the 25 dug wells for measurement of electrical conductivity EC, and chemical analysis in laboratory for Na, K, Ca, Mg, F, SO<sub>4</sub> and hardness.

Results show that the main depletion in groundwater level takes place from May onwards with the range of depletion of the groundwater being between 3.0 to 6.0 m b.g.l. and takes place over a 23 week period up to October. The depth to depletion increases with the macro-elevation of the landscape, with the wells located in the higher aspects having a depth to depletion of between 6 to 8 m as compared with 3 to 4 m in the lower aspects.

In respect of the mode of replenishment it was observed that by the end November a majority of the dug wells had reached their maximum groundwater level except four wells which showed a slower rate of replenishment and reached this maximum level only by the last week of December. These latter four wells are situated further away from the main drainage valley, and are located in the upper aspects of the landscape. It is also observed that a cumulative rainfall of 170 mm is needed to saturate the soil profile, and that a response of the groundwater commences only after this amount of rainfall has been received. In sum, it is observed that the mode of replenishment is very similar in relation to the macro-topography and relief, but that slight variations can be observed in relation to differences in the micro-topography of the relief.

Three broad categories of electrical conductivity (EC) of low, medium and high were recognized on the basis of the monitored values for EC. Despite a decline in groundwater

levels through the dry season (May to September) no corresponding change in EC could be observed. It is therefore argued that the underlying regolith aquifer which feeds these wells has adequate recovery capacity that would enable the maintenance of the quality of dug wells water over the six month dry period. It is also clearly evident that all wells located along the natural drainage ways have a low EC value because there is sufficient flushing out of soluble salts which drain into these free draining situations. Wells that show a high EC value are located at the break of slope in the landscape, and also where there is an underlying sub-surface obstruction.

Wells that have a low fluoride content are found to be located in positions of the landscape where drainage is very good and also where the flushing out of the groundwater water under natural conditions is also very good. Wells that have a moderate fluoride content are found to be located in positions which are close to the axis of the main drainage system where there is moderate sufficiency of drainage and flushing out. Wells that have a high fluoride content are all located at interflow sites in the landscape where there is insufficient flushing out of the water table.

Both the chloride contents as well as the seasonal trends in chloride contents follow the same pattern as the fluoride values described above.

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A.A.A.K.K. Seneviratne  
Deepthi Wijekoon  
Francois Molle

## Appendix 6

### *Select Publications/Reports available for reference at Water Resources Board Library*

<i>WRB Reference No.</i>	<i>Title</i>
R307	Geology for water supply: Presid.Address CAAS Sec.D./ Sirimanne, C.H.L., 1952
R325	The occurrence of groundwater in Ceylon: Groundwater symposium;68-75p/ Sirimanne,C.H.L.,1955
R305	Some aspects of engineering geology in Ceylon: Presid.Address CAAS Sec.D.143-175/Pattiarachchi, D.B., 1956
R043	Geology and groundwater resources in North-West Ceylon/ Department of International Cooperation, 1967.
R183	Ceylon geological survey: The investigation of groundwater resources and suggested program of exploration/ Fernando, L.J.D., 1967
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**GLOSSARY**

<b>Alluvium</b>	Mud, silt, and sand brought down by a river and deposited on the surrounding plain during periods of flood.
<b>Aquifer</b>	A formation saturated with water from which groundwater can be pumped or drained, obtaining flows of local importance.
<b>Aquifer, confined</b>	An aquifer bounded above and below by confining beds and in which the static head is above the top of the aquifer.
<b>Aquifer system</b>	A formation that contains aquifers and aquitards, and behaves hydrogeologically as a unit.
<b>Aquitard</b>	A formation saturated with water, unable to yield groundwater flows of local importance.
<b>Barrier bar, beach</b>	Elongate sand ridge rising slightly above high-tide level, extending generally parallel to the coast and separated from it by a lagoon.
<b>Bore-hole</b>	Any mechanical drill ; generally it includes the casing and some kind of screen.
<b>Conceptual model</b>	A simplified representation of the hydrogeologic setting and the response of the flow system to stress.
<b>Cone of depression</b>	A depression in groundwater levels around a well or group of wells in response to groundwater withdrawal.
<b>Conjunctive use</b>	The variable use of different sources of water to try to optimize some function, such as available flow. Generally includes surface and groundwater sources.
<b>Contaminant</b>	Substance, including any radiological material, that is potentially hazardous to human health or the environment and is present in the environment.
<b>Drawdown</b>	Vertical distance the static head is lowered due to the removal of water.
<b>Dune</b>	A mound or ridge of blown sand, commonly crescentic or linear in shape.
<b>Estuary</b>	The portion of a river or stream which is influenced by the tides of the sea.
<b>Ferruginous</b>	Containing a large proportion of iron compounds ; generally rusty coloured.
<b>Flood plain</b>	The flat portion of a river valley adjacent to the river channel that has been built up by sediments laid down by intermittent floods.
<b>Fluvial</b>	Of or pertaining to rivers.
<b>Geomorphology</b>	The study of the character, origin, and evolution of the surface features of the earth.
<b>Gravel</b>	Loose, detrital material, composed chiefly of small, rounded pebbles mixed with sand and clay.
<b>Groundwater</b>	Any water existing below the ground surface. The term is generally restricted to water in the saturated zone.
<b>Groundwater body</b>	(See aquifer system). This is a new term introduced by the European Union Water Framework Directive.
<b>Groundwater, intensive use</b>	Groundwater development that has a significant impact on the hydrological cycle.
<b>Groundwater, overexploitation</b>	a) (Strict) abstraction is assumed to exceed recharge

<b>Head, static</b>	The height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point.
<b>Highland Series</b>	One of the main Precambrian units of Sri Lanka ; made up of metasediments and charnockitic gneisses and metamorphosed under granulite facies conditions.
<b>Hydrology</b>	The science that relates to the water of the earth.
<b>Hydrogeology</b>	The geology of underground water supplies.
<b>Hydraulic Conductivity</b>	A term used to describe the rate (distance travelled per unit of time) water will move through soil or a saturated geologic formation. The rate groundwater travels is controlled by the type of material comprising and aquifer, the porosity of the material, the slope the water table, and the degree to which existing pores are interconnected.
<b>Infiltration</b>	The penetration of surface water into the ground through the land surface.
<b>Intrusion</b>	The encroachment of a different kind of water into an aquifer.
<b>Kabook</b>	(See Laterite)
<b>Laterite</b>	A reddish weathering product of many rock types in wet tropical regions, resulting from the leaching out of silica, alkali and alkaline earths and the concentration of hydrated oxides of iron and aluminium ; hardens on exposure to air. Known in Sri Lanka as Cabook.
<b>Littoral</b>	Belonging to the shore, between tide marks.
<b>Observation well</b>	A well open to all or part of an aquifer, and used to make measurements.
<b>Peneplain</b>	A nearly flat surface of country produced by long periods of subaerial erosion : 'almost a plain'.
<b>Perched water tables</b>	Occur when a low permeability material, located above the water table, blocks or intercepts the downward flow of water from the land surface. Water mounds up over the impermeable material creating a water table.
<b>Percolation</b>	The flow of water through the unsaturated zone.
<b>Permeability</b>	A property of porous soils indicating how rapidly water will be transmitted through soils toward the groundwater; sand and gravel have high permeabilities while clay has low permeability.
<b>Piezometer</b>	A device constructed and sealed as to measure head at a point in the subsurface.
<b>Plateau</b>	An elevated area of comparatively flat land usually bounded by abrupt slopes.
<b>Pleistocene</b>	The earlier of the two epochs comprising the Quarternary Period ; from about 1 million years age.
<b>Porosity</b>	The percentage of the formation that consists of open spaces or voids that could contain air or water. Porosity determines the amount of water that can be stored in a saturated zone.
<b>Precambrian</b>	all rocks formed before Cambrian time and found below rocks of that age.
<b>Quartzite</b>	A metamorphosed sandstone consisting of an interlocking mosaic of quartz crystals.
<b>Quaternary</b>	The youngest half of the Cainozoic Era, including all deposits from the end of the <i>Tertiary</i> (that is, the <i>Pliocene</i> ) to the present day. Made up of <i>Pleistocene</i> and <i>Recent</i> .

<b>Raised beach</b>	An old beach occurring above and separated from the present beach, due to a rise of the land or to a fall in mean sea level.
<b>Recent</b>	The last 10,000 years after the <i>Pleistocene</i> .
<b>Recharge</b>	The process of introducing water into a groundwater body. a) Natural: Produced naturally as a result of rainfall, streamflow, snowmelt. b) Artificial: Produced by the direct intervention of man.
<b>Safe yield</b>	(See yield, safe)
<b>Saturated zone</b>	Part of ground in which the pores and fissures contain only water.
<b>Silt</b>	Material of which the average grain size lies between sand and clay.
<b>Static water level</b>	The water level in a well located in an unconfined aquifer when the pump is not operating and no water has been discharged from the well for several days.
<b>Sustainability</b>	Ability to meet the needs of the present generations without compromising the ability of future generations to meet their needs. (Bruntland's report definition)
<b>Tectonic</b>	Structural, belonging to the structure of the earth's crust.
<b>Terrace</b>	A horizontal or gently inclined bench-like step, often long and narrow, bounded by steep slopes or escarpments.
<b>Unconfined aquifer</b>	An aquifer that has a water table. The upper water surface of an unconfined aquifer is called the water table.
<b>Unsaturated zone</b>	Part of ground below land surface in which the pore and fissures contain air and water.
<b>Vadose zone</b>	(See unsaturated zone)
<b>Vesicular texture</b>	Containing many small cavities, generally formed by expansion or bubbles of gas or steam trapped in a rock during solidification; common in volcanic rocks.
<b>Vijayan Complex (of Sri Lanka)</b>	A heterogeneous group of gneisses, migmatites, and granites with scattered metasedimentary bands, thought to have resulted from the further metamorphism of the Highland Series and therefore to have formed at a later stage than the latter. Rocks of the Vijayan Complex outcrop on either side of the Highland Series.
<b>Water resources</b>	volume of water that can be used during a given time from a given volume of terrain or water body.
<b>Water table</b>	The upper limit of the saturated zone where pore water pressure equals atmospheric pressure.
<b>Well</b>	Any vertical hole in the ground prepared to allow groundwater abstraction.
<b>Yield, maximum sustained</b>	The maximum rate at which water can be drawn perennially from a particular source.
<b>Yield, perennial</b>	The flow of water that can be abstracted from a given aquifer without producing an undesired result.
<b>Yield, safe</b>	Water that can be abstracted from an aquifer permanently without producing an imbalance.

## INDEX

- Abstraction, 20, 21, 72, 81, 83, 93, 120, 121, 122, 123, 131, 140, 143, 145  
 Abstraction rates, 72, 81, 123, 131  
 Agro-wells, 78, 79, 80, 81, 82, 83, 91, 122, 123, 123, 125, 126, 130, 132, 141  
 Alluvial aquifers, 57, 99, 100, 101, 102  
 Alluvial plain, 102, 103  
 Alluvium, 24, 43, 44, 57, 99, 100, 102, 105, 143  
 Anthropogenic pollution, 120  
 Anuradhapura, 20, 25, 46, 79, 82, 83, 84, 116, 122, 123, 125, 126, 132, 138, 140,  
 Aquifer, 19, 43, 45, 49, 61, 69, 100, 90, 145  
 Artesian, 57, 68, 69, 72, 99, 101, 128  
 Barrier beach, 91  
 Basement crystalline rocks, 20  
 Basement rock, 45, 52, 54, 55, 67, 68, 77, 78, 83, 91, 109, 120, 139,  
 Beach fringed, 56  
 Beach plain, 56, 93, 94  
 Beaches, 45, 55, 56, 89, 90, 96  
 Bed of gravels, 101  
 Bedrock, 52, 53, 54, 56, 58, 76, 79, 83, 100, 101, 122, 123,  
 Bubulas, 113  
 Cabook, 45, 58, 105, 106, 144  
 Carcinogenic substances, 39  
 Cascades, 80, 81, 82, 83, 122, 123, 134  
 Chemical quality of groundwater, 24, 25  
 Chlorides, 25, 92, 117  
 Coastal plain, 30, 44, 45, 50, 57, 67, 90, 96  
 Coastal sand aquifers, 55, 87, 88, 96, 121, 124, 125  
 Coastal sands, 20, 24, 45, 87, 90, 92  
 Coastal Spit, 45, 87  
 Coastline, 56, 90, 94  
 Collector wells, 38  
 Confined aquifers, 30, 50, 51, 68, 69, 96, 107, 121  
 Coning, 56  
 Contamination, 25, 83, 119, 121, 137  
 Coralline limestones, 63  
 Crystalline basement, 34, 39, 52, 71, 77  
 Cultivation, 67, 121, 122, 124  
 Cyclic-path, 125  
 Darcy's Law, 22  
 Databases, 33, 129  
 Deduru Oya, 57, 99, 100  
 Deep fracture zone aquifer, 53, 54, 55, 78  
 Deeper bore wells, 20, 53  
 Deeper fracture, 52  
 Degree of recharge, 79, 81  
 Depth of bore, 54, 55, 78  
 Depth of water columns, 122  
 Diversified alluvial land forms, 57, 99  
 Divining rod, 26  
 Dry season, 58, 76, 73, 81, 82, 86, 91, 102, 108, 110, 113, 115, 122, 123, 124, 125, 134, 38  
 Dry zone, 20, 25, 29, 32, 35, 37, 44, 45, 52, 56, 57, 58  
 Dune water, 0, 85  
 Dynamics, 19, 77, 78, 121  
 Electrical conductivity, 39, 72, 73, 87, 91, 92, 134  
 Electrical resistivity methods, 56  
 Elevation, 71, 86, 115, 134  
 Excessive abstraction, 120, 121, 122  
 Exploitation, 29, 30, 31, 33, 34, 38, 62, 66, 72, 77, 82, 91, 95, 119, 121, 122, 123, 126, 130, 131, 132, 136  
 Extraction, 122  
 Extraction rate, 119  
 Fossiliferous limestone, 70  
 Fissures, 20, 23, 41, 49, 52, 54, 61, 75, 83, 116, 118, 78, 145  
 Flat alluvial plain, 102, 103  
 Fluorides, 24, 25, 39, 40, 83, 135, 139  
 Fracture zone, 2, 53, 54, 55, 77, 78, 79, 81, 85  
 Fractured, 23, 37, 39, 52, 54, 77, 79  
 Freshwater lenses, 64  
 Geological Survey Department, 29, 127  
 Geology, 25, 29, 30, 32, 36, 40, 52, 56, 61, 62, 63, 66, 84, 97, 104, 108  
 Geomorphic setting, 43  
 Groundwater basins, 50, 69  
 Groundwater management, 119, 120, 141  
 Groundwater table drawdown, 119  
 Gyben-Herzberg lens of fresh water, 56  
 Gyben-Herzberg, 56, 64, 133  
 Hand-dug wells, 79, 83  
 Hard rock, 25, 30, 38, 45, 46, 51, 52, 54, 55, 69, 75, 76, 77, 78, 79, 109, 120, 121, 125, 126, 130, 132, 138, 140, 141  
 Hard rock, 30, 45, 46, 52  
 Hard rock areas, 25, 30, 52, 55, 77, 84, 125, 130, 132, 138, 141  
 Highly karstic, 50, 69, 70  
 Hot springs, 113, 116, 117  
 Hydraulic, 21, 22, 39, 79, 81, 110, 123  
 Hydraulic conductivity, 22, 81, 123, 144  
 Hydraulic properties, 21  
 Hydrogeological map, 44  
 Hydrogeological map of Sri Lanka, 36  
 Hydrogeological reconnaissance maps, 38

- Igneous and metamorphic rocks, 23  
 Industrial pollutions, 120  
 Investigations, 32, 69, 71, 7, 91, 93, 104, 107, 108  
 Iron, 24, 25, 84, 83, 92, 144, 143,  
 Irreversible deterioration, 121  
 Irrigation, 30, 32, 40, 44, 65, 67, 70, 73, 83, 84, 87,  
 102, 120, 124, 125, 127, 130, 131, 136, 137,  
 139, 140, 141,  
 Jaffna peninsula, 30, 49, 50, 52, 61, 62, 63, 64, 65,  
 87, 116  
 Joints, 20, 23, 49, 54, 75, 78, 83, 116, 118  
 Kalpitiya aquifer, 87, 89, 90, 125  
 Kalpitiya peninsula, 56, 87, 95, 124, 139  
 Karstic aquifer, 30, 45, 49  
 Kelani Ganga, 43, 57, 99, 100  
 Kirama Oya, 99, 100, 101  
 Kirindi Oya, 57  
 Lagoon, 49, 57, 85, 86, 90, 96, 125, 143,  
 Landform, 43, 56, 105, 109, 110, 111  
 Landscape, 43, 44, 46, 48, 55, 58, 59, 61, 77, 79, 83,  
 105, 107, 108, 109, 110, 111, 134, 135,  
 Larger river systems, 101  
 Laterite, 5, 44, 45, 58, 59, 105, 106, 107, 144  
 Laterite (cabook), 58, 105, 106  
 Laterite formation, 58, 105  
 Lift irrigation, 122  
 Lineaments, 54, 55, 78, 79  
 Low-cost deflouridation method, 40  
 Maha rainfall, 32, 56, 72, 87, 102, 116, 117, 118,  
 124, 125  
 Mahaweli Ganga, 57, 100, 137  
 Main aquifer types, 44  
 Malabar coast type, 58  
 Malwatu Oya, 57, 132, 141  
 Manganese, 24, 25, 84  
 Mannar sandstone formation, 63, 67, 68, 69  
 Meso - catchment, 80  
 Metamorphic rock, 23, 54, 77, 78, 83, 122  
 Metamorphic terrain, 33, 77, 138, 139  
 Mi Oya, 57, 99, 100, 101  
 Mioecne, 38, 44, 45, 49, 50, 51, 55, 56, 63, 67, 69,  
 73, 87, 100, 107, 128, 139,  
 Monitoring programme, 125  
 Monsoon, 56, 59, 63, 64, 90, 109  
 Moongil Aru formation, 67, 96, 70  
 Mulankavil basin, 50, 71, 72  
 Multiple sand barriers, 56  
 Murunkan basin, 50, 70, 71, 72  
 Narrow valleys, 109, 111  
 Nitrate, 25, 39, 65, 87, 99, 120, 124  
 Nitrate concentration, 95, 124  
 Nitrates in the groundwater in Sri Lanka, 32, 39  
 Nomographs, 82, 123  
 Old (prior) beach plain, 92  
 Old coastal plain, 57  
 Open dug wells, 46, 111, 122, 134  
 Optimum number of agro-wells, 82, 123  
 Over- exploration 122  
 Palavi aquifer, 72  
 Pallid zone, 106  
 Perennial, 113, 115, 116  
 Permeability, 21, 22, 23, 53, 58, 83, 105, 144  
 Permeability of the rock, 21  
 Phreatic, 87, 110, 111, 120  
 Phreatic water, 110, 111  
*Pihilas*, 115  
 Pit-latrline soakaways, 39  
 Pleistocene age, 56  
 Pocket beaches, 56  
 Policy guidelines for groundwater use and extraction, 37  
 Pollution, 25, 31, 32, 39, 55, 65, 81, 97, 108, 119,  
 120, 125, 138, 140  
 Porosity, 20, 21, 23, 24, 39, 52, 58, 61, 101, 106, 144  
 Precambrian Basement, 63, 69, 70  
 Primary porosity, 24, 52, 61  
 Pumping tests, 32, 61, 71  
 Puttur well, 65  
 Quality, 112, 117, 119, 120, 121, 124, 125, 126  
 quality and quality of the, 125  
 Quality of groundwater, 122, 124  
 Quaternary sedimentary formations, 50  
 Raised beach, 45, 55, 56, 90, 125, 145  
 Recharge, 21, 39, 40, 55, 56, 58, 71, 79, 82, 83, 87,  
 91, 92, 93, 94, 101, 102, 103, 109, 110, 111,  
 120, 122, 123, 124, 125, 140, 145  
 Red-yellow latosols, 44  
 Regolith, 33 38 51 52 53 55 59 75 77 78 79 80 81 82  
 85 121 122 .....  
 Regolith aquifer, 33, 38, 52, 55, 59, 75, 77, 81, 84,  
 121, 122, 123, 126, 132, 134,  
 Replenishment, 65, 85, 101, 108, 119, 134  
 Reports, 32, 72, 84, 95, 99  
 Reservoirs, 19, 61, 102, 111  
 Safe yield, 39, 83, 86, 91, 145  
 Saline water, 64, 92, 94, 95, 96, 119, 121  
 Salt water, 56, 62, 63, 64, 65, 66, 96, 119, 133  
 Salt water upcoming, 119  
 Sand dunes, 20, 55, 56, 85  
 Sandy clay, 58, 93, 101  
 Saprock, 53, 54, 78  
 Saprolite, 52, 53, 78  
 SAR values, 122  
 Saturated zone, 21, 143, 144, 145  
 Schematic, 44, 46, 49, 54, 61, 78, 80, 87, 89, 90, 100,  
 101, 102, 105, 106, 107, 111  
 Seasonal recharge, 81, 123  
 Secondary porosity, 23, 39, 52

- Sedimentary formations, 23, 24, 30, 35, 44, 50, 67, 100  
 Seepage channels, 50  
 Semi-confined aquifers, 30  
 Settlements, 28, 79, 83, 86, 96, 108  
 Seven semi confined aquifers, 50  
 Shallow, 75, 77, 78, 80, 82, 85, 87, 91, 95, 96, 99, 101, 111, 120, 121, 122  
 Shallow dug wells, 20, 53, 65  
 Shallow regolith, 52, 54, 55, 77, 79, 80, 82, 123, 134  
 Silavathurai Basin, 71  
 Sink holes, 50, 63, 69  
 Small tank cascade systems, 55, 79, 84, 141  
 Soil landscapes or soliscales, 44  
 Solution caverns, 50, 61, 63  
 Spas, 117  
 Specific yield, 20, 21, 81, 122, 123  
 Springs, 35, 37, 46, 50, 61, 64, 101, 113, 115, 116, 117, 118, 136  
 Strategic programme, 31  
 Studies, 27, 30, 31, 32, 43, 52, 57, 61, 62, 65, 67.....  
 Sustainability, 119, 125  
 Thematic Papers, 33  
 Therapeutic, 117, 118  
 Thermal springs, 113, 116, 117, 118  
 Tsunami, 96, 97  
 Tube wells, 20, 25, 34, 30, 33, 45, 40, 55, 72, 79, 83  
 Ulpothas, 113  
 Uncontrolled abstraction, 121  
 Underflow, 100  
 Underground, 21, 26, 30, 40, 50, 52, 62, 64, 65, 82, 85, 97, 102, 127, 133, 144  
 Underground water, 26, 30, 40, 52, 63, 85, 97, 127, 144  
 Vadose zone, 21, 120, 145  
 Vanathavillu limestone, 67, 68, 69, 71  
 Various dune formation, 57  
 Vesicular laterite responds, 58  
 Vesicular nature, 58  
 Vesicular soft laterite, 106  
 Water columns of more than, 122  
 Water divining, 26, 27  
 Water table behaviour, 76  
 Weathered rock topography, 76  
 Weathered zone, 38, 52, 77, 109, 111  
 Wet season, 58, 76, 77, 81, 115, 134  
 Yala, 49, 54, 77, 102, 122, 124,  
 Yield, 20, 21, 29, 32, 38, 39, 45, 52, 55, 58, 65, 71, 72, 78, 79, 86, 87, 91, 93, 105, 106, 119, 113, 122, 123, 139, 145

## METRIC ENGLISH EQUIVALENTS

Length

1 cm = 0.3937 in.

1 cm = 3.281 ft

1 km = 0.6214 mi

1 chain = 23 m

Area

1 cm<sup>2</sup> = 0.1550 in.<sup>2</sup>

1 m<sup>2</sup> = 10.76 ft<sup>2</sup>

1 ha = 2.471 acre

1 km = 0.3861 mi<sup>2</sup>

Volume

1 cm<sup>3</sup> = 0.06102 in.<sup>3</sup>

1 l = 0.2642 gal  
= 0.03531 ft<sup>3</sup>

1 m<sup>3</sup> = 264.2 gal  
= 35.31 ft<sup>3</sup>  
= 8.106 x 10<sup>-4</sup> acre-ft

Mass

1 g = 2.205 x 10<sup>-3</sup> lb (mass)

1 kg = 2.205 lb (mass)  
= 9.842 x 10<sup>-4</sup> long ton

Flow Rate

1 l/s = 15.85 gpm  
= 0.02282 mgd  
= 0.03531 cfs

1 m<sup>3</sup>/s = 1.585 x 10<sup>4</sup> gpm  
= 22.82 mgd  
= 35.31 cfs

1 m<sup>3</sup>/day = 0.1834 gpm  
= 2.642 x 10<sup>-4</sup> mgd  
= 4.087 x 10<sup>-4</sup> cfs

Hydraulic Conductivity

1 m/day = 24.54 gpd/ft<sup>2</sup>

1 cm/s = 2.121 x 10<sup>4</sup> gpd/ft<sup>2</sup>

1m/day = 1.198 darcy (for water at 20 °C)

1cm/s = 1035 darcy (for water at 20 °C)

Water Quality

1 mg/l = 1 ppm  
= 0.0584 grain/gal

Equivalent weight of ion =  $\frac{\text{atomic weight of ion}}{\text{valence of ion}}$

meq/l of ion =  $\frac{\text{mg/l of ion}}{\text{equivalent wt of ion}}$

1 meq/l = 1 me/l

= 1 epm

1 μS/cm = 1 μmho/cm

1 μS/cm = 0.65 mg/l

$\left. \begin{array}{l} \\ \\ \\ \end{array} \right\}$	Approximations for most natural waters in the range of 100 to 5000 μS/cm of cations at 25 °C
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= 0.10 meq/l

## **About the Author**

Dr C. R. Panabokke received his Ph.D. in Soil Science from Adelaide University South Australia in 1956, while working with the CSIRO Division of Soils. He has provided leadership to land and water management research in Sri Lanka for over 25 years as Head, Land Use Division, Department of Irrigation (1960-1974) and as Director of Research (1974-1979) and Director of Agriculture (1979-1982) respectively at the Department of Agriculture. Dr Panabokke is a leading authority on tropical soils in Asia with over 70 scientific papers and research publications to his name. He received the National Science Council award for outstanding scientific research in 1982 and was bestowed with *Vidya Jyothi*, the highest scientific honour in Sri Lanka, by H.E. the President in 1986. He was conferred the D.Sc. (Honoris Causa) by the University of Peradeniya in December 1994. Dr Panabokke served as Senior Research Fellow at the International Service for National Agricultural Research (ISNAR) at The Hague; and he was a member of the Board of Governors, International Board for Soil Research and Management (IBSRAM) from 1983-1989. Until recently, he was affiliated with IWMI as a Senior Research Fellow. He is currently engaged as an Emeritus Fellow at HARTI, working on a set of volumes on the small village tank systems of Sri Lanka, the first volume of which is to be published shortly.

# Groundwater Conditions in Sri Lanka

A Geomorphic Perspective

Groundwater is one of Sri Lanka's most precious natural resources. When compared with surface water, groundwater is a hidden resource, which is more reliable and also less subject to the type of year-round variation as in the case with surface streams and rivers. Groundwater however, is yet insufficiently understood; irrationally exploited and inadequately protected. ***The fear is that scientific ignorance may lead to its over-exploitation.***

In writing this book, the author has adopted a geomorphic approach and attempted to bring together all available references to past studies and investigations carried out in the island. Chapters 2- 9 cover the geomorphic setting of the six main types of groundwater aquifers that have been identified in Sri Lanka, their geographic spread across the country and their main properties and present utilization, including potential threats. The final Chapter addresses contemporary issues on sustainable use of groundwater in Sri Lanka.

This book provides an invaluable knowledge base to the State, Provincial, Private and Non-Governmental agencies to build an effective scientific foundation for policies governing the management and protection of our groundwater resources.

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