WATER RESOURCES DEVELOPMENT IN THE JAFFNA PENINSULA

Rajathurai Mathanakaran

Water Resources Development

in the

Jaffna Peninsula – Sri Lanka

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JAFFNA PENINSULA – SRI LANKA

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Note of the Editor cum Publisher

This book that comes out now is the PhD thesis of my father, the late Dr. Rajathurai Mathanakaran, submitted to the University of Mysore in 1982. I am glad that the effort I initiated as a tribute to my father coincides with the Golden Jubilee of the University of Jaffna, where he was one of the founder academic staff.

I would like to thank the University of Mysore for allowing me to publish my father's PhD thesis in book format. My sincere gratitude goes to all those who supported my father in his research and thesis process, many of whom are listed in his personal acknowledgements. This publication would not have come to fruition without the tireless encouragement and support of my father's friend and colleague, Dr. Ponnampalam Ragupathy.

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The topic, Water Resources Development in the Jaffna Peninsula was close to my father's heart. My mother, Mrs. Baleswary Mathanakaran, my brother, Dr. Thayaparan Mathanakaran and I earnestly hope that this book will be well received in serving current development needs in Jaffna as well as further academic research in this field.

Ajanthie Mathanakaran
Scarborough, Ontario, Canada

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Part One

THEORETICAL BACKGROUND

I. INTRODUCTION

A. THE PROBLEM

This study is concerned with the assessment and the state of surface and groundwater resources development and the problem of groundwater management for optimal utilization of available water resources. The data used to throw light on the development and management relates to Jaffna Peninsula, Sri Lanka.

Though the geographic aim of the present research is to assess the state of surface and groundwater resources development, it is also necessary to look into the problem of groundwater management for optimal utilization of available water resources. Further, it discusses certain attempts to answer a question frequently voiced during drought periods. Namely, to what extent is the livelihood of the Peninsula threatened by deterioration in groundwater quantity and quality? The idea is that fresh groundwater occurs in the aquifer as lenses overlying saltwater. Recharge to the aquifer and buildup of groundwater storage occur predominantly during a three month period from October to December each year. The rapid decline in water levels and groundwater storage generally starts in January primarily as a result of groundwater discharge to the sea through an extensive network of solution channels in the limestone and secondarily because of withdrawal from the wells. Within three months, water levels are so lowered and groundwater storage is depleted, and, in some areas, salinity increased as to severely limit the amount of water available for cultivation and other purposes.

B. THE OBJECTIVES

The objectives of this study are:

1. To assess both theoretically and empirically the quantity of rainwater that percolates annually.
2. To assess the extent of the flow of groundwater into the sea.
3. To assess the quantity of groundwater available for use in agricultural and other enterprises.

4. To determine the direction, duration and extent of saline infiltration.
5. To determine the methods of controlling discharge to the sea.
6. To determine the methods of controlling saline infiltration.
7. To determine the ecological implications of over extraction of water in the Peninsula.

C. HYPOTHESES

In pursuance of the objectives outlined above, the following hypotheses are framed to be tested in the field:

1. The variability in the rainfall will reflect in the fluctuation of the water table.
2. The aquifer in the Peninsula cannot hold all the water that percolates into it from the rainfall.
3. The fluctuation in the water table will affect the pattern of land use.
4. Overdrawing of water in the aquifer will promote salinity conditions, and perhaps more wells in future will turn into brackishness or saline conditions.
5. There exists a correlation between land use and the quality of water available.

D. METHODOLOGY

The objectives of this study are to be achieved in six interrelated steps:

1. Development and interpretation of water table maps and evaluation of flow patterns in the aquifer.
2. Determination, where feasible of the velocity of flow of water in the ground using Darcy's law on hydraulic gradient or the slopes of the groundwater level.
3. Evaluation of salinity maps and salinity profile and define the freshwater lenses.
4. Development of water balance, if possible, to evaluate recharge, discharge and changes in storage within the freshwater lenses.
5. Application of Ghyben - Herzberg saltwater freshwater lens analysis.
6. Use of other appropriate mathematical models wherever suitable for analysis.

The design of the study is based largely on the measurement of static water level and total dissolved solids and chloride concentration in pumped samples from a systematic program of data collection by the Irrigation Department and Water Resources Board, Jaffna from 411 representative wells along with the following:

1. Rainfall data from selected meteorological stations in the Peninsula.
2. Groundwater withdrawal data from domestic wells, agricultural wells, and domestic and agricultural wells.
3. Periodic measurement of the flow of springs and seeps in the Peninsula.

Among the other sources of data:

1. Crop-water requirement data from the agriculture department, Jaffna.
2. Open pan evaporation data from the agricultural research station and agrometeorological station, Thirunelvely, Jaffna has been gathered for analysis.

For the purpose of obtaining primary data, the author has done field investigation extensively in the Peninsula. In order to maintain the accuracy of the information and data solicited from the Government Departments, the author has collected samples from selected wells and prepared separate notes and observations for comparison. Thus, the data used in this research are both primary and secondary.

Apart from those mentioned above, the author has taken into consideration the available data, with the water Resources Board on the North and North- West of Valigamam area to carry out a detailed investigation. 725 hand dug observation wells were selected within this area of 55 sq. miles, thus covering 16 wells per sq. mile when compared to the initial 4 wells per sq. mile. Apart from general groundwater quality, other information required on geology of the area, rainfall, runoff etc.; were also collected within this area. This area comprised of the numerous springs and sub-surface groundwater discharge zones, area of heavy agricultural and domestic water withdrawal with many freak wells situated are the primary reasons to select as a specialised study area.

However, the partial study of this sample area of the Peninsula leaving the rest of the area uncorrelated was a limitation to this study due to lack of data available to other areas.

E. NEED

The incentive for this study stems from several reports of the incidence of saline infiltration in wells and water shortages for domestic as well as in agricultural enterprises. Since there are no rivers in the Peninsula, the only source of water resolves into tapping of groundwater. Other surface water sources have their limitations due to the nature and porosity of the limestone and the long dry season that lasts for about eight months in a year which leads to high evaporation. In the last decade, this region has achieved major increase in food production by intensification of cropping and by extension of irrigated acreage. The increasing use of groundwater for well irrigation makes acute the need for careful planning of water resources for optimal use and to safeguard the welfare of the people.

F. RELEVANCE OF THE STUDY

Groundwater is the key to human existence and agricultural enterprise in the Peninsula. In the last decade this region has achieved a major increase in food production by an intensification of cropping and, to a lesser degree, by extension of irrigated acreage. The concomitant increase in the use of groundwater for well irrigation makes acute the need for positive management of water resources in order to conserve groundwater quality. In order to identify numerous facets of the water problems and the underlying severity of the situation, it is necessary to formulate an effective policy of water resources development and management based on study of this nature.

G. ORGANIZATION

This research report is composed of three parts.

Part I. Theoretical Background

The present chapter gives the problem, sets out the objectives, and formulates hypotheses, the methodology, and the scope of the study.

Chapter II reviews the available literature at three levels, which forms the base to the present study of water resources development in the Jaffna Peninsula.

Part II. Empirical Analysis

Chapter III attempts toward a theoretical basis to water resources development which gives the necessary base to the groundwater regime in the Peninsula.

Chapter IV discusses the nature and occurrence of surface and groundwater, aquifer characteristics, groundwater mounds, groundwater storage, groundwater recharge and discharge, flow characteristics, salinity conditions and thickness and shape of the freshwater lens.

Chapter V evaluates the various aspects of water resources on a selected area, the North and Northwestern part of Valigamam of the Peninsula, taking into consideration groundwater recharge, abstraction and saline intrusion etc., based on aquifer characteristics.

Chapter VI identifies the numerous facets of the water problems in various uses such as drinking water, agricultural water and industrial uses and focusing attention on the problem of water shortages in many parts of the Peninsula and water quality and ecological implications.

Chapter VII emphasizes the need for the development and an effective policy of water resources management in light of the above discussion. This focusses attention on the recently introduced District Development Councils to integrate water resources development and management policies in its integrated planning. Finally, based on the findings this research brings out the future research frontiers and prospects of water resources in the Jaffna Peninsula.

II. GROUND WATER RESOURCES DEVELOPMENT - REVIEW AND APPRAISAL

A. REVIEW OF RELEVANT LITERATURE

1. Global Outlook

Groundwater development dates from ancient times. The Old Testament contains numerous references to groundwater, springs, and wells; Tolman (1937) described the large underground water tunnels, or canals, in Persia and Egypt dating from 800 B.C. Utilization of groundwater greatly preceded understanding of its origin, occurrence, and movement. The writings of Greek and Roman philosophers to explain the origins of springs and groundwater contain theories ranging from fantasy to nearly correct accounts. As late as the seventeenth century it was generally assumed that water emerging from springs could not be derived from rainfall, for it was believed that the quantity was inadequate and the earth too impervious to permit penetration of rainwater far below the surface. Thus, early Greek philosophers such as Homer, Thales, and Plato hypothesized that springs were formed by sea water conducted through subterranean channels below the mountains, then purified and raised to the surface. Aristotle suggested that air enters into cold dark caverns under the mountains when it condenses into water and contributes to springs.

The Roman philosophers, including Seneca and Pliny, followed the Greek ideas and contributed little to the subject. An important step forward, however, was made by the Roman architect Vitruvius. He explained the now accepted infiltration theory that the mountains received large amounts of rain which percolate through the rock strata and emerged at their base to form streams.

The Greek theories persisted through the Middle Ages with no advances made until the end of the Renaissance. The French potter and philosopher Palissy (C. 1510-1589) reiterated the infiltration theory in 1580, but his teachings were generally ignored. The German astronomer Kepler (1571 - 1630) was a man of strong imagination who likened the earth to a huge animal which takes in the water of the ocean, digests and assimilates it, and discharges the end products of these physiological processes as groundwater and springs. The sea water theory of the Greeks, supplemented by vaporization and condensation processes within the earth, was restated by French philosopher Descartes (1596-1650).

A clear understanding of the hydrologic cycle was achieved by the latter part of the seventeenth century. For the first time theories were based upon observations and quantitative data. Three Europeans made notable contributions, although others contributed to and supported these advances. Perrault (1608-1680) measured rainfall during three years and estimated run-off of the upper Seine River drainage basin. He reported in 1674 that precipitation on the basin was about six times the river discharge, thereby demonstrating as false the early assumptions of inadequate rainfall. The French physicist Mariotte (C. 1620-1684) made measurements of the Seine at Paris and confirmed Perrault's work. His publications appeared in 1686, after his death, and contained factual data strongly supporting the infiltration theory. Meinzer, once stated "Mariotte ... probably deserves more than any other man the distinction of being regarded as the father of ground water hydrology, perhaps I should say of the entire science of hydrology". The third contribution came from the English astronomer Halley (1656-1742) who reported in 1693 on measurements of evaporation, demonstrating that sea evaporation was sufficient to account for all springs and stream flow.

During the eighteenth century, fundamentals in geology were established which provided a basis for understanding the occurrence and movement of groundwater. During the first half of the nineteenth century many artesian wells were drilled in France, stimulating interest in groundwater. The French hydraulic engineer Darcy (1803-1858) studied the movement of water through sand. His treatise of 1856 defined the relation, now known as Darcy's law, governing groundwater flow in most alluvial and sedimentary formations.

Later European contributions of the nineteenth century emphasized the hydraulics of groundwater development; Significant contributions were made by Boussinesq, Daubree, Dupuit, Forchheimer, and Thiem.

Episodic investigations of groundwater, dating as far back as the end of the nineteenth and the beginning of the twentieth centuries, have established that the groundwater table as well as spring discharges, are directly related to precipitation, evaporation, moisture deficit, temperature, atmospheric pressure, and level fluctuations of adjacent streams and basins. An understanding of the regime of ground water was then very limited, having been confined to a study of level variations conditioned by the above-mentioned factors, but without consideration of methods of mathematical analysis.

Later studies developed along three principal lines:

1. Mathematical analysis of water table fluctuations based upon the theory of unsteady flow.
2. Laboratory experiments of individual groundwater phenomena and observations of separate processes of such behaviour at experimental field installations.
3. Development of a permanent network of observation posts intended for long-term study of groundwater levels, discharges, temperatures and chemical composition.

The fundamental differential equation for the unsteady flow of groundwaters was deduced by Boussinesq in 1877.

Several particular problems within the framework of the theory of unsteady flow were proposed by Maillex in 1903 [? Editor], Forchheimer in 1919 and later by Felber (1931, 1932).

In the twentieth century, increased activity in all phases of groundwater hydrology has occurred. Many Europeans have participated with publications of either specialized or comprehensive works. Although too numerous to mention, the names of Dachler, Imbeaux, Keilhack, Koehne, Kozeny, Prinz and Theim are best known in the United States.

The principles for the modern theory of the movement of the ground waters were laid down by Soviet scientists, Academicians Zhukovsky (1923), Pavlevsley (1922) and Leibenzon (1934).

Important early theoretical contributions on groundwater were made by Hazen, King, and Slichter, and detailed field investigations were begun by men such as Chamberlin, Darton. Lee, and Mendenhall. Much of the progress in groundwater hydrology this century attributed to Meinzer who, through his consuming interest in groundwater and his dynamic leadership of groundwater activities of the U.S. Geological Survey, stimulated - many individuals in the quest for groundwater knowledge.

2. The Sri Lanka Perspective

In Sri Lanka though plentifully blessed by rainfall and an adequate system of rivers distributed to most parts of the Island, there are areas where for at least four to five months in the year, surface water fades out. Traditionally the need for the exploitation and utilisation of groundwater arose in areas where surface water sources were scarce and limited. In Sri Lanka groundwater exploitation was mainly restricted to the sedimentary formations in the Jaffna Peninsula and the Vannathavillu area off Puttalam. No attempt was made for the exploitation of groundwater in the Hard Rock areas.

The first scientific investigations on groundwater were carefully studied by Mahadeva (1938), who published his results in the Transactions of the Engineering Association of Ceylon in 1938. Vaidya, after investigating the geological conditions of the Peninsula, agreed with Mahadeva's conditions in regard to general principles. Sirimanne continued the work of Vaidya and has made a considerable contribution to the understanding of the Hydrogeology of the Island while working both in the Department of Geological Survey and the Irrigation Department.

A Hydrological division was set up in the Irrigation Department in the mid- sixties and Sirimanne was the head of this division and has done useful work on groundwater which was published in the Proceedings of the Ceylon Association for the advancement of science. Now this division has been incorporated in the newly created Water Resources Board and it has concentrated its investigations mainly on the Miocene belt of Sri Lanka. Considerable work has also been done by Arumugam of the Water Resources Board. Herath of the Ministry of Agriculture and Madduma Bandara of the Peradeniya University have made valuable contributions in this field. From the early sixties, Fernandez was associated with various aspects of groundwater exploration. He presented the first Hydrology Map of Sri Lanka to the Ceylon Association for the Advancement of Science. He estimated the groundwater resources through natural recharge and presented his estimate in 1973 in a booklet published by the Ministry of Irrigation, Power and Highways.

He divided this into seven major categories of varying groundwater potentials based on groundwater recharge using Indian parameters for this computation adapted to the local conditions in the absence of available data in the country.

3. The Jaffna Realm

Literature concerning Jaffna Peninsula on this subject is very limited. The potentials and limitations of groundwater resources in the Peninsula have never been systematically investigated earlier. The subject came into prominence recently due to several reports of the incidence of saline infiltration in wells that have never been brackish before. At the request of the Ministry of Land Irrigation and Power, an Israeli team of experts on Groundwater with Arnon Arad of the Hydrological Survey, Israel visited the Jaffna Peninsula in 1965, and on the advice of this team, a hydrological survey was initiated.

On the basis of this survey, Balendran (1968), Arumugam, Sirimanne and some others have attempted to analyse the data and given a summary of a preliminary nature. The subject has also been touched upon subsequently in other rather general works on groundwater in Sri Lanka. Among them, papers presented to the Institution of Engineers give a basic understanding of various aspects of water resources in the Peninsula.

In 1973, Goldberg visited Sri Lanka under the auspices of the United Nations Economic Commission for Asia and the Far East for the purpose for future investigations of the groundwater potential and development works in Sri Lanka. In reference to the Jaffna Peninsula, Goldberg observed that “there appear to be no economic means of controlling or reducing this loss (groundwater discharge to the sea) … optimum utilization of the available resources has already been passed and that more detailed investigations would only be of academic value; however, a limited program of data collection should be undertaken”.

A reconnaissance survey of natural wells (called freak wells) formed by the collapse of cavern roofs was made by Patkunam in 1974.

In 1976, a mission sponsored by the British Ministry of Overseas Development made a study of areas of groundwater and Land potential in Sri Lanka. A report was prepared by Foster on the ‘Problem of Groundwater quality management in Jaffna, Sri Lanka’ in December 1976.

Upon termination of the Peninsula-wide program of data collection, intensive data collection, from 725 dug wells was conducted by the Water Resources Board Jaffna, from 1973 to 1976 in a 55 square miles area in the northwestern part of the Peninsula. In 1977 intensive study of two areas having a total of 77 square miles was started in the south-western and north-eastern parts of the Peninsula. Other planned groundwater observations include the drilling of several 6-inch diameter wells, approximately sixty feet deep and smaller diameter observation wells for the purpose of conducting pumping tests (Gunasegaram, oral communication).

Wijesinghe defined the thicknesses and shape of the freshwater lenses in the Jaffna Peninsula in 1975. He states that "good quality groundwater exists only in the form of scattered lenses ranging in depths down to about eighty feet in most parts of the Peninsula...even during the height of the drought".

In 1980, Gunasegaram highlighted clear signs of natural contamination as well as manmade contamination of the fresh groundwater body of the Peninsula.

Among the earlier works, previous to 1965, Mahadeva (1938), Sirimanne, and Vaidya (1955) on Hydrology and Groundwater aspects of the Peninsula forms elementary descriptive in nature.

B. THE TECHNIQUES USED IN GROUNDWATER DEVELOPMENT – STUDY

The groundwater aquifer gets water as a result of recharge from rainfall, rivers, streams, irrigation water etc., and loses water due to regeneration in streams, the movement towards other aquifers, and man-made withdrawals. A study of groundwater balance is essential in order to evaluate the total groundwater resources of a region. Groundwater flows and surface water flows in a region are intimately connected. Hence water balance studies can be divided into two parts:

1. Water Balance Studies
2. Groundwater Balance Studies

This section provides an insight into techniques for studying the groundwater development of a region.

1. Water Balance Studies

The water balance of an area is defined by the hydrologic equation, which states that in a specified period of time, all water entering a given area must be consumed, stored, or go out as surface or subsurface flow. The following equation describes the water balance of a given region:

$$P + W_i = R + E_t + W_e \pm \Delta S_g \pm \Delta S_s$$

where all quantities are in volume for a specified period and

P = Precipitation

W_i = Surface and groundwater imported from areas outside the region.

R = Stream outflow.

E_t = Evapotranspiration

W_e = Groundwater outflow

ΔS_g = Change in groundwater storage.

ΔS_s = Change in soil moisture storage.

Water balance for a given region should be worked out for a long period so that the various items approach a steady state due to averaging out of climatic effects. The various items in the above equation are determined as follows:

i) Precipitation (P) - Average rainfall over the region can be worked out by using a suitable averaging technique.

ii) Imported water (W_i) - The quantity of surface water imported can be determined from stream flow records. Quantity of groundwater can be determined by applying the Darcy Law to the boundaries of the region after determining the thickness and the permeability of the aquifer and the slope of the groundwater table.

iii) Stream outflow (E) - This can be determined from stream flow data.

iv) Evapotranspiration (E_t) - This is water lost by evaporation from the ground surface or transpiration through the leaves of plants. It affects the groundwater storage in the former case if the capillary zone extends to the ground surface or in the latter case if the plant roots extend down to the capillary zone or to the water table. It can be obtained from observations on evapotranspiration pans or by the Penman formula that is based on climatological factors.

v) Groundwater outflow (W_e) - This is calculated by application of the Darcy Law.

vi) Change in groundwater storage (ΔS_g) - The change in the volume of the saturated thickness of the aquifer at the beginning and end of the specified period is calculated by multiplying the change of groundwater level with the area and the storage coefficient. Maps showing groundwater level contours are useful for this calculation.

vii) Change in soil moisture storage (ΔS_s) - This can generally be taken to be negligible over a very long period.

2. Groundwater Balance Studies

A groundwater inventory of an area quantifies the various means of recharge to or discharge from the groundwater reservoir as well as charges in storage therein. It may be stated as follows:

$$\Delta S_g = (R_p + R_n + R_a + G_i) - (E_t + D_e + D_c + G_o + G_e)$$

where:

ΔS_g = change in groundwater storage during the period in question

R_p = recharge due to precipitation

R_n = natural recharge from streams and lakes, i.e., influent seepage

R_a = artificial recharge from canals, reservoirs, irrigation return flow, spreading, and injection wells

G_i = groundwater inflow from areas outside the basin

E_t = evapotranspiration from the capillary fringe in shallow water table areas and from vegetation

D_e = natural discharge by seepage and stream flow, i.e., effluent seepage loss

D_c = artificial discharge due to pumping and consumptive use

G_o = leakage from a bottom semi-confining layer

G_e = Groundwater outflow to areas outside the basin

Groundwater balance is usually worked out for the rainy and non-rainy seasons separately. The methods of calculating the various factors involved in the above equation, except those already discussed, are described below:

i) Change in groundwater storage (ΔS_g) - Water table or piezometric level contours at the beginning and end of a period are plotted, and the average change of groundwater level is multiplied by the area and the specific yield.

ii) Recharge due to rainfall (R_p) - Only a small fraction of the annual precipitation percolated downward. A major portion runs off on the surface or is lost by evapotranspiration. Downward percolation to the groundwater reservoir depends upon the intensity, duration, and seasonal distribution of rainfall, topography, and vegetal cover. The humidity of the area and characteristics of the soil cover is maximum during periods of intense rainfall and during humid seasons when evapotranspiration is small, and soil moisture is at or above field capacity. Recharge to deep buried aquifers is not influenced by short periods of drought and such aquifers yield water even when shallow wells go dry. In cases when a saturated thickness intervenes between the recharge area and the aquifer, the recharge rate is given by (Walton, 1970).

$$Q_c / A_c = K' (\triangle h / B')$$

where:

Q_c = vertical leakage through saturated deposits in m^3/day

A_c = area of leakage in m^2

K' = hydraulic conductivity of the deposit in m/day

B' = saturated thickness of the deposit, in m

$\triangle h$ = difference in head, in m

The recharge rate is dependent upon $\triangle h$ and is more in the deepest part of the cones of depression and where the piezometric surface is low.

Four methods can be used to determine the recharge rate. The first is using the above equation (Walton,1970). The second is by analyzing the drawdown curves obtained on some wells considering uniform recharge over the area of influence. The actual recharge rate is the one that gives the closest approximation to the observed drawdown curve. The third is by observing the groundwater movement by injecting radio-active tritium in some wells and observing its concentration as a function of time in other wells. The movement and dispersion of groundwater are then obtained and correlated with changes in the groundwater levels before and after monsoons. The fourth and the most reliable method is by evaluating the various parameters of the first equation mentioned in this section and solving it for R_p. Empirical methods of determination by observation will be discussed later.

iii) Natural recharge (R_n) - This can be obtained by determining the slope of the groundwater table in the vicinity of the rivers and ponds and applying the Darcy formula. In some cases, the recharge is taken as a function of the wetted perimeter of the river.

iv) Artificial recharge (R_a) - Recharge from canals and watercourses is generally calculated as a function of the wetted perimeter.

The recharge element was estimated by casting the water balance equation in the modified form and by substituting measured values in the equation given below:

$$R = P - (Q_0 + ET)$$

where:

R = recharge

P = precipitation

Q_0 = discharge (exclusive of groundwater outflow)

ET = evapotranspiration

The R-value so estimated included recharge to soil moisture storage and recharge to groundwater storage.

During monsoons, because of the continuous interaction between soil moisture and evapotranspiration, the soil conditions are in a state of flux. Accurate measurements of recharge to soil moisture are not easily measured. In the present analysis, reliable values of recharge to soil moisture storage were not available. In the absence of more specific data, the available water storage capacity of the effective textural depth of different soil groups was taken as the equivalent of recharge to soil moisture storage. To arrive at these values, it was assumed that the initial moisture at the beginning of the monsoon was zero. The soil was charged to the available water storage capacity by the end of the rainfall season. The intermediate variations in soil moisture storage during monsoons formed a part of evapotranspiration. With these assumptions, available water storage capacity was calculated by multiplying the effective textural depth of a soil group by a factor. The depth values so obtained were calculated into weighted area averages by a method similar to the estimation of weighted mean rainfall for the area by the Theissen method. The average value so obtained for a year constituted soil moisture storage.

v) Natural discharge (D_n) - This is equal to outflow from the aquifer plus base outflow on the surface. The outflow from the aquifer can be determined by applying the Darcy Law to known values of the coefficient of transmissivity and groundwater slope. Runoff from the Peninsula was also estimated using Khosla's empirical formula given below:

$$R_m = (P_m – L_m)$$

$$L_m = (T_m - 32) / 9.5 \quad \text{in inches.}$$

where:

R_m = the monthly runoff in inches

P_m = the monthly rainfall in inches

L_m = the monthly loss taken as a function of mean temperature in degrees Fahrenheit (F), and

T_m = the mean temperature for the month

Temperature values recorded in the Jaffna meteorological station were assumed to prevail over the entire Peninsula during the period for which runoff estimates were calculated by Khosla's formula.

vi) Artificial discharge (D_a) - The total quantity of water pumped out in the area is determined for the period in question.

3. Chemical Analysis

Chemical analysis of 411 groundwater samples was available for processing and interpretation with the Water Resources Board, Jaffna, and the author has himself collected samples for verification of the data. The mg/l (milligrams of dissolved constituents per litre of solution) or parts per million (ppm) values of dissolved constituents were calculated into reacting values expressed in milligram equivalents per litre. The sum of reacting values or cations and anions were matched for verification in the error of analysis. Analysis with a percentage error of up to 12 was used for interpretation in the present work. The reacting values of cations and anions were calculated into respective percentage rations. The results were estimated by the procedure given by Todd (1959). Total hardness, which is a measure of calcium and magnesium content, was also estimated.

C. RESEARCHES UP-TO-DATE ON GROUNDWATER RESOURCES DEVELOPMENT OF THE JAFFNA PENINSULA

The initial groundwater investigations in the Jaffna Peninsula were first commenced with the visit of Israel experts to Sri Lanka in 1965. The team of specialists from Israel cautioned on the unplanned, unmonitored use of groundwater, especially in the Peninsula, due to its complicated geographical setting. As a result, a hydrological survey committee was formulated under the chairmanship of the Government Agent, Jaffna.

Primarily, the committee comprised officers from the Department of Irrigation, Department of Education, Divisional Revenue Officers of the district, and other officers from the departments indirectly connected in district administration. A team of officials from the Department of Irrigation, was detailed by the then Deputy Director of Irrigation, who was pioneering the project of groundwater quality monitoring. The team of officers was requested to select limited hand-dug wells to cover the entire Peninsula in order to study the basic generalized water quality changes and the water level fluctuations. Due to the limitation of advanced technology on groundwater occurrence and limited funds, the program was formulated to be carried out with the help of Grama Sevakas, science teachers from the schools of the Northern District, and a few officers from the department of Irrigation. 411 hand-dug observation wells were selected in the entire Peninsula and the Islands. The Grama Sevakas were entrusted with the duty of collecting the samples, and the officers of the department of Irrigation coordinated the collection of samples by the Grama Sevakas and handed them over to the selected schools for analysis and collection of the results. This programme of monitoring the general groundwater quality of the Peninsula and its changes were observed until 1972. A generalised report was prepared, and tentative assumptions on the available resources were formulated. But it was observed that the collection of data during this period was not very satisfactory, as some of the Grama Sevakas appeared to have supplied erroneous samples and inaccurate information. As a result, the hydrological survey committee decided to open up a small groundwater unit in Jaffna under the Department of Irrigation. The collection of samples and analysis were then transferred into the hands of this unit of the department to minimise errors and have effective control of the whole system of monitoring.

Based on the findings of the generalized conditions of groundwater quality of the Peninsula that was carried out from 1966 to 1973, the groundwater unit of the irrigation department decided to carry out a detailed investigation within a selected area of the Peninsula consisting of complicated groundwater existence and its use. Probably the decision to limit the area of detailed investigation to 55 sq. miles out of a total of 410 sq. miles of the Peninsula must have been to concentrate the studies in detail and also due to limitation of available funds.

The area in the north and northwest of Valikamam was undertaken for this study. 725 hand-dug observation wells were selected within this area of 55 sq. miles, thus covering 16 wells per sq. mile when compared to the initial 4 wells per sq. mile during the period of 1966-1972. Apart from general groundwater quality, monitoring other information required on the geology of the area, rainfall, runoff, etc., were also collected within this area. This area comprised the numerous springs and sub-surface groundwater discharge zones, an area of agricultural and domestic use, with many freak wells situated in the area.

This study continued till 1977, and a few drilling operations were carried out to assess the vertical component of the groundwater storage as well as the geology governing the occurrence of groundwater.

However, the partial study of a small area of the Peninsula, leaving the rest of the area un-correlated to the study area, was a limitation to the investigations of the Peninsula's financial allocation which was a serious limitation to carrying out a detailed investigation in large areas of the Peninsula. A detailed report was prepared for the 55 sq. miles extent that was investigated during 1973-1977, which shed more light and understanding of the groundwater conditions and the geology. This study and report enabled the extension of the study area with more financial allocation. Hence, the study area was extended to move the entire Valikamam area (120 sq. miles) and the Vadamaradchi area (46 sq. miles). This commenced in the latter part of 1977 and continued till October 1978.

During the period 1973 to 1978, the groundwater investigation unit of the Department of Irrigation was more confined to investigation and research only, with little advice rendered to the water supply and very little advice to the public. The groundwater study and analysis were confined to determine the chloride, total hardness, and total dissolved solids of water by the titration method only. No other equipment or facilities were available for detailed water analysis and investigation.

In October 1978, the hydrological survey committee of Jaffna District unanimously decided to hand over the groundwater investigation of the Peninsula to the Water Resources Board, which was handling the groundwater investigation in the rest of the island. As a result, the Water Resources Board took over the groundwater investigation of the Peninsula and opened its Regional Office in Jaffna. Consequent to the takeover by the Water Resources Board, action was initiated to update the laboratory facilities, drilling facilities and modify the monitoring and investigation pattern in the Peninsula.

The area of detailed investigations was increased during the year 1979 and covered the entire Valikamam, Vadamaradchi, and the Islands. In 1980, the Thenmaradchi area covering an extent of 135 sq. miles was also incorporated under the detailed investigation programme, thus bringing the entire Peninsula and the islands under simultaneous detailed investigation.

REFERENCES

Adams, F.D. : The Origin of Springs and Rivers - A Historical Review, *Fennia* 50, No. 1, Helsingfors, Finland, 1928; The Birth and Development of the Geological Sciences, Baltimore, 1938.

Altovsky, M. and Konoplyantsev, A. (Ed.) : Manual for the Systematic Study of the Regime of Underground Waters, Foreign Languages Publishing House Moscow, 1959.

Arumugam, S. : Development of Groundwater and its Exploitation in the Jaffna Peninsula. *Institution of Engineers,* Ceylon, Vol.1 Transactions for 1970.

Balendran, V.S., C.H.L., Arumugam, S. : Groundwater in Jaffna, Water Resources Board, Colombo, 1968.

Beardmore, Nathaniel : Manual of Hydrology, London, 1850.

Bernard, Merrill : Hydrometeorology - A Coordination of Meteorology and Hydrology. Am. Geophys, *Union Transactions*, 1938.

Chorley : Introduction to Physical Hydrology Methuen & Co., 1973.

Cooray, P.G. : An introduction to the Geology of Ceylon. *Museum Publication*, Ceylon. 1967.

Darcy, Henry : Les Fontaines Publiques de la Ville de Dijon, Paris, 1856.

Dolcini, Albert J. : Groundwater Resources Planning, Biennial Conference on Groundwater, Recharge Development and Management at the University of California, Los Angeles, Sept. 1, 1965, CDWR, Sacramento, 1965, (Mimeograph).

Gard, S.P. : Groundwater and Tube Wells, Oxford & IBH Pub. *The Company*, New Delhi, 1978.

Kazmann (R.G.) : Modern Hydrology, Harper & Row Pub, 1965.

Meinzer, O.E. : Outline of Methods for Estimating Groundwater Supplies, U.S.Geol. Survey Water supply, Paper 638, pp, 99-144, 1932; The History and Development of Groundwater Hydrology, Washington Acad. Sce. Jour, Vol. 24, 1934.

Meyer, A.F. : The Elements of Hydrology. 1st Ed, New York, 1917.

Nefedov, K.E., Popova, T.A. : Deciphering of Groundwater from Aerial Photographs, Avering Publishing Co. Pvt. Ltd. New Delhi, Bombay, Calcutta, 1972.

Patkunam, V.R. : "General Hydrogeologic Reconnaissance Survey of Freak Wells and Coastal Springs in Jaffna Peninsula" - Unpublished Report in the File of the Irrigation Department, Colombo, 1974.

Rao, K.N., George, and Ramasastri, K.S. : India - Meteorological Department Scientific Report No. 136, New Delhi.

Slichter, C.S. : Field Measurements of the Rate of Underground Water, U.S. Geol Survey Water-Supply Paper 140, 1905; Theoretical Investigation of the Motion of Groundwaters, H.S. Geol. Survey 19th Ann. Reports pt. 2, pp. 295-384, 1899.

Theis, C.V. : Relation Between Tie Lowering of Piezometric Surface and the Rate and Duration of Discharge of a Well-Using Groundwater Storage, *Trans. Am. Geophys*. Un. Pt. 2, pp. 529-524, 1935; The significance and Nature of the Cone of Depression in Groundwater Bodies. *Econ. Geology.* Vol. 33, pp. 889-902, 1938.

Thomas King : Water - Miracle of Nature, *Collier Books*, New York, 1961.

Sirimanne, C.H.L. : Geology for Water Supply - Proceedings of the Eighth Annual Session of the Ceylon Association for the Advancement of Science, Transactions, 1952.

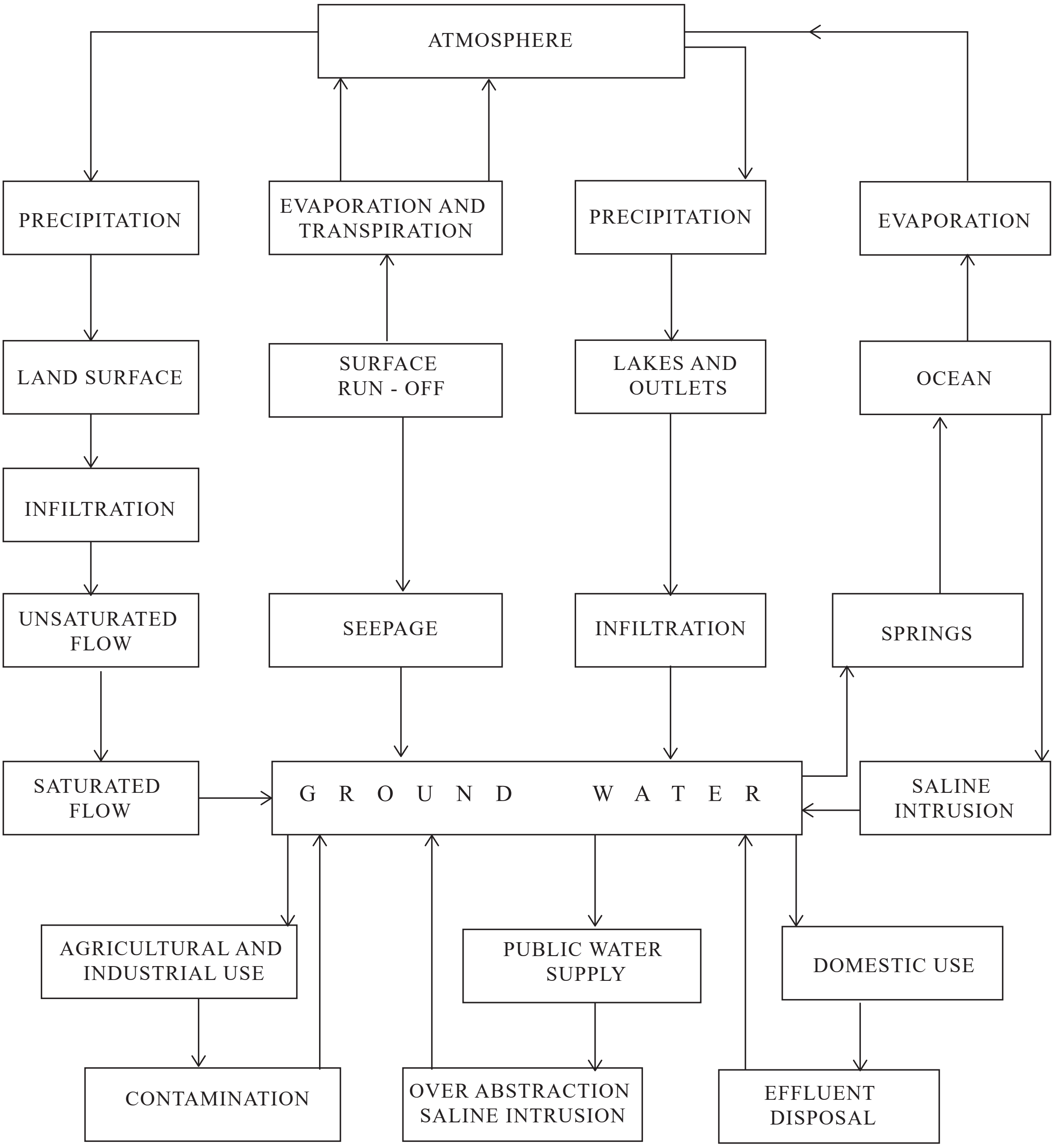
Walton, W.C. : Groundwater Resources Evaluation, *McGraw Hill Book Co*, New York, 1970.

Ward (R.C.) : Principles of Hydrology, *Mc. Graw Hill*, 1967.

Warren Viessman Jr., Terance E. Harbaugh., John W. Knapp : Introduction to Hydrology, *Intext Educational Publishers*, New York, 1972.

Water : The Yearbook of Agriculture 1955, The United States Department of Agriculture, Oxford IBA Publishing Company.

Wijesinghe, M.W.P. : Groundwater Hydrology*, Ceylon Association for the Advancement of Science, Colombo, Transaction*, 1973; Groundwater Exploration and Development Work Conducted by the Department of Irrigation; Irrigation Department, Groundwater section-Unpublished Report, 1974.



SCHEMATIC FLOW CHART TO ILLUSTRATE
THE REGIME OF GROUND WATER IN THE
JAFFNA PENINSULA

Part Two

EMPIRICAL ANALYSIS

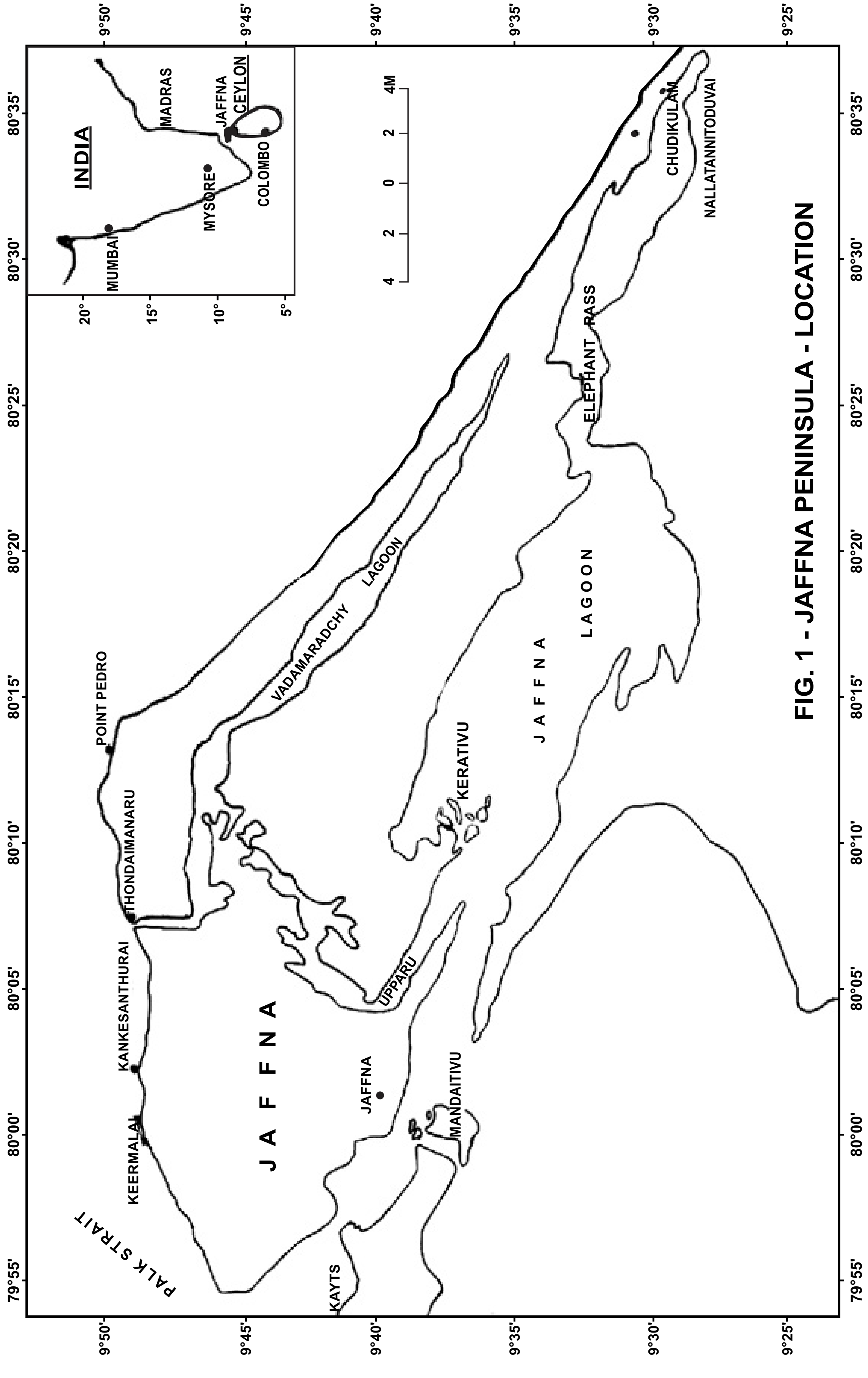
III. BACKGROUND TO THE STUDY AREA - JAFFNA PENINSULA

A. LOCATION

The Jaffna Peninsula, longitude 79° 54' - 80° 2' E, latitude 9° 30' - 9° 50' N, with an area of approximately 410 square miles, forms the northern extremity of Sri Lanka. The Peninsula is about 40 miles long with a width of 4 to 14 miles and bounded by the Palk strait on its western, northern, and eastern sides and by the Jaffna Lagoon on the south. Several saline water lagoons occur on the Peninsula and are separated from the mainland by two external lagoons - the western called the Jaffna Lagoon, and the eastern called the Elephant Pass Lagoon. The internal Lagoon situated within the Peninsula is called the Vadamaradchi Lagoon. Very often, all three Lagoons are collectively and sometimes individually referred to as the Jaffna Lagoon. Only a narrow strip between the eastern part of the Lagoon connects the Peninsula to the main island. The internal lagoons divide the Peninsula into two drainage outlets. The Thondaiman Aru and the Uppu Aru drain the major lagoon while a small stream, the Valukkai Aru, which is over 8 miles long, drains the southwestern areas. To the west of the Peninsula are small islands.

Jaffna itself is today the second largest town in Sri Lanka, with a population of about one lakh in 1981. Although it has lost the pre-eminence as a port and administration center which it had in the past, it still retains some trade in small strips and is effectively the railhead. The Peninsula is also linked with Colombo, the Capital of Sri Lanka, and with other parts of the major road network, and air route and by ferry service to the neighbouring islands.

FIGURE 1 - Jaffna Peninsula – Location



B. GEOLOGY AND EVOLUTION

The Jaffna Peninsula is underlain by the Jaffna Limestone, which is a grey-yellow and white organogenic porous limestone (reef limestone) very Karstic in its upper near surface part. This limestone is typically a compact, hard, partly crystalline rock and belongs to the Miocene age, which, according to the geological time scale, was about 35 million years ago. Cooray classifies the 'Jaffna Limestone, which underlies the whole of the Jaffna Peninsula and the surrounding islands' as being tertiary rocks of the Miocene age.

During this period, that part of the coast of Sri Lanka extending from what is now Puttalam to the Jaffna Peninsula and the corresponding section of the Indian coast were submerged, and the gradual solution of the atmospheric carbon dioxide in the sea was resulted in the insoluble calcium carbonate. This was extracted by the living organism, which, on death contributed to the slow growth of sedimentary limestone rock that became pressed into hardness by super incumbent layers. Differential movements deep in the body of the earth have been responsible for lowering and raising parts of the solid earth. Thus, the sedimentary formations of the Miocene Limestone have been presented above sea level. The texture varies from 'somewhat cellular material, occasionally full of corals, to a massive rock in which gastropods are common and appear to represent accumulations associated with ancient coral growth. The rock usually weathers into a honeycombed mass'.
This limestone is very slightly disturbed, buckling into gentle folds running in an east north easterly direction, while vertical movements appear to be more marked. Aerial photographs indicate a rectangular pattern with the principal directions being NW-SE and NE-SW (Cooray 1967 and Sirimanne and Vaidya 1958).

FIGURE 2 - Jaffna Peninsula – Geology

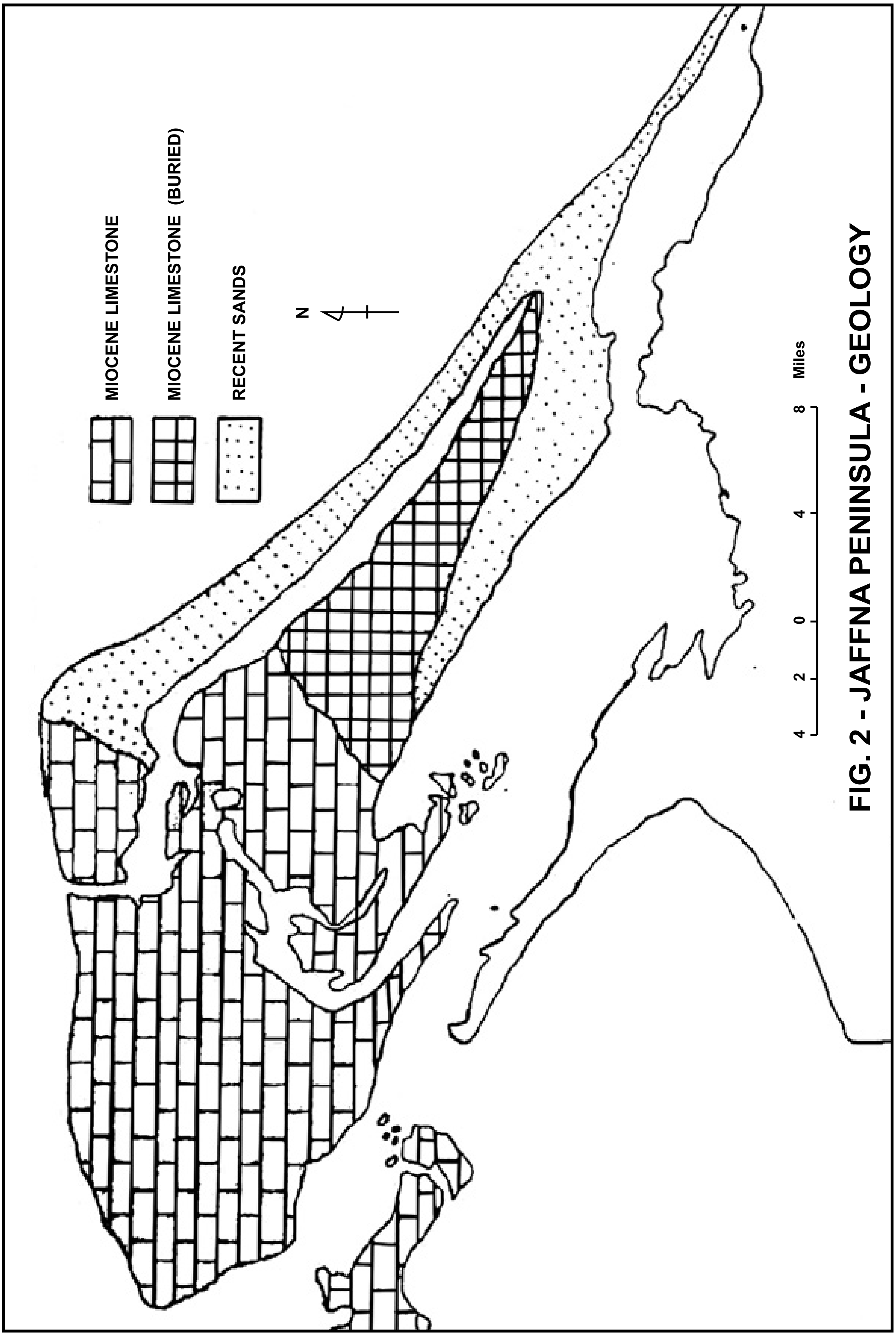
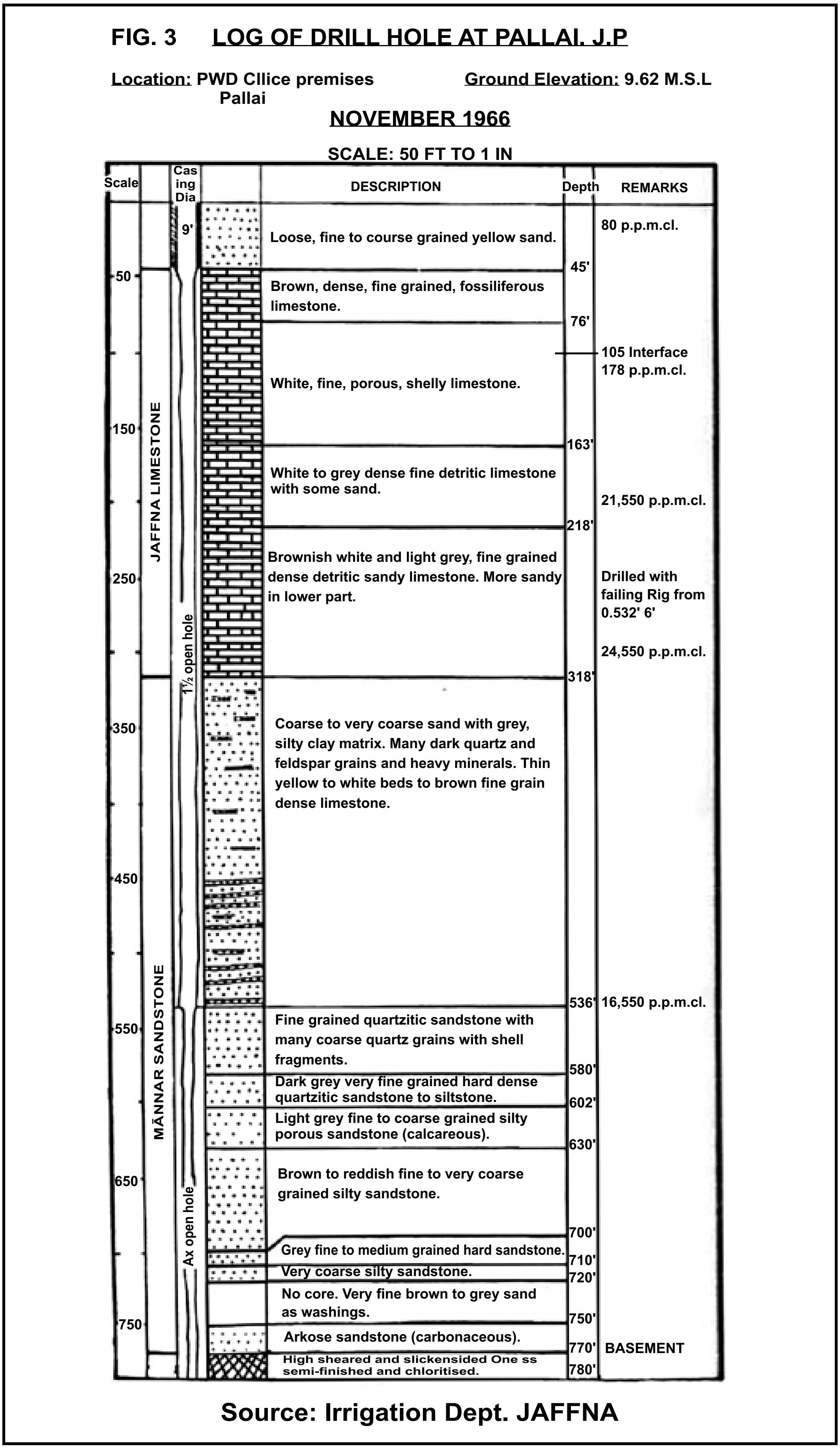


FIG. 2 - JAFFNA PENINSULA - GEOLOGY

FIGURE 3 - Log of Drill Hole at Pallai



The limestone is well jointed, and the thickness of the formation, according to the drilling exploration carried out in 1953, showed the presence of limestone down to the bottom depth of 270 feet. The most recent drill hole at Pallai to a depth of 780 feet showed that 270 feet thick limestone was underlain by a thick sandstone formation above the pre-Cambrian basement. This sandstone which had already been encountered all along the sedimentary basin from Vannathavillu, becomes 430 feet thick at Pallai.

An examination of Figure 4 shows that the sandy areas of the Peninsula are made up of four distinct tracts. All of them stretch in a northwest-to-southeast direction, attached in the northwest to the limestone region. A triangular portion of the limestone is itself buried under these sands. The sandy tracts themselves are spits, evidently formed by longshore rifts caused by wave action and currents. During the period of the northeast monsoon and the southwest monsoon, these shores of north Sri Lanka are subjected to the southerly and northerly monsoon currents, respectively. The northerly current during the months from May to October (S.W. monsoon period) carries along the eastern coast debris, which becomes the raw material for the building up of spits during the period of the north-east monsoon. The waves at this time approach the coast obliquely and thereby help the longshore drifting in the eastern section; they, being separated from one another by an enclosed lagoon, unite again to form a low sandy pass that bridges the Peninsula with the mainland at Chundikulam. The eastern spit is obviously the more recent formation. This view is also supported by the fact that the sands are more sterile, supporting very little vegetation cover, and in many places are not yet fixed giving rise to shifting dunes. Therefore, it would be correct to assume that the spit west was the first one to be formed in the face of an emergent land, and the other came to be built subsequently first as an offshore bar giving cause to a Lagoon and then as a spit. The two small spits still further west were creations of the currents and waves that operated along the western and southern coast of the Peninsula. The smaller size of these spits is explained by the limited amount of debris material available in these shallow protected seas together with the curbed wave and current action one could visualize in such a situation. The work done by Somerville lends support to this way of explaining the evolution of the sandy tracts of the Jaffna Peninsula.

FIGURE 4 - Jaffna Peninsula – Stages in Evolution

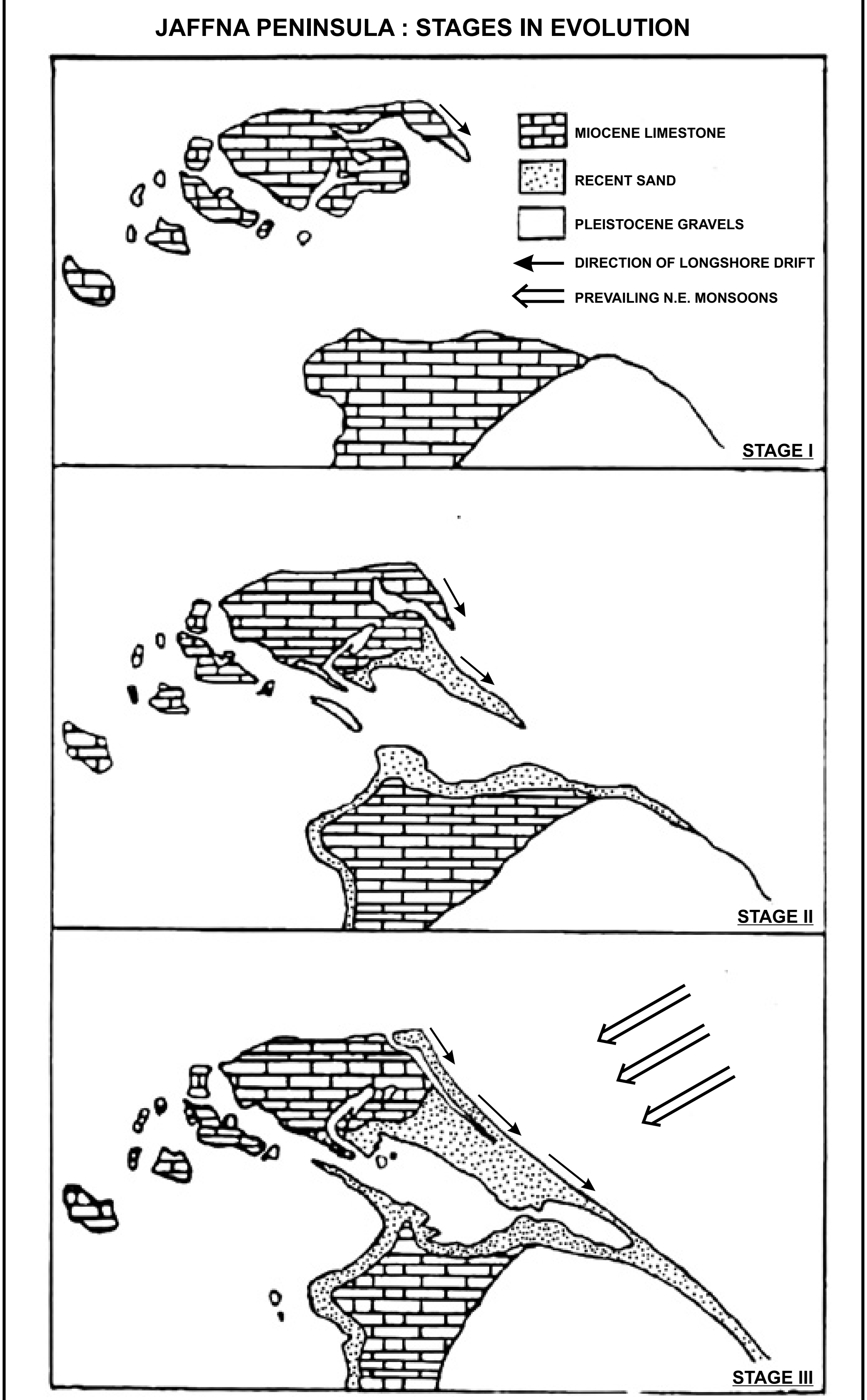
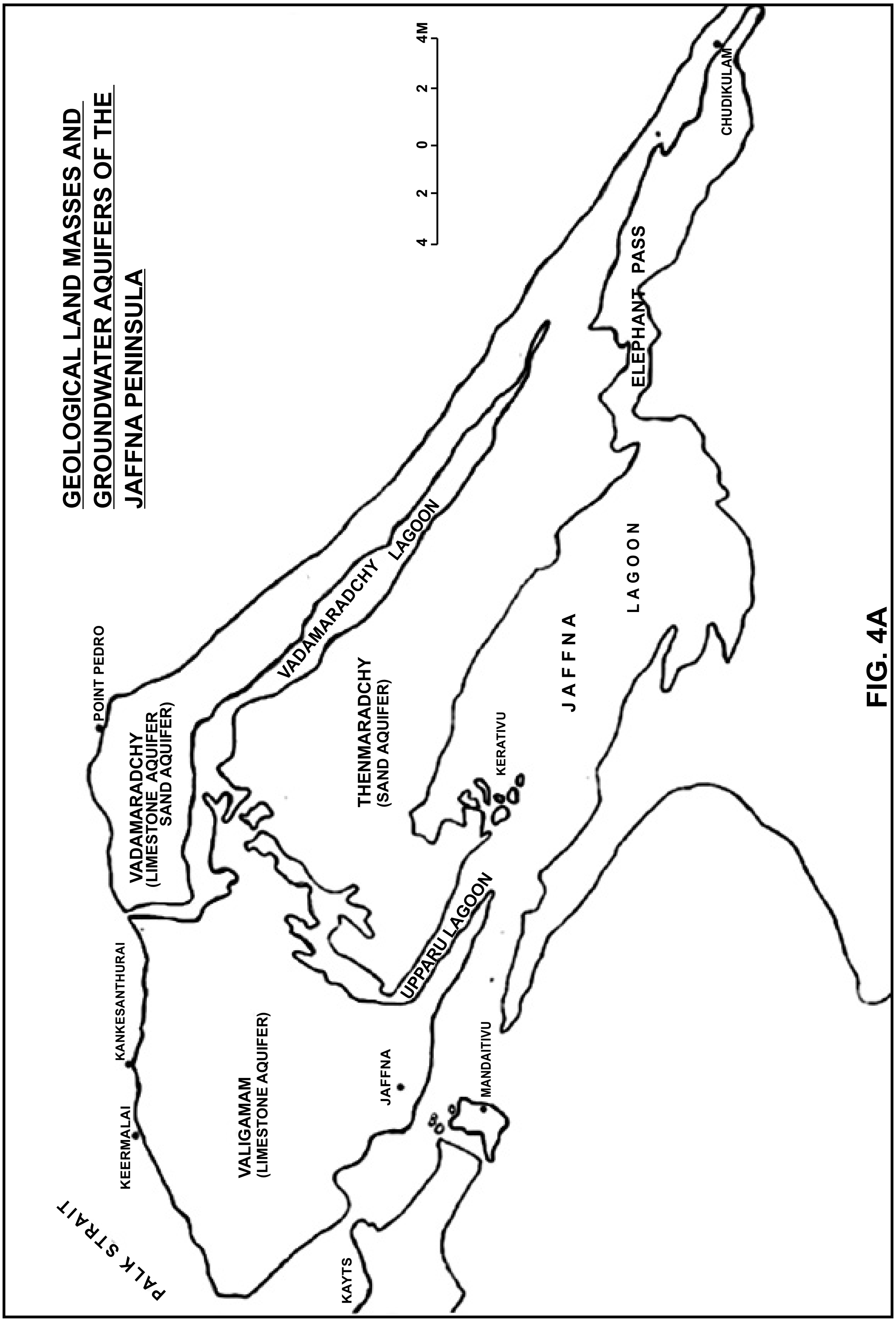


FIG 4 - JAFFNA PENINSULA - STAGES IN EVOLUTION

For the purposes of this discussion, geology is treated in two parts - the Peninsula and the Islands. The Peninsula is further subdivided into three areas - Valigamam, Vadamaradchi, and Thenmaradchi (see Fig. 4a).

FIGURE 4a - Geological Land Masses and Groundwater Aquifers of the Jaffna Peninsula



PENINSULA GEOLOGY

The Jaffna Peninsula is an attachment to rather than an extension of the mainland of Sri Lanka. The basement lithology of Sri Lanka and its submarine extension beneath the Gulf of Mannar to India consists of pre-paleozoic igneous and metamorphic rocks. A Bouguer anomaly map of the Jaffna Peninsula shows the extension of the crystalline basement beneath the Peninsula. These basement formations, estimated to have a depth of at least 2 metres in the center of the basin, are too deep to have been exposed in the Jaffna region but shallow enough to have served as a platform for the accumulation of sediment. Quartz sedimentary deposits from the mainland and from ocean currents are accumulated on the basement. Coral reef associations grew on the sedimentary deposits and were subsequently alternatively exposed and drowned with changes in relative sea level. At present, the fossil reefs are attached to the mainland and form the Jaffna Peninsula.

Portions of the fossil reefs lie above sea level to a maximum elevation of about 1 m, and portions are submerged and covered by a blanket of Holocene quartzitic sands.

The major fossil reefs are of mid-Tertiary age (predominantly Miocene) and probably grew contemporaneously with principal reefs elsewhere in the Indian Ocean, in particular the Chagos, Maldives, and Laccadive Archipelagos. Later, reef-building was less voluminous, and in Jaffna, only a thin remnant, less than 2 m thick and evident only in the western part of the Peninsula. The Tertiary reef underlies the entire Peninsula and extends to the mainland of Sri Lanka. A large, submerged barrier reef reaches from Jaffna to Tuticorin, India.

The geologic column in Jaffna consists of three formations that appear to underlie all of the region and two younger ones that occur sporadically. Based on a boring at Pallai in the southeastern part of the Peninsula and on previous works, the typical lithologic succession from youngest to eldest is shown in Table I.

The quartzitic sedimentary deposits, which lie unconformably on the pre-paleozoic basement rocks, comprise the Mannar sandstone of early Tertiary, though not younger than lower Miocene age. The Mannar consists mostly of grey, coarse to very coarse-grained sandstone with horizons of silts and clays in the upper part and lenses of calcareous material in the middle part (see Fig. 4b).

The Mannar, which is found to be 430 feet (130 metres) thick at Pallai, most likely thickens to the northwest in the deeper part of the basin. Neither the Mannar Sandstone nor the basement complex plays a role in the hydrogeology of the freshwater resources being investigated. The Mannar Sandstone provided the platform on which the Miocene reef could grow because the igneous basement was too deep.

TABLE - I			
GROLOGIC FORMATION JAFFNA PENINSULA			
Thickness (M)	**Age**	**Name**	**Description**
0 to 15	Holocene	Pallai	Unlithified very fine to medium quartz sand containing a small quantity of heavy minerals and calcareous fragments.
L 2	Pleistocene	(None)	Fosseiliferous, porous, uncompacted reef limestone
10 to 100	Mid-Tertiary	Jaffina	Recrystallized Compact, hard fossil reef limestone with numerous solution features and irregular fractures. Locally rubbly or highly lithified. Often weathered to a "popcorn" surface.
125	Early Tertiary	Mannar	Variable but typically medium to coarse sands with layers of silt and clay. Much clay in upper part, calcareous in midsection.
	Pre paleozoic	Basement	Massive crystaltine igneous and metamorphic.

FIGURE 4b - Geologic Log of Pallai Well

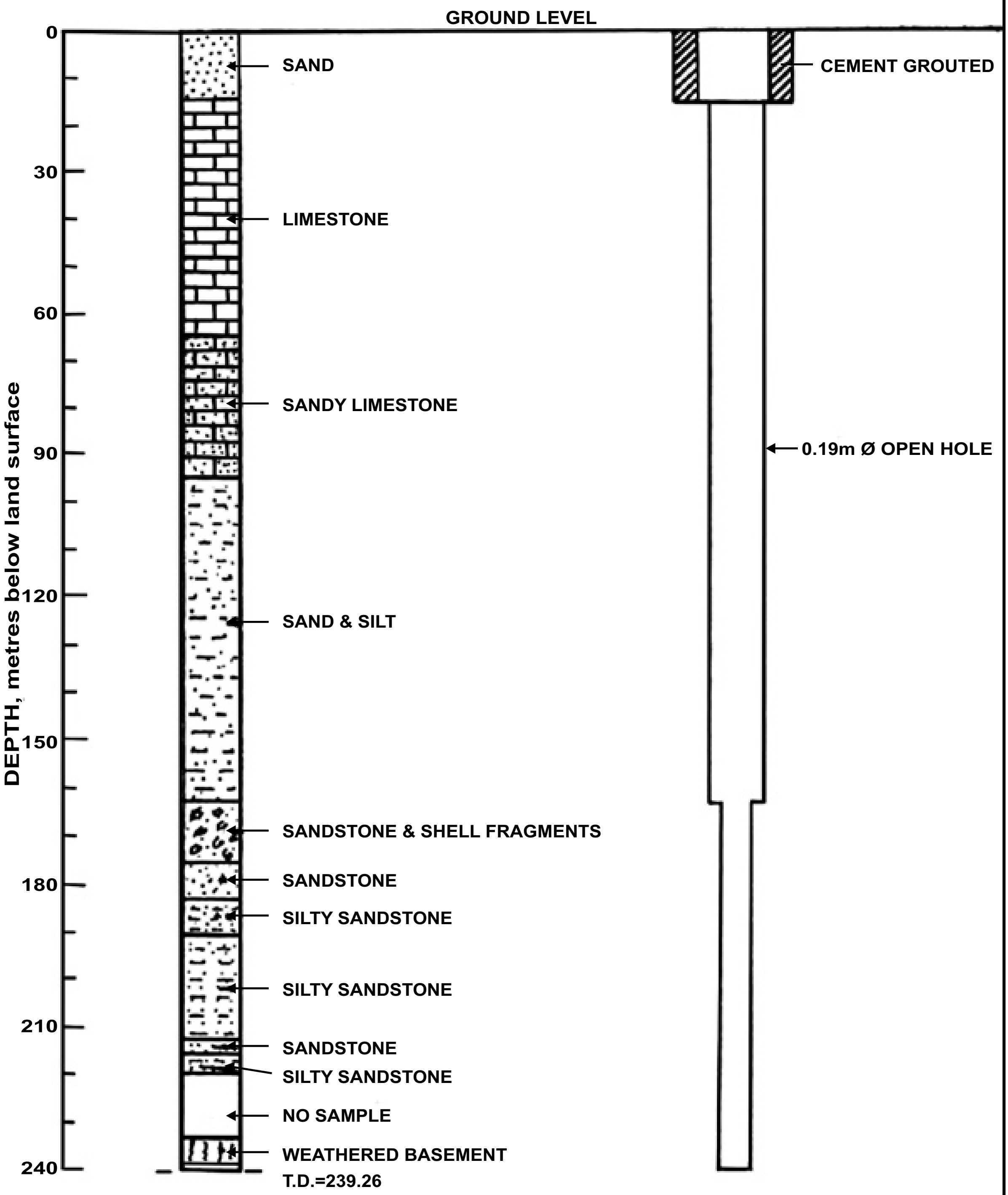


FIG 4 B - GEOLOGIC LOG OF PALLAI WELL

SOURCE: TAHAL REPORT, 1967

Overlying the Mannar Sandstone is the Jaffna Limestone. The age of the Jaffna Limestone has been estimated by the characteristic Foramminifera, Tabesina Malabania, which belongs to the upper part of the lower Miocene. The Jaffna limestone is a light brown to light grey or white, finely crystalline, dense fossiliferous limestone. In places, it is detrital, made up of transported calcareous materials (Tahan, 1967). In an exposure at the Keerimalai cement plant quarry, it is dense, crystalline, devoid of bedding planes, and off-white to buff in color. It is the remnant of vast associations that formed in mid-Tertiary time and since then has suffered erosional and geochemical alteration. At some locations within the quarry, it is a massive, soft chalky deposit, and still, in other locations, where it is weathered, it has a cemented "popcorn" appearance. Drilling shows it to be very Karstic, with openings ranging from small pores to large crystalline cavities. In most places, the formation is hard and solid with numerous solution features, but occasionally it consists of rubbly material or massive compact layers of fossiliferous marks. Freshly exposed surfaces of recrystallized material have a glassy look that is often mistaken for chert, a vitreous form of silica. The Jaffna limestone, however, is not chertified. Mostly it is a clean limestone that, in places, is argillaceous.

Like most reef associations, the Jaffna limestone did not accumulate uniformly in its horizontal and vertical dimensions over the whole of the Peninsula. The structure of the original reef is not known, but undoubtedly it consisted of a variety of forms ranging from mounds of massive growth in favorable environments to layers of weak growth in deep erosive channels. Sea level changes significantly affected the surface of the formation. The mode of growth of the original reef and subsequent erosional depositional history allows a framework within which variations in features and position of the limestone can be explained. Structural displacements due to tectonic disturbances are not required to justify the configuration of the formation.

The Jaffna limestone is approximately 300 feet (90 m) thick in the southeast part of the Peninsula at Pallai. Elsewhere it is likely to vary about this value but to be of the same order of magnitude. The formation weathers to a characteristic reddish- brown residuum that forms the most fertile soil in the region. Variation in soil color to lighter hues is caused by mixtures of sand or extraneous clay.

The Jaffna limestone is the principal aquifer of the Peninsula, either as a single unit or in combination with the overlying Pallai formation. Nowhere do the Ghyben-Herzberg freshwater lenses of the Peninsula extend below the base of the limestone. The formation is, therefore, the "basement" rock of the hydrogeological system.

The Pallai is the surface formation of the dunes area southeast of Vadamaradchi and of much of the Thenmaradchi area, but it is not continuous throughout the Jaffna region to the west. It sporadically occurs in the islands. In some locations in western Jaffna and in the islands, it consists predominantly of clay rather than sand. Along the coast, the pallai is continuously being formed and adjusted, while inland, it is relatively stable. The main part of it was deposited by littoral currents, but inland eolian deposition has been important.

Composition and grain size of littoral sediments is controlled by the strength and direction of current movement. Clays were deposited where current velocity was unable to sustain sand-sized particles in suspension, while the fine to medium sands of the dunes resulted from the strong littoral activity. Eolian deposits, which may be widespread in Thenmaradchi, consist of silt size to very fine sand. Where the Pallai formation is continuous, it appears to be 30-45 feet (10 to 15 m) thick.

The most recently deposited sand facies of the Pallai are essentially devoid of soil-building components and, as a consequence, forms a barren landscape. Where the sand is argillaceous, as in Thenmaradchi, fertile soils have evolved.

The Pallai sands constitute some of the principal aquifers of the Peninsula. The geology of the three major land masses of the Peninsula, although similar, have some distinctive characteristics. These differences are described below.

VALIGAMAM AREA

The Valigamam area is characterized by the absence of or only a thin layer of sediment overlying the limestone. The sediment, which is mostly soil, is primarily a result of limestone weathering. Wind-blown sands overlie the soils but only as a veneer. The absence of Pallai or more recent sands is likely a result of the protected position of the area in relation to northwest littoral current movements. Control of sediment accumulation must have persisted through the Pleistocene, as is evidenced by Pleistocene reef limestone that veneers some of the western portions of the Peninsula. Pleistocene reef development, however, is not widespread throughout the Peninsula. The formation is composed of limestone still in its nearly original, non-compacted condition. It has no significance as an aquifer.

VADAMARADCHI AREA

The Vadamaradchi area is separated from the Valigamam and Thenmaradchi areas by the Vadamaradchi and Uppu Aru Lagoons that form a unique physiographic feature of the Peninsula. The lithologic succession beneath these depressions is the same as in the slightly more elevated major portions of the Peninsula, but the surface layer in the lagoons consists of poorly permeable clays and muds in contrast to the infiltrable soils, sand, and limestone rock covering the higher ground. The floor of the lagoon is an accumulation of fine sediments brought in by weak littoral currents and washed in during the monsoon rains. All the paddy land now above sea level had its origin as a lagoonal environment. The lagoons are a recent feature, the result of sea level change in Holocene time.

The Western portion of the Vadamaradchi area is similar to the Valigamam area in having limestone at the surface with little or no soil cover and with Pleistocene coral in the coastal areas. The Vadamaradchi area is distinguished, however, by the thick eolian sand dunes extending to the southeast. These dune deposits are a result of northwest littoral currents carrying sediments from the mainland northward and of the northeast monsoon winds and wave action, which transports the sediment southwest over the limestone reef deposits. (see Fig. 4d) This process is active today and will eventually result in the sedimentation of the Vadamaradchi lagoon.

THENMARADCHI AREA

The Thenmaradchi Area is characterised by a relatively thick section of the Pallai formation. Here it consists of thick (7-15 m) fine, silty sands with clay overlying the limestone. Clay also may occur at the surface; its thickness forms a distinctive horizon to the southeast. The surface in this area contains a large number of natural ponds. The ponds intercept groundwater. In some cases, groundwater is perched on the clay.

The topography becomes irregular to the NE as a result of remnant dunes. Clay in the sands is not well defined, but its presence causes the sands to be poorly permeable. The sands are siliceous with small amounts of calcareous shell fragments. The shells appear to be predominantly pleopod and gastropod fragments rather than coral. Some heavy minerals are identifiable rather than coral. Some heavy minerals are identifiable in the sands, not affected by limestone coloration. Limestone beneath this area appears to have a SE dip [Original text unclear: Editor] in the central area. Drill cuttings indicate that the limestone immediately below the sand is a soft chalky limestone that becomes dense crystalline and highly porous to cavernous at depth.

ISLAND GEOLOGY

The islands to the south of the Peninsula have had the same origin as the Peninsula. On portions of each island the limestones have been overlain by silica sands of recent deposition. It is most probable that during glacial periods, with lower sea levels, the islands were connected to the Peninsula.

Boreholes drilled on Kayts, and Punkudutivu provided sub-surface data for the islands. Although the islands are geologically quite similar, some features are worth noting.

KARAITIVU

Karaitivu is characterized by a number of ponds, especially in the northern portion. These ponds are a result of sinkholes in the limestone that have intercepted the groundwater. Sands throughout Karaitivu tend to be fine, grey, thin deposits. The "fresh" looking Pleistocene coral at the surface is far more typical.

KAYTS

Kayts contain the thickest and most extensive sands in any of the islands. These silica sands contain numerous shell fragments and overlay a thick, silty, clayer material that rests on the limestone. The sands, however, seem to be free of clay material. Large-diameter dug wells are completed in the sand and used for a small water supply scheme.

A gray-brown clay also covers a large portion of the northwestern part of the island. These clays may represent pallai time deposition in conjunction with the erosion of the limestone. Limestone fragments in the clay give it a till-like character. Limestone sinkholes covered with these clays create numerous ponds, some of which provide irrigation water during the dry season when the actual water table is below the bottom of the ponds.

DELFT

There are no boreholes on Delft, and the geology is known only from shallow dug wells. The most characteristic feature of the island is the barren nature of its surface. Sand occurs over limestone only along the southern coastal area. These sands are relatively thin, less than three metres deep, and occur only within 1 metre of the shore. Some dug wells are constructed along the south shore in the sands, but the water tends to be brackish.

The limestone exposed on the island varies from a very rough Pleistocene coral deposit to a flat, smooth concrete-appearing limestone. Municipal dug wells are completed within the more massive appearing limestone, but the water is very brackish.

OTHER ISLANDS

The remaining islands, Mandaitivu, Punkudutivu, Nayinativu, Analaitivu and Eluvaitivu contain thin deposits of sand over limestone. The sands from beach ridges and, to a minor extent, some low dune development. None are extensive enough or thick enough to provide a secure supply. Seasonal fishing camps rely on shallow (less than 2 m) dug wells in these sands in some areas.

C. TOPOGRAPHY

In the strata of the limestone in the Jaffna Peninsula, very slight folds with minor anticlines and synclines are brought about by vertical movements. An examination of aerial photographs and mosaics for this region shows clear indications of faulting, which are shown in Figure 4c. The highest part is at Keerimalai, where a limestone and calcareous sandstone hill, rises to the height of about 30 feet above sea level. The coastline is cliffy here, and many remnants are found along it in the sea. It may be that the coastal strip also formed due to the fault lines. Except for a few locations where the limestone outcrops are found, or the sand dunes are found to infringe, the upper layer has a thin soil cover. The deposits of sand, wind-blown and water-borne, lie in areas where the limestone surface sinks gradually below sea level, especially on the East, West, and South.

FIGURE 4c - Probable Fault Lines in the Jaffna Peninsula

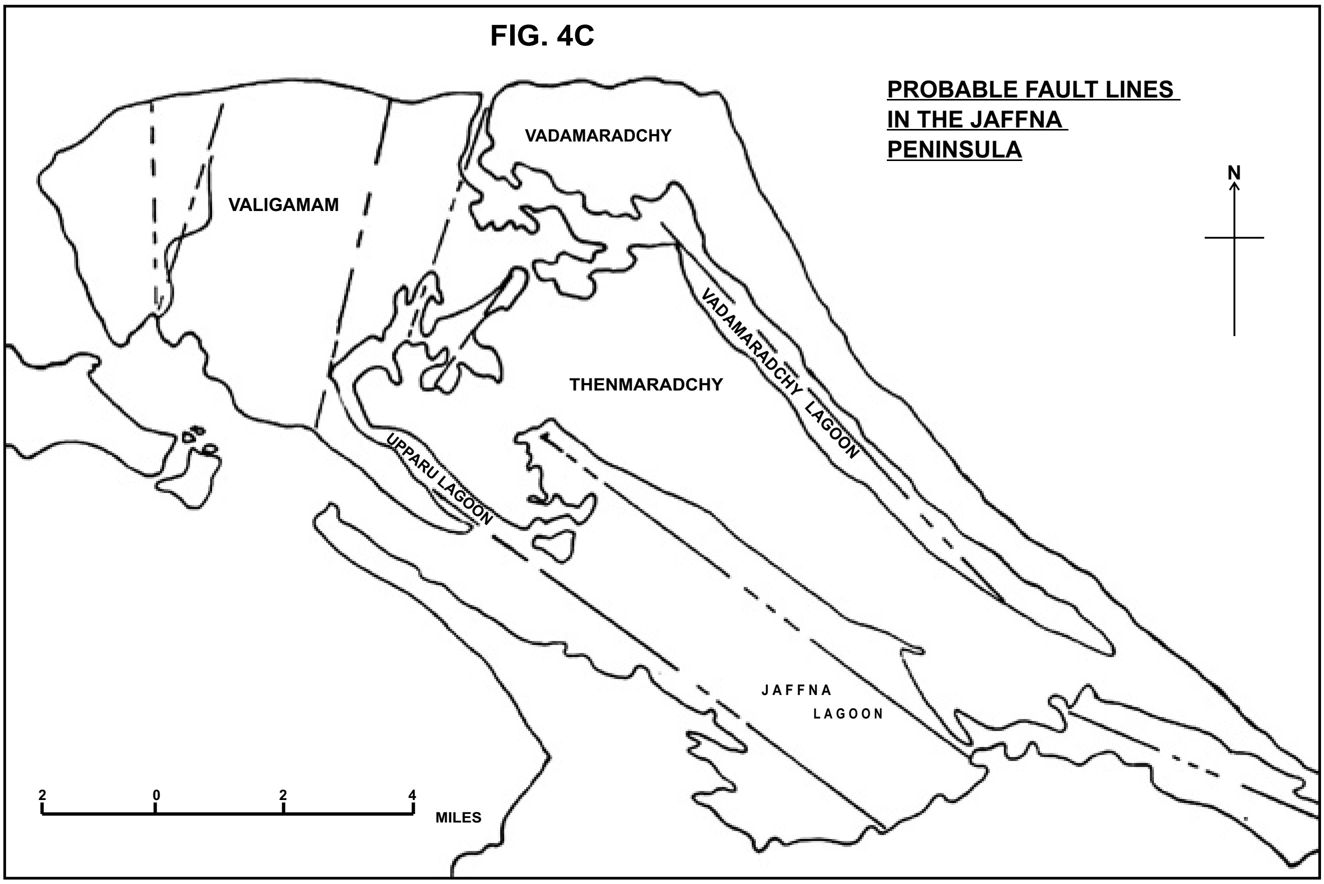
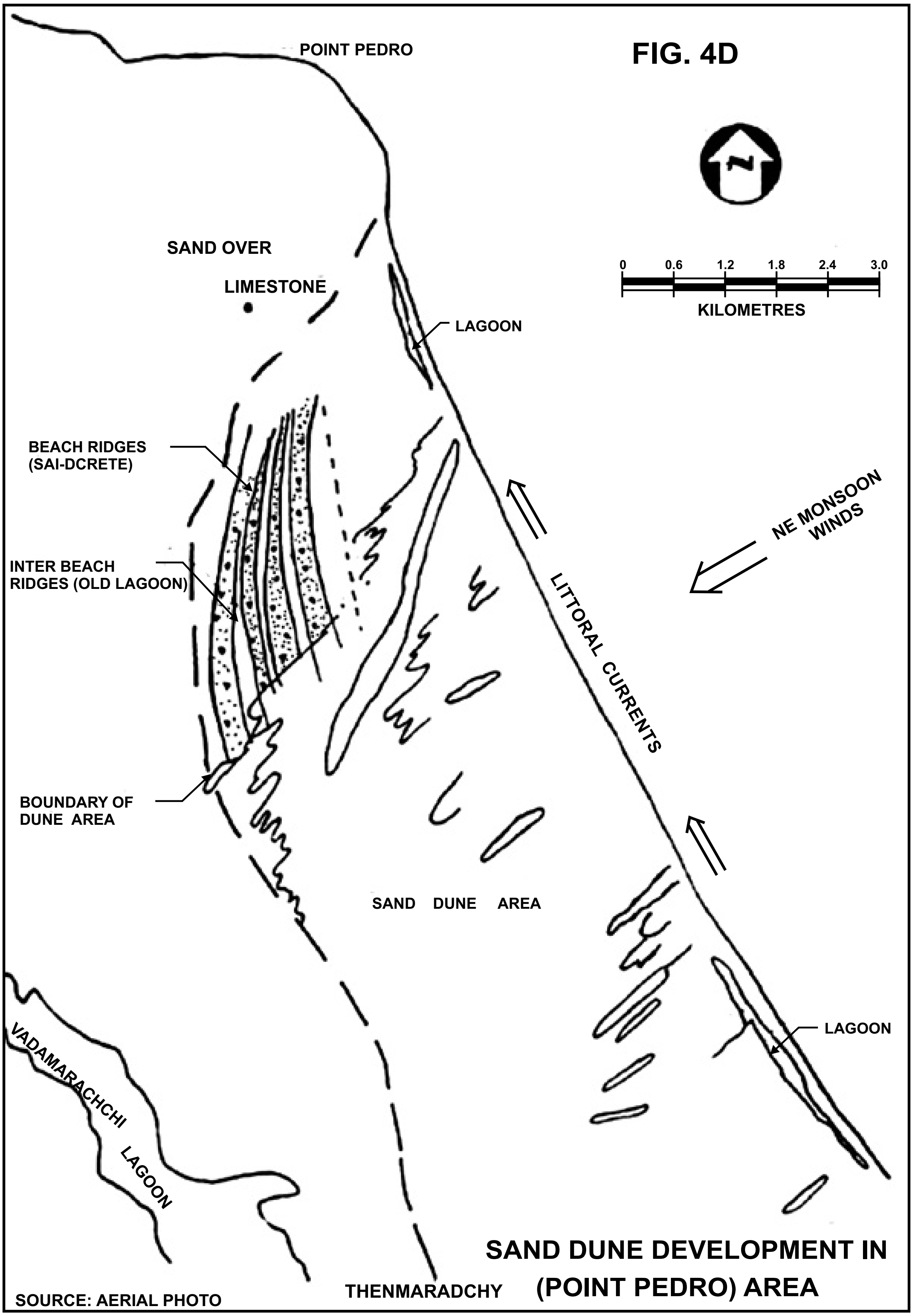


FIGURE 4d - Sand Dune Development in Point-Pedro Area



1. SALIENT FEATURES

a. CAVERNS

The Limestone in Jaffna is widespread and varied in occurrence, but essentially, it consists of calcium carbonate, which is soluble in rainwater containing carbon dioxide. The rainwater percolates through the openings, which are natural and due to joints and faults. Since the soluble parts are carried away, the remaining form is a cavern. The [Original text unclear: Editor] caverns in the Jaffna Peninsula are found at Urikkadu. [Original text unclear: Editor] washed off the exposed area.

These caverns have fragile covering material which decays in the course of time. The identical low areas are covered with recent sediments, which in most cases are the eroded particles of the relatively higher areas.

The absence of surface rivers make solution as the chief weathering process, and therefore, the other related features such as solution chamber (e.g., one in Puttur occupied by the Tidal Well), sink holes are familiar in this area.

b. CLIFFS

The coasts near Keerimalai are cliffy, and the same could also be said in the case of the whole of the northern coast, which is exposed to strong sea erosion and where a limestone shelf runs out for some distance below the sea. The cliffs have a landward slope from an elevation of about 30 feet. These are exposed to the erosive actions of the sea. Remnant rock fragments in the sea are found a little distance from the coast. The stones and pebbles along the coast have a rounded appearance. The coastline abounds in cave like formations.

c. OUTCROPS

The limestone as said earlier underlies the whole area of the Jaffna Peninsula, but it is seen as outcrops only in the north and north-western sections, in abundance. The soil cover is washed off, and the rainwater falling on the bare rock has brought about sharp edges. There are small cavities where water stagnated and helps in the disintegration by exerting pressure.

FIGURE 5 - Jaffna Peninsula – Limestones Features

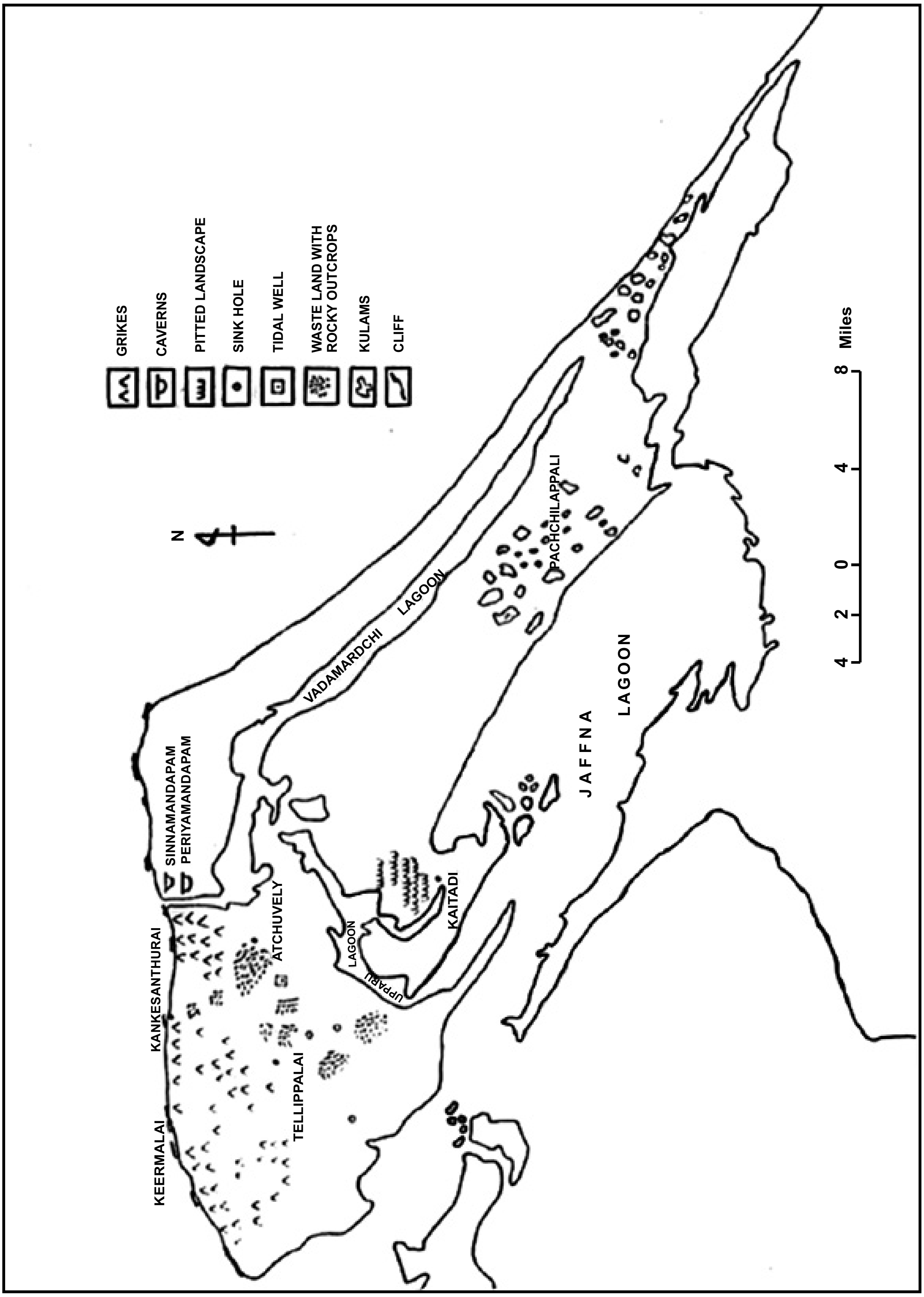


FIG. 5 - JAFFNA PENNINSULA - LIMESTONE FEATURES

D. CLIMATE

The Jaffna Peninsula is situated within ten degrees of latitude to the north of the equator. It is in close proximity to the sub-continent of India and separated from it by the Palk Strait and Bay of Bengal. In size the area is small since no place in it is more than 20-25 miles from the sea. The land nowhere rises more than 50 feet above mean sea level. These locational and physiographic conditions are acted upon by the 'equatorial atmospheric phenomena' to create a set of weather conditions that have their individualities to make the region a climate unit by itself (Tropical Monsoonal Type).

1. TEMPERATURE

The latitudinal positions of the region result in high temperatures from the high solar intensity due to the high angle of incidence of solar rays at all times of the year. However, there is an amelioration of temperature conditions due to the processes of convection adiabatic cooling and resulting condensation; the latter accounts for the high percentage of humidity in the lower atmosphere. This and the cumulus cloud-covered skies absorb and reflect the incoming solar radiation in addition. The process of convection also leads to the development of land-sea breezes, which affect the temperature conditions on the seaboard by making it more equable. The average monthly temperature given for two stations in Table II indicates that there are:

(a) two periods of maximum coinciding with the periods of the overhead sun, one in April- May and the other in August-September; the April-May maximum is higher than the August-September maximum; in the case of Kankesanthurai, the first maximum is not discernible,

(b) the coolest part of the year is in December or January, and this coincides with the lowest sun; and,

(c) the yearly averages in all cases fall in the neighborhood of 83°F.

TABLE - II

The average monthly temperature for Jaffna and Kankesanthurai

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Jaffna	83.4	85.6	88.6	91.2	88.8	86.7	86.2	86.1	86.3	85.4	83.2	83.0	86.2
Kankesanthurai	83.4	85.0	89.0	92.9	91.7	90.0	90.2	90.0	90.0	85.9	83.0	83.0	87.8

Source: Report of the Colombo meteorological observatory, 1967.

The highest maximum air temperature and the lowest minimum air temperature of the same two stations in 1967 are given in the following table.

TABLE - III

Maximum and lowest minimum air temperature for Jaffna and Kankesanthurai

Jaffna	68.2 (January)	93.6 (April)
Kankesanthurai	63.2 (February)	96.0 (April)

Source: Report of the Colombo Meteorological Observatory, 1967.

2. PRESSURE AND WINDS

Thermal differences give rise to pressure differences which in turn initiate air movements called winds. To understand the pressure controls on the climate of Sri Lanka, one has to consider the pressure systems over India. Following the march of the sun towards the Tropic of Cancer, beginning from the March equinox there develops over northwest India. A low-pressure system begins to weaken as the sun begins its southward march towards the Tropic of Capricorn. By December, the low-pressure system has vanished and has given rise to an equally intense high-pressure system over northwest India. This type of alternate high and low-pressure development takes place over India year after year with the rhythmic movements of the sun. These systems are almost nonexistent during the March and September equinoxes.

It has been generally believed that at the Doldrum belt, the air from the northern and southern hemispheres meet. Recent works on the study of the convergence zone in equatorial regions have revealed that the equatorial air (Equatorial Westerlies) is a distinct air mass with its own characteristics. Jayamaha advances the theory that the equatorial air stream presents two clear zones of demarcation, one with the northern hemisphere air and the other with the southern hemisphere air. These two boundaries appear in the day-to-day synoptic charts. One of these zones is found to remain between 05°N and 05°S while the other oscillates between 25°N (July-August) and 10°S (January-February). The southern zone of convergence always keeps to the south of Sri Lanka. Hence the winds of Sri Lanka have to be explained in terms of the pressure system that dominates India and the Northern zone of convergence, which is over Sri Lanka and to the north of it at different times of the year. Jayamaha has further shown that the N. Convergence zone is either active or inactive. Whenever it is inactive, the weather of the island will be controlled by thermal influences. The active periods are when true convergence is associated with clouding and precipitation.

By way of actual distribution, the pressure over Sri Lanka varies seasonally between 1014 and 1007 millibars. During the March and April months, the pressure gradient is much lower, amounting to less than 0.5 millibars while May to September show variation from 2.0 to 3.0 millibars only. During the rest of the year, the variation is between 1.0 and 2.0 millibars.

Table IV gives the percentage of wind directions for Jaffna in 1967. Observations were made to sixteen points but are summarised here in terms of eight points only.

From the table, it can be deduced that the southwest monsoon begins to operate in May, and continues to blow as far as October through the month of October, experiencing calm for nearly one-third of the time-space. The southwest monsoon, as meteorologists understand it today, consists of two phases, the shallow and the deep phase. In its shallow phase, it is the equatorial westerlies associated with the northern convergence zone. These winds appear in the early part of the monsoon period. The deeper phase which comes subsequently is believed to be caused by the westerly upper air currents that accentuate the equatorial westerlies.

TABLE - IV

Percentage of Wind Directions for Jaffna 1967

	Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec	
N	27	39	21	16	8	5	0	3	0	0	0	0	0	0	0	0	0	3	11	16	33	37	29	16
NE	47	55	55	80	21	48	8	23	0	6	0	0	0	0	0	0	0	0	8	27	37	47	50	61
E	8	3	18	4	35	40	3	10	3	3	0	0	0	0	0	0	0	0	6	5	7	2	10	15
SE	10	0	2	0	35	3	60	13	16	5	3	0	5	2	31	26	3	0	11	0	7	0	6	3
S	0	0	2	0	0	0	25	10	31	47	25	42	63	74	55	65	35	35	11	10	2	3	3	0
SW	0	0	2	0	0	0	3	35	48	39	70	58	32	24	8	10	60	62	35	34	3	5	0	0
W	0	0	0	0	0	0	0	3	2	0	2	0	0	0	0	0	2	0	3	2	2	2	0	3
NW	8	3	0	0	0	3	0	2	0	0	0	0	0	0	0	0	0	0	10	3	10	5	2	2
CALM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	3	2	0	0	0	0

Source: Report of the Colombo meteorological observatory, 1967.

Coming back to Table IV we see that October is the month of variable winds with some persistence of winds from the southwest. Thereafter the North East Monsoon begins to appear and continues to blow between the compass points north to east and south to west in the months of March-April and October are really part of the variable winds and, therefore are the result of the doldrum weather conditions.

3. RAINFALL

Owing to the absence of any high relief in the Jaffna Peninsula, the orographic control on rainfall is practically nil. Instability in the air is caused by convectional activity during the equinoctial periods (March-April and September-October). Cyclonic activity again during the inter-monsoon periods, and North convergence zonal activity, which operates effectively during the periods of the 'retreating southwest monsoon' and the early northeast monsoon. Thus, we see that the main meteorological phenomenon, the southwest monsoon, has no device by which it can give rain to the Jaffna region. (The air masses that play a role in the climate of Sri Lanka are (1) the Equatorial air, (2) the Indian continental air, and (3) the North Pacific Trades air. The South Pacific air, which never reaches Sri Lanka, has an influence on the weather immediately to the south of Sri Lanka. The Siberian air originating in North Central Asia exerts an indirect influence on the weather of the island because it affects the weather of the Bay of Bengal. Of these, the Equatorial air contributes the most moisture to Sri Lanka through the southwest monsoons, while the Indian continental air and North East Trades air, the former on account of its land origin, and both on account of their subsiding nature, carry a limited amount of moisture).

The rainfall year for the Jaffna Peninsula can be divided into

i. The south-west monsoon period

ii. The inter-monsoon period, and

iii. The northeast monsoon period

The southwest monsoon in its early and middle periods blows as a dry wind over the Jaffna Peninsula. During its late period, as the northern convergence zone approaches Sri Lanka on its southward march, rain is received. In the absence of orographic upliftment, the monsoon continues to be dry till the convergence zone provides the necessary condition for uplifting. Hence part of the rainfall recorded in the months of September and October is due to the 'Retreating Monsoon'.

March-April and October are periods during which the island comes under the influence of normal convectional activity, which induces a certain amount of rainfall. Thunderstorms are a common feature in these months, and rainfall caused by this phenomenon tends to be of short duration but heavy and accompanied by strong winds, thunder, and lightning. The northeast monsoon period is rainy too, but in the latter months, the monsoon weakens considerably, and therefore, the rain received during this phase is very limited. Cyclonic activity is one other cause of rainfall in this region. During the months of October-November, cyclones or tropical storms originate over the Bay of Bengal and traverse across the island or to the north of it. The highest frequency of these storms is recorded during the month of November, during which the average number of occurrences is one per year, while October records one every two years. During the March-April periods of equinoctial weather, the frequency is one every six years. These storms result in torrential downpours, and some of the highest rainfall for a space of 24 hours has been recorded during periods of such storms.

FIGURE 6 - Average Annual Rainfall Distribution of Jaffna Peninsula

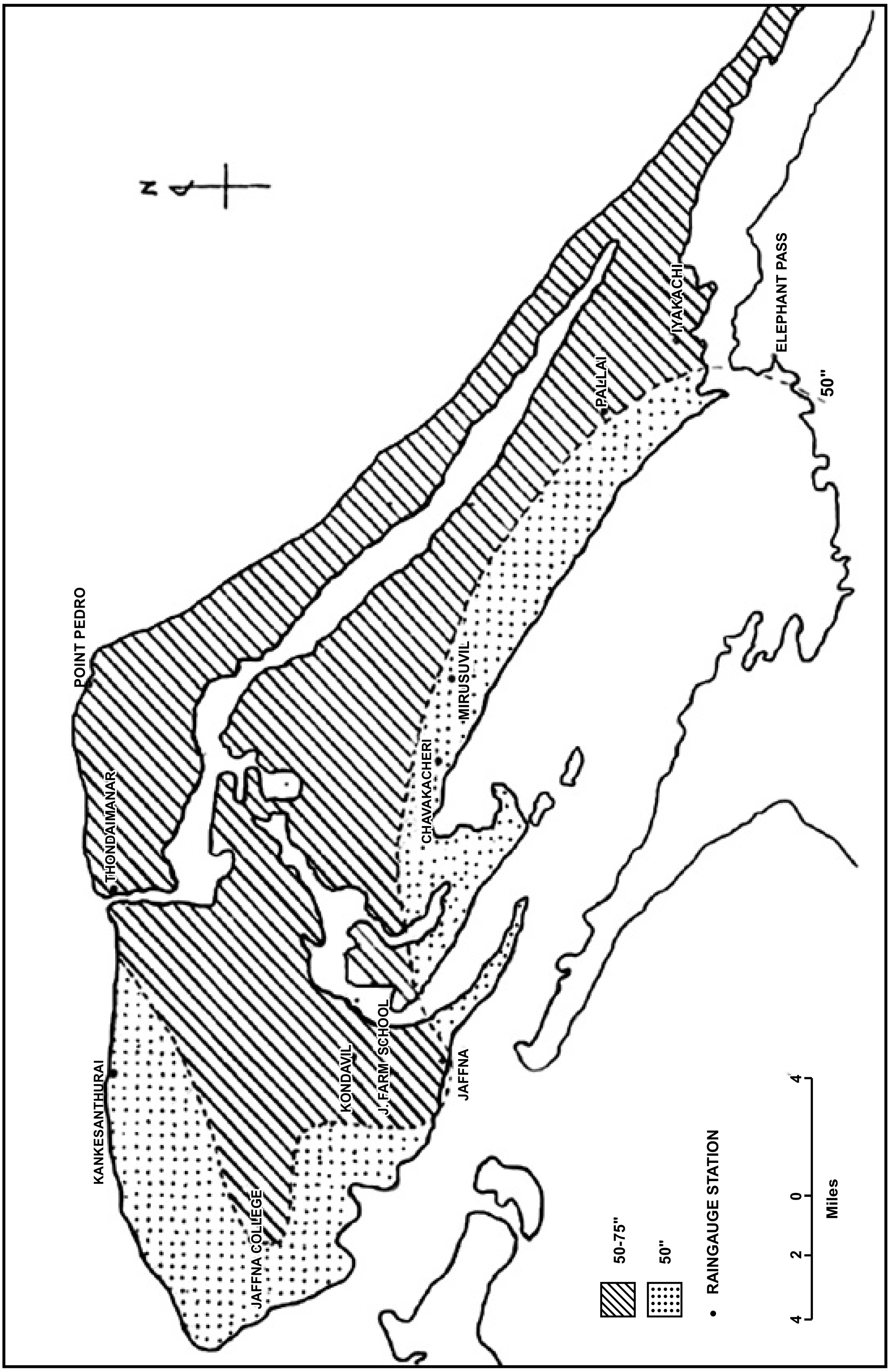


FIG. 6 - AVERAGE ANNUAL RAINFALL DISTRIBUTION OF JAFFNA PENINSULA

The rainfall distribution map of the Jaffna Peninsula shows (see Fig. 6) that the mean annual rainfall of the western section is below 50, and that of the eastern section is 50-75 inches. However, it is not uncommon for the absolute total for a year to deviate either way from the mean 32.44 inches in the year 1936 and a total of 73.79 inches in 1932, in both cases the deviation being more than 20 inches from its mean annual of 53 inches. The true nature of this variability can be observed further by examining the annual average rainfall and three-year moving average curve for Jaffna for a period of fifty years, presented in Figure 7. The wet months, as well as the dry months, are equally subject to this vagory. In light of this, the consideration of the mean monthly or the mean annual rainfall can be considered a reliable indicator of the rainfall to be expected for the whole year or a part of the year. It will be noted that every month shows a mean which is higher than the corresponding median point. It is, therefore, reasonable to conclude that the median point gives us a more reliable measure of rainfall expectancy than the means.

The mean (ten-year) annual and the mean northeast monsoonal rainfall are shown in Table V, together with the yearly rainfall in 1967 and 1968.

It is found that the northeast monsoonal rainfall in the Peninsula (32 inches) forms 82% of the total annual rainfall. (While the seasonal rainfall exhibits a definite rhythmic pattern, there is, however, considerable variation in it from year to year. This variability of rainfall has always been a major hazard in agricultural enterprises in the area). Hence it is assumed that the southwest monsoonal rains in relation to groundwater replenishment in the Jaffna Peninsula are negligible.

FIGURE 7 - Jaffna Met. Station Average Annual Rainfall and Three-Year Annual Rainfall Moving Average Curve Based on Long-Period Mean (1923-1973)

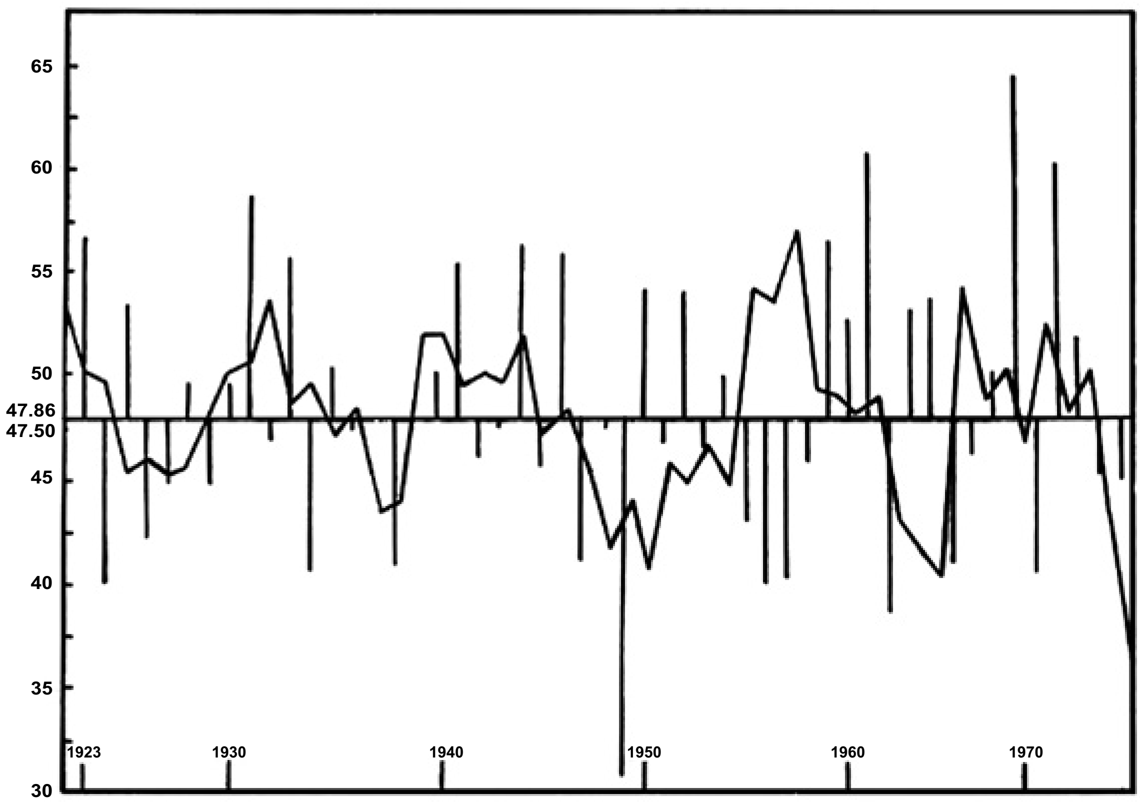


FIG. 7 - JAFFNA MET. STATION - AVERAGE ANNUAL RAINFALL AND THREE YEAR ANNUAL RAINFALL MOVING AVERAGES CURVE BASED ON THE LONG PERIOD MEAN (1923-1973)

TABLE V - The Mean (Ten-Year) Annual and the North East Monsoonal Rainfalls

TABLE - V

The Mean (Ten Year) Annual and the North East Monsoonal Rainfall

		Annual Rainfall			N.E. Monsoonal Rainfall (Oct. – Jan.)		
		Mean (10 year)	During the Year		Mean (10 year)	During the Year	
			1967	1968		1967	1968
1.	Jaffna	47.07	53.2	27.75	38.05	39.5	22.1
2.	Jaffna Farm School	51.7	65.4	33.9	40.9	37.2	25.4
3.	Kondavil	-	-	36.2	-	28.1	28.1
4.	Ramanathan College	51.8	-	-	42.2	-	-
5.	Puttur	-	-	49.97	-	-	39.6
6.	Pallai	47.4	57.6	35.68	43.9	28.0	24.6
7.	Mirusuvil	-	-	33.35	-	-	20.9
8.	Ampan	-	-	39.0	-	-	27.4
9.	Point Pedro	42.4	-	34.0	34.8	-	-
10.	Kankesanthurai	49.7	83.4	31.6	39.7	33.2	24.1
11.	Tholapuram	-	-	34.4	-	-	26.6
12.	Jaffna College	51.5	68.8	32.4	39.2	42.1	23.8
13.	Kayts	40.7	-	24.8	31.7	-	20.9
14.	Delft	37.1	-	-	29.5	-	-

The next important consideration in this region is the effectiveness of rainfall. Owing to the high incidence of sunshine with cloudless days, long periods of drought, and high wind velocity, the loss of moisture due to evaporation is very great. This condition would be further complicated by edaphic conditions. Therefore, the effectiveness of rainfall is much less than the absolute rainfall. Farmer estimated that there are at least five months in the year where the reliability of effective rainfall is less than 30% for the 40 years considered. The problem of water for agricultural and other purposes for a continuous period of 5-6 months (April-September) is a serious one assuming that in February and March, one could depend on the surprise of the surplus of the proceedings during the rainy season.

This problem in the Jaffna Peninsula is offset to a degree by the use of underground water in the limestone strata.

E. SOILS

Geology as a soil characterising soil agent is best exemplified in the case of Jaffna soils associated with Limestone parent materials.

Farmer, in order to arrive at the P/E ratio, used the Formula

$$E = K(0.03\ S_d)/1 + W/10$$

where:

E = monthly free water evaporation in inches

S_d = the mean monthly saturation deficit in inches

K = 20, and

W = the average wind velocity in miles per hour for the month in question.

P/E greater than 2 is considered effective rainfall.

FIGURE 8 - Jaffna Peninsula Soils

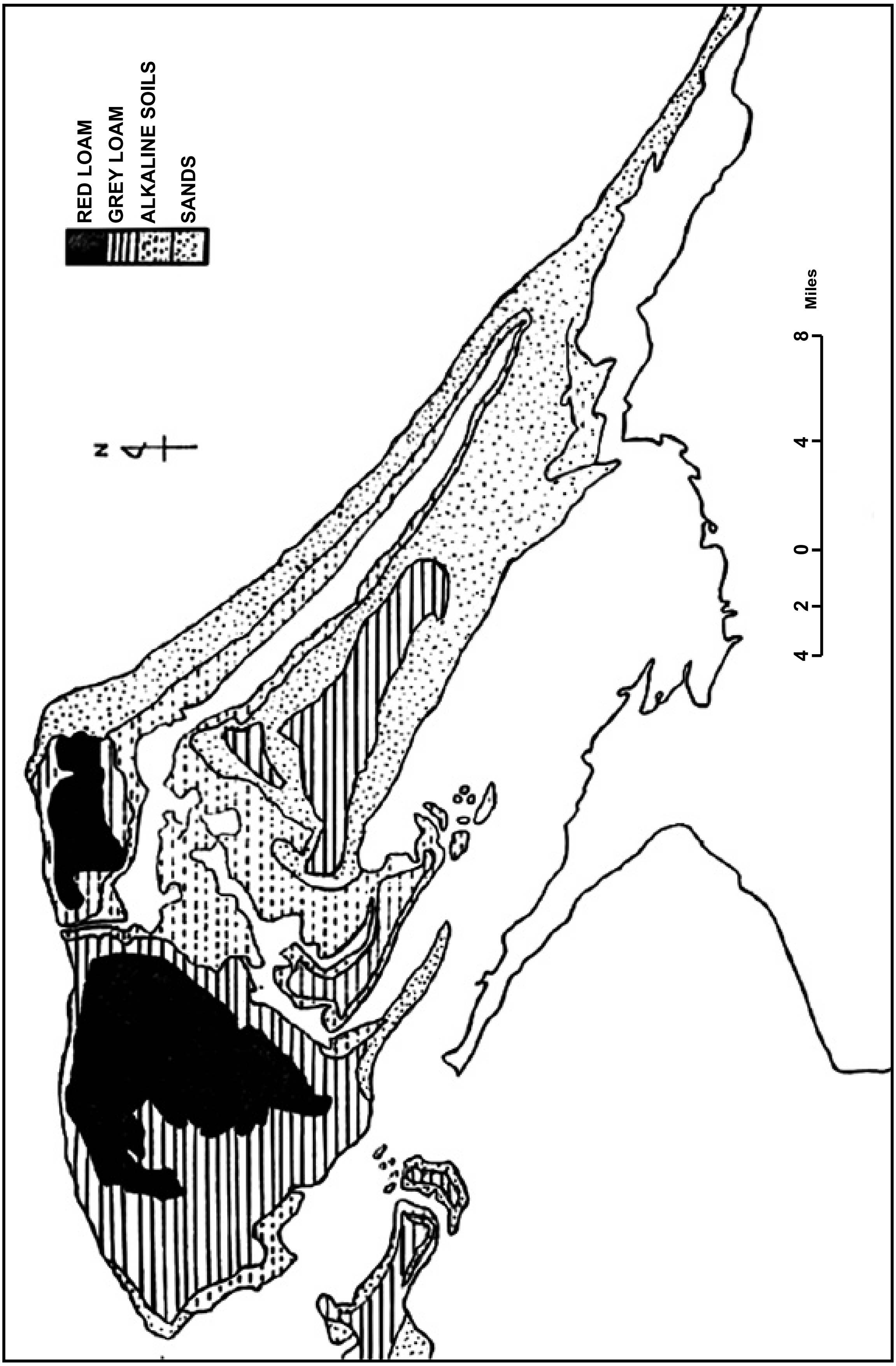


FIG. 8 - JAFFNA PENINSULA SOILS

1. RED SOILS

The uniform free-draining, deep red soils (similar to the terra rossa of the Mediterranean region) to which the limestone rocks give rise to, are independent of climatic influences. These are uniform in texture, colour, etc., down to the parent rock, which occurs at a depth from 1 to 30 feet from the surface. The red soil is found usually on the relatively higher areas. The red colour is due to the soil not being leached. These are rich in iron oxides, as could be seen from the luxuriant growth of vegetables which contain more iron vitamins. These have many rock fragments embedded in them and have to be dug and reclaimed before utilising for cultivation.

2. GREY LOAMS

In the comparatively low-lying (paddy) areas, the wash from higher areas is deposited. Typically, the paddy soils are generally either submerged underwater or poorly drained. As a result, the soils are of the characteristic grey loams: the lower layers being bluish grey or dark in colour and mottled brown by brown hydrated oxides.

Both the above soil derived from the parent limestone have a very fine texture permitting root development and accretion. The soil layer is on the whole rather than and therefore is not quite suited to extensive growth of trees but valuable for garden crops. Besides, the soils are not naturally fertile, lacking plant food and humus. So, the soil retains very little moisture, especially during the dry period.

3. OTHER KINDS

The soils not directly derived or that have undergone many modifications are grouped under this title. Along the northeast and southeast margins of the Peninsula are extensive tracts of sand. They are mostly wind-blown. In the narrow strip of land along the Lagoons, the soil is alkaline. This is due to saltwater having covered these parts.

F. VEGETATION

The vegetation of the Jaffna Peninsula is largely determined by climate, and on a broad view, rainfall is more important than temperature. Soil factors and topography are generally of secondary significance.

Much of the natural vegetation has been cleared now for agricultural practices. Some form of xerophyte-type of vegetation exists in lands unsuitable for agriculture, especially in sandy areas and in limestone wastes. At present, there are two types of natural vegetation found in the Peninsula.

i. Growth of Mangrove in Swamps. These are found in the Lagoons.

ii. Scrubs and Jungles. These are scattered in the Pachilapalli area on the way to Elephant Pass.

In the northern and western fringes and many scattered parts of the Peninsula, the limestone waste contains little or no soil covering, and hence tiny scrubs and cactus plants alone find a means of thriving. Palmyra palms, too, grow in these areas, and their long roots force their way down to tap the water underneath the surface.

REFERENCES

Adams : Geology of Ceylon, *Canadian Journal of Research*, Vol. 1, pp. 425-511, 1929.

Arumugam, S. : Development of Groundwater and its Exploitation in the Jaffna Peninsula, *The Institution of Engineers, Ceylon Transactions*, 1970.

Brohier, R.L. : Ancient Irrigation Works in Ceylon, 3 vols, Govt. Press, Colombo, 1934

Cooray, P.D. : An Introduction to the Geology of Ceylon, Museum Publication, 1967.

Crowe, P.R. : Wind and Weather in Equatorial Zone, *Transactions, Institute of British Geographers*, 1951.

Ekanayake, L.A.D.I. : Some Observations on Ceylon Weather and Climate, *Bulletin of the Ceylon Geographical Society No. 2*, July 1945.

Farmer, B.H. : Pioneer Peasant Colonization in Ceylon, A study in Asian Agrarian Problems, Oxford University Press, London, 1957; Ceylon: A Divided Nation, Oxford University Press, London, 1963; Green Revolution London, Macmillan *(Cambridge Commonwealth Series)*, 1977; Agriculture in Ceylon. *Geographical Review* XL pp. 42-67, 1950; Some Thoughts on the Dry Zone, *Ceylon Geographical Society Bulletin*, Vol. VI. Nos. 2 and 3.

Jameson, H. : The Heavy Rains Over Ceylon of Sept. 29-30, 1924, *Ceylon Journal Science Section* E.1 pp. 39-47, 1926.

Jayamaha, G.S. : A Summary of the meteorological characteristics of Ceylon, *Bulletin of the Geographical Society,* Vol. 9, No. 1, 1955

Jeyasingham, W.L. : Urban Geography of Jaffna Town – Unpublished PhD. Thesis, Clark University, 1958.

Kendrew, W.G. : The Climate of the Continents. Oxford University Press, New York, 1942.

Report of the Colombo Observatory, Sri Lanka, 1967.

Report of the Colombo Observatory, Sri Lanka, 1968.

Sirimanne, C.H.L. : Groundwater Resources in the Dry Zone, *Ceylon Association for the Advancement of Science Proceedings*, Colombo, 1967.

Somerville, B.T. : The Submerged Plateau Surrounding Ceylon: Some Considerations Regarding the Formation of the Coastline, *Spolia Zeylanica*, 1908.

Thambyahpillay, G. : Climatic Controls in Ceylon*, University of Ceylon Review,* Vol. XI, Nos. 3 and 4, 1963

Thompson, B.W. : An Essay in the General Circulation of the Atmosphere over S.E. Asia and the West Pacific, *Quarterly Journal of the Royal Meteorological Society*, Oct. 1951.

Wayland, E.J. : Outline of the Stone Ages of Ceylon, *Spolia Zeylanica,* Vol. II, pp. 85-125, 1921.

Wayland, E.J. and Davis, A.M. : The Miocene of Ceylon, *Quarterly Journal Geological Society,* Part 4, LXXIX, 1923.

IV. NATURE AND OCCURRENCE OF WATER RESOURCES IN THE JAFFNA PENINSULA

A. SURFACE WATER

Having discussed the background of the nature of the occurrence of water in the previous chapter, it is proposed to discuss in some detail the main sources of water in the Peninsula and their characteristics as a basis for its occurrence.

Water resources of this area comprise two sectors, namely the surface and underground water. The surface water is mainly contained in the karstic depressions of the limestone called the “ponds” or “kulams”. Many artificial depressions on this surface also have been formed to retain much of the rainwater run-off. All these depressions are filled annually with water derived from the monsoonal precipitation that occurs mainly during the months of October through December. The groundwater storage and recharge of this area also occurs during the months of October through December with the rainfall. The geological formation of the Peninsula favours the storage and existence of groundwater resources. Surface water and groundwater are very closely interrelated to each other in this area, and thus it needs a correlated study of both resources.

Over the centuries groundwater as well as surface water has been used for domestic and agricultural purposes in this region. An examination of the one inch to one-mile topographical maps of the Peninsula will show that it abounds with kulams (tanks). There are large and small tanks within the Land area of 360 square miles. (Lagoons occupy the balance of the total 410 square miles of the Peninsula). Over 1000 of them have been enumerated, of which only about 200 are in good function. Their aggregate storage capacity has been assessed at 6350 ac. ft. (Please see Appendix V for details). They border fields and water courses; the water courses become the right of way - cart - tracks to the kulams and eventually become winding lanes, and roadways as the Kulams get encroached and gradually dwindle to extinction.

These kulams are not man-made storage tanks as found elsewhere on the Island. As Kularatnam (1964) explains

> “The ponds are not depressions excavated by man to store rainwater. The limestone is subject to chemical weathering under the action of rain water charged with carbon dioxide from the air. As this water passes into the rock, it dissolves into the rock and causes hollowed ponds and kulams of the North are thus natural features caused by the solution of the limestone and the collapse of the roofs of subterranean limestone cavities” (e.g., Puttur well).

He mentions that,

> "The natural surface depressions, hollows, and kulams act like funnels to conduct the surplus rainwater underground. Naturally, therefore, the bottoms of these funnels should be kept clear of silt and clay deposits which would choke the underground passages, and thus reduces the amount of water that can flow down to the reservoir.”

Therefore, the only use for which these tanks could be put to use is to augment the underground water supply in the Peninsula as they help to replenish the underground source.

It is presumed that the Peninsula aquifer cannot hold all the rainwater that percolates into it from the regular annual rainfall. Some of it seeps in the normal source of events into the sea through various seepage channels (or springs as they are called). One has only to walk along the beach from Keerimalai towards Kankesanthurai in the month of January to see a countless numbers of these springs flowing out.

If then, the aquifer is already unable to hold what it receives now, the question would obviously be raised as to the need or necessity, or usefulness served in desilting beds of tanks or sinking hole wells in the beds of tanks for increasing more percolation into the aquifer.

Clearly it would be a case of putting more into the aquifer, and increasing percolation, even to the extent of 100%, with the consequential effect of increased permeability to send more and more water quickly to the sea. This is actually so. If more rainwater percolates, more would seep out. This is to say by desilting tank beds, we certainly would provide increased seepage.

But the fact remains that, if, for instance, there were no percolation, rainwater would readily flow off to the sea as surface drainage and would be lost completely (to man) in December itself, whereas when persuaded into the ground or subsoil, there is a time lag; it would take some time to permeate through the limestone to the sea, during which period it is available for use by man, such as for pumping during February and March when wells recuperate much more than later on in the year. Thus, the Kulams of Jaffna perform a critical function in the hydrological cycle of the Peninsula by both detaining and percolating the drainage of the area.

Apart from these tanks, a small non-perennial stream called the Valukkai Aru, rising from the Central 35 feet elevation in the area called Tellippalai, runs over 8 miles through Alaveddy, Uduvil, and Manipay, conveying the drainage from the southwestern areas. As this stream basin is composed of clay mainly, the infiltration capacity is very low, and thus, the contribution for groundwater storage is meagre.

B. OCCURRENCE OF GROUNDWATER AND AQUIFER CHARACTERISTICS

According to Meinzer, groundwater may be classified as being of either internal or external origin. Internal water (Juvenile water) is derived from atmospheric or surface water and may be trapped in rocks at the time the constituent material was deposited (connate water), or it may be absorbed into interstices sometime after deposition (absorbed water). Almost all groundwater is derived from precipitation. That which is not, is so deep below the earth's surface that it has never been involved in the hydrologic cycle. Such water is called Juvenile water. Juvenile water reaches the surface from volcanic sources. When it does, it enters the hydrologic cycle for the first time. Other groundwater was once involved in the hydrologic cycle, but because of changes in the earth's surface, it has been locked out of that cycle for a long period of time. Such water, called Connate water, is trapped in layers of sediment laid down by ancient rivers or seas. Further changes in the lithosphere could release this water and return it to participate in the hydrologic cycle. However, by far, the largest proportion of groundwater is meteoric, meaning that it is derived from atmosphere sources. Virtually all waters comprising a part of man's environment are continuously being cycled in response to the forces exerted primarily by the sun's energy and by the earth's gravity. Water at or near the surface of the lithosphere tends to move upward into the atmosphere through processes of evaporation and transpiration. The moisture eventually falls back to the earth's surface through processes of condensation and precipitation. This continuous recirculation of water is referred to as the hydrological cycle. In this continuous cycle of water movement, the oceans provide the principal source of water. The atmosphere functions as the mover, and the land receives the primary benefit. Of the water that falls on the land, a part immediately returns to the atmosphere through evaporation. A part will have a surface runoff, and a part enters the ground. The water enters into the ground by infiltration through the voids and other interstices of loose soil, sand, and other previous formation, or it may percolate through the cracks, fissures, and joints of impervious formation, and all the water that soaks below ground is known as groundwater.

The supply of groundwater in an area depends on a variety of factors. Most fundamental is the amount of precipitation that falls in a given area and in areas that drain into it. Related to this factor is the rate of evaporation, which also affects groundwater supply. A third factor is the amount and type of vegetation cover on the land. Although dense vegetation transpires great amounts of moisture back into the atmosphere, it prevents rapid run-off of rainfall and encourages the percolation of water into the ground. A fourth factor affecting the supply of groundwater is the porosity of the soil and rocks. Porosity refers to the ability of soil or rock to hold or contain water. Thus, some gravels have large pore spaces in which they can hold large amounts of water. Dense, fine-grained material, on the other hand, can hold and transmit very little water.

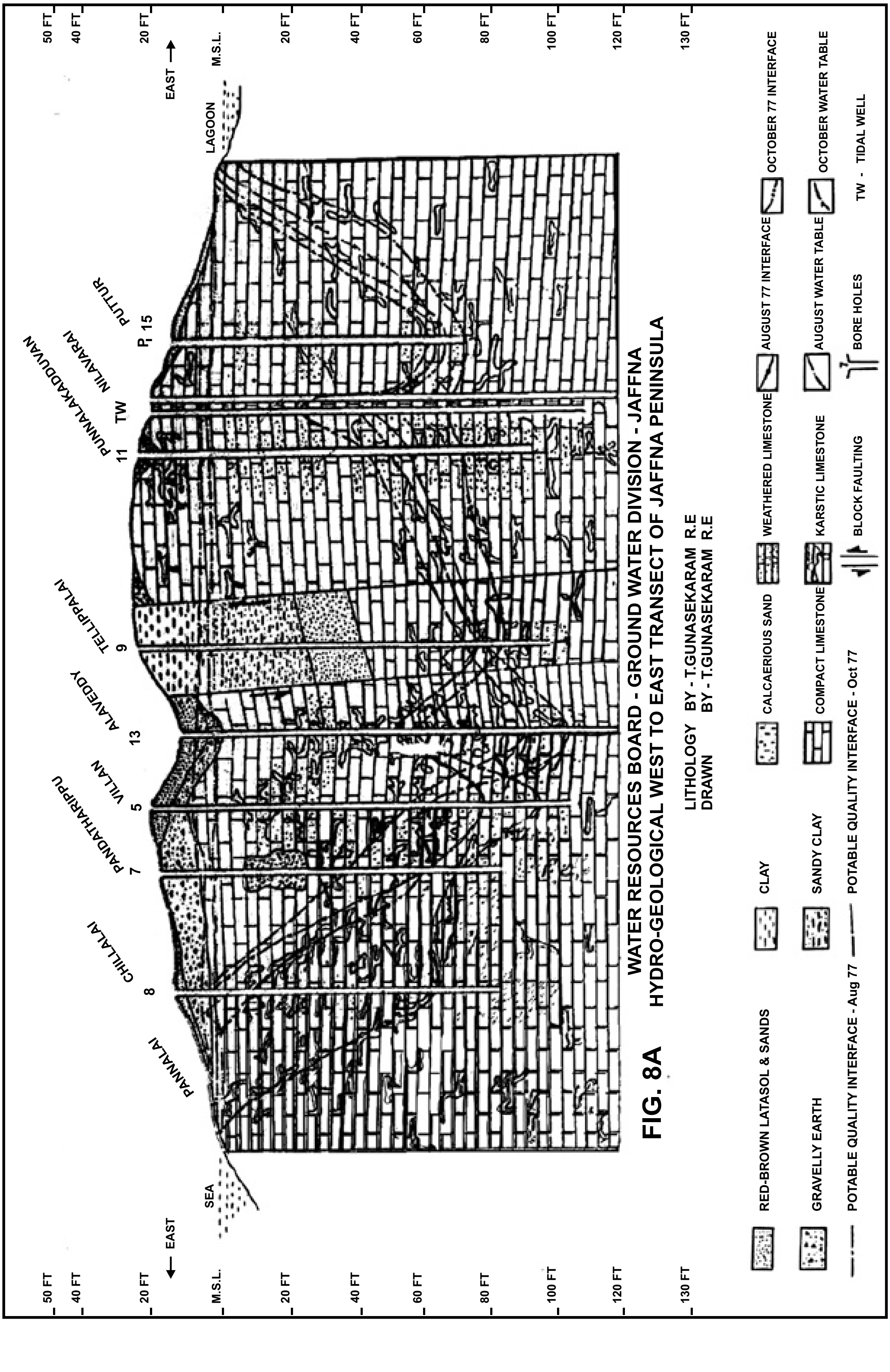
In order for groundwater to move through the ground from high points to low points or from storage areas to springs and wells where it is needed, the soil or rocks must be permeable. That is, the ground must have enough openings and passages through which the water can move from one place to another. The permeability of a material is related to the number and size of the spaces in it and the number and size of the openings between them. Porosity affects the storage of groundwater, and permeability affects groundwater movement. Both of these factors affect the availability of water in wells and springs.

The ability of different rock layers below the earth's surface to absorb and transmit water is obviously related to the porosity and permeability of those layers. A layer of sand or gravel, for example, because it is particularly porous and permeable, can act as a container and transmitter of water called an aquifer. Materials that are dense and compact and that are not very permeable cannot hold much water and tend to restrict its movement underground. A relatively impermeable and nonporous layer that restricts the flow of water and limits its storage is called an aquiclude.

Prior to making a determination of the amount of water available from groundwater sources, the characteristics and features of the water-bearing material, the aquifer must be known or estimated. Two fundamental parameters describe aquifer behaviour: storage coefficient or specific yield (S); and hydraulic conductivity (k). Depth of flow in the aquifer is taken into account in the transmissivity, T, which is the product of depth of flow and conductivity. The values of T, S, and K are normally determined by pumping tests. Transmissivity is a measure of the rate of flow through a cross-section of unit width over the saturated thickness under a hydraulic gradient of unity. It is expressed in square metres per day (sq m/d). Hydraulic conductivity (k) is defined as the rate of flow through a unit crosssectional area of a porous medium under a hydraulic gradient of unity as measured at right angles to the direction of flow. It is the constant in Darcy's Law of porous media in flow. K is generally expressed as metres per day (m/d) or metres per sec (m/s). Storage coefficient is the discharge fraction from a unit volume in a confined aquifer. Specific yield is the same for the unconfined aquifers. Confined aquifers are not exploited in Jaffna. In unconfined aquifers, like those of the Jaffna Peninsula, specific yield may be considered equal to effective porosity. This is a dimensionless value that normally ranges from 1 to 3 for unconfined aquifers.

The Ghyben-Herzberg principle, which controls groundwater in the Jaffna Peninsula aquifers, is sustained by the buoyancy of freshwater relative to seawater. The difference in densities between seawater (p = 1.025 as standard) and freshwater (p = 1.0 as standard) results in a depth of 40 metre of freshwater below sea level for every metre above sea level. This is the ideal static condition in which no mixing between the fresh and sea waters takes place. Even though the ideal condition would seem to be unusually restrictive, requiring a sharp interface between the freshwater and the underlying saltwater, most Ghyben-Herzberg systems on islands and along the coasts are surprisingly accurately described by the 40:1 ratio inland of the coastal discharge boundary.

FIGURE 8a - Hydro-Geological West to East Transect of Jaffna Peninsula



A sharp interface is not necessary in the application of the 40:1 ratio. The zone of dispersion, commonly called the transition zone between seawater and the freshwater core, is symmetrical about the 50 percent relative seawater concentration contour. This symmetry, although an equilibrium condition, is typically very persistent and allows the 40:1 ratio to be applied to the depth of the 50 percent contour.

The characteristic average groundwater head is obtained by dividing the depth below sea level to the 50 percent concentration by 40. This head is a true Ghyben-Herzberg head in contrast to the transitory head measure at the water table. The Ghyben-Herzberg head, which may be called the storage head, measures the size of the lens and the value of water in storage. It does not change easily; for every metre of water that accumulates in storage above the level for the true Ghyben-Herzberg condition to prevail. For instance, in Jaffna, water table elevations between the dry and wet seasons often exceed 1 metre. If at the end of the wet season, a water table elevation was measured as 1 metre higher than during the dry season, the 50 percent contour would have to be depressed 40 metres for the Ghyben-Herzberg conditions to apply. One metre of water in an aquifer with 0.15 porosity is equivalent to 150 mm; 40 metres in the same aquifer is equivalent to 6000 mm. Seasonal rainfall at Jaffna is about 1020 mm, or nearly 5000 mm less than would be required, even if all the rainwater infiltrated to the aquifer.

There are two distinct but interconnected aquifers in the Peninsula, the limestone and the sand. In relation to the Ghyben-Herzberg principle, they respond as one. Recognizing this characteristic, estimates of freshwater volume available were made using contours generated from the 1000 micromho interface data.

These movements of vertical conductivity profiles in drilled wells have defined for the first time the position of the freshwater-saltwater interface on the Jaffna Peninsula, and therefore, the vertical section of the freshwater displays a lens shape (see Fig. 9) created by freshwater floating on saline water. Groundwater is recharged by vertical percolation of rainfall and is discharged by horizontal flow to the nearest coastal periphery.

FIGURE 9 - Diagram of a Typical Groundwater Lens

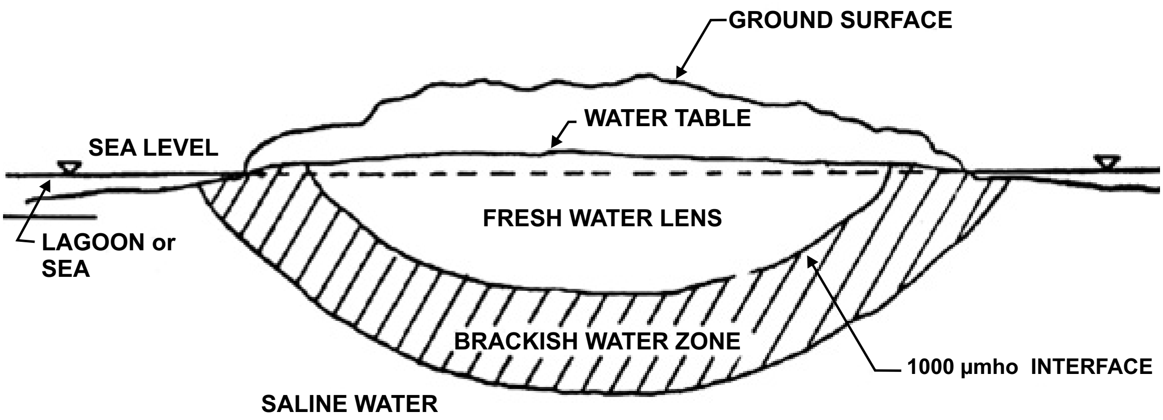


FIG. 9 DIAGRAM OF A TYPICAL GROUNDWATER LENS
(NOT TO SCALE)

PENINSULA

Both limestone and a sand aquifer are present on the Peninsula. The Jaffna limestone constitutes the major aquifer in the Valigamam area, and the Pallai sands constitute the major aquifer in the Vadamaradchi and Thenmaradchi areas.

VALIGAMAM

The Jaffna limestone provides the sole source of groundwater in this area. All municipal and irrigation wells are completely in limestone. Aquifer tests were conducted at ES-sites 7, 8, 9 and 10 to determine the aquifer characteristics of this formation. Data from tests at sites ES-9 and 10 were analyzed using distance drawdown methods. (ES – "Engineering Science drill holes") Transmissivity and hydraulic conductivity values determined showed the variability of parameters expected in karst environments. An apparent T of 3700 sq m/d and a K of 200 m/d exist at ES-9, but the specific yield was not readily determinable. The limestone is too permeable for reliable interpretation of test data at the small pumping rates employed. A specific yield of 0.15 was assigned to the limestone based on the past experience of the investigator in unconfined karstic aquifers in similar environments. Laboratory tests performed by the WRB indicated an average porosity of about 0.10.

Using the area and thickness given on the thousand micromho interface contour map, the estimated quantity of freshwater above the transition zone is 212 million cu. m. This volume of groundwater is the largest in the entire study area and the most heavily developed.

Water table heads in a freshwater-seawater system are transitory phenomena that occur too rapidly and erratically to reflect the Ghyben-Herzberg balance. They are ambient heads affected by sporadic infiltration and pumpage. Near the coast, tides also cyclically affect these ambient heads. The intervals over which the addition to or subtraction from lens storage takes place are generally too short for the bottom of the lens to be measurably affected. The deeper storage responds over the long term, during which accumulations and depletions have been averaged. The ambient heads, which are those measured at dug wells and other water table sites, have little value in the quantitative analysis of lens behaviour.

The limestone aquifer of Valigamam is so transmissive that pumping tests at low rates are unable to depress the water table sufficiently to generate measurable drawdowns at observation wells. This is in contrast to the behavior of the sand aquifers, where pumping rates as low as 50 cu. m/d induce drawdowns that can be accurately measured. Thus, reliable values of hydraulic conductivity have been computed for sand aquifers, but for the limestone, an estimate had to be elicited from water table movements generated by tide fluctuations. The hydraulic conductivity of the sand is less than 50 m/d, while that of the limestone is more than 500 m/d, an order of magnitude greater.

Heads in the limestone are small because recharge moves relatively rapidly down the gradient to discharge along the coastline. The inability for high heads to become established poses problems for water development by restricting pumping rates, but the great permeability of the aquifer inhibits upconing so that carefully designed drilled wells could be used to extract water from the freshwater core of the lens at continuous rates of approximately 82 cu. m/d from each well. Although the aquifer of Valigamam is the most highly exploited in the entire Peninsula and the groundwater model shows that about two-thirds of the recharge are already being withdrawn, an additional increment of 4000 cu. m/d will not materially affect the present balance. This 4000-cu. m/d can consist of potable or nearly potable water by selecting proper sites for the wells, carefully constructing them, and outfitting each with an 82-cu. m/d pump and operating it continuously.

The well hydraulics model on which the above conclusions were based is the upconing analysis of Bear and Dagan. The definition sketch for the central portion of the Valigamam area is shown in Figure 10.

The dry season storage head (0.40 m) for the central portion of the Peninsula is probably conservative. The average for 1982 was about 0.50 m. The thickness of the transition zone between the 50 percent seawater isochlor and 1000 micromho level was obtained by averaging the 1982 data on conductivity profile graphs. The average for all of Valigamam was 9.6 m; in 1977-78, it was 9.9 m.

FIGURE 10 - Groundwater Condition for Valigamam Limestones Aquifer at End of Dry Season

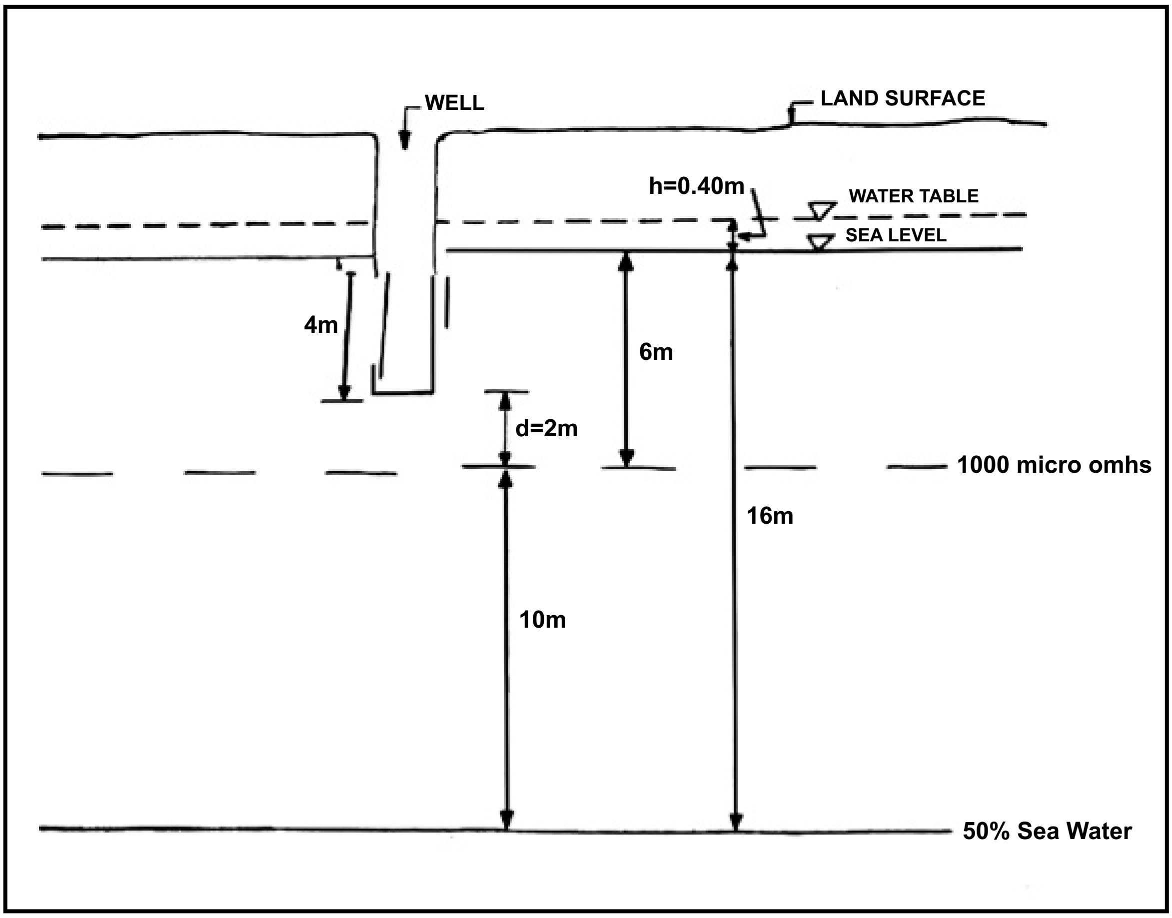


FIG. 10

GROUND WATER CONDITION FOR WALIGAMAM LIMESTONE AQUIFER AT END OF DRY SEASON

SOURCE : ENGINERRING - SCIENCE

VADAMARADCHI AREA

In the western portion of the Vadamaradchi area, the limestone Aquifer occurs as in the Valigamam area, but in the southern portion, it is covered with thick eolian sands. Where the limestone is exposed, it responds in a manner similar to limestone in the Valigamam area.

The sand dune region extending southeast from Point Pedro is underlain by a continuous aquifer composed of sand lying on limestone that contains freshwater as a Ghyben-Herzberg lens. The buoyancy relationally occurs throughout the sand and continues into the limestone. At all of the locations where exploratory borings were drilled, the sand is not thick enough to accommodate the full depth of the freshwater lens. As a result, part of the freshwater core and the whole of the transition zone lies within the limestone.

The head in the sand is controlled by the high permeability of the limestone. Increases in water level in the sand, induced by rainfall recharge, are compensated by leakage into the limestone. In the limestones, flow moves rapidly down-gradient because of the high permeability until head exceeds that in the sand, at which point the water seeps upward across the formation boundary.

Dynamic equilibrium exists between the sand and limestone layers because an increase in potential in one of the layers drives water into the other until a balance is established. A typical sequence takes place in the wet season when recharge enters the sand, increasing its potential so that water moves across the unconformity into the limestone. The increase in head in the limestone enhances flow down-gradient, but head loss per unit horizontal distance in the limestone is less than in the sand because of the great disparity in permeability. Then, at a distance down-gradient, the head in the limestone will exceed that in the sand. This behaviour goes on continuously. When large transfers of water are underway, the head in the two formations may be appreciably different.

FIGURE 11 - Flow Between Limestone and Sand

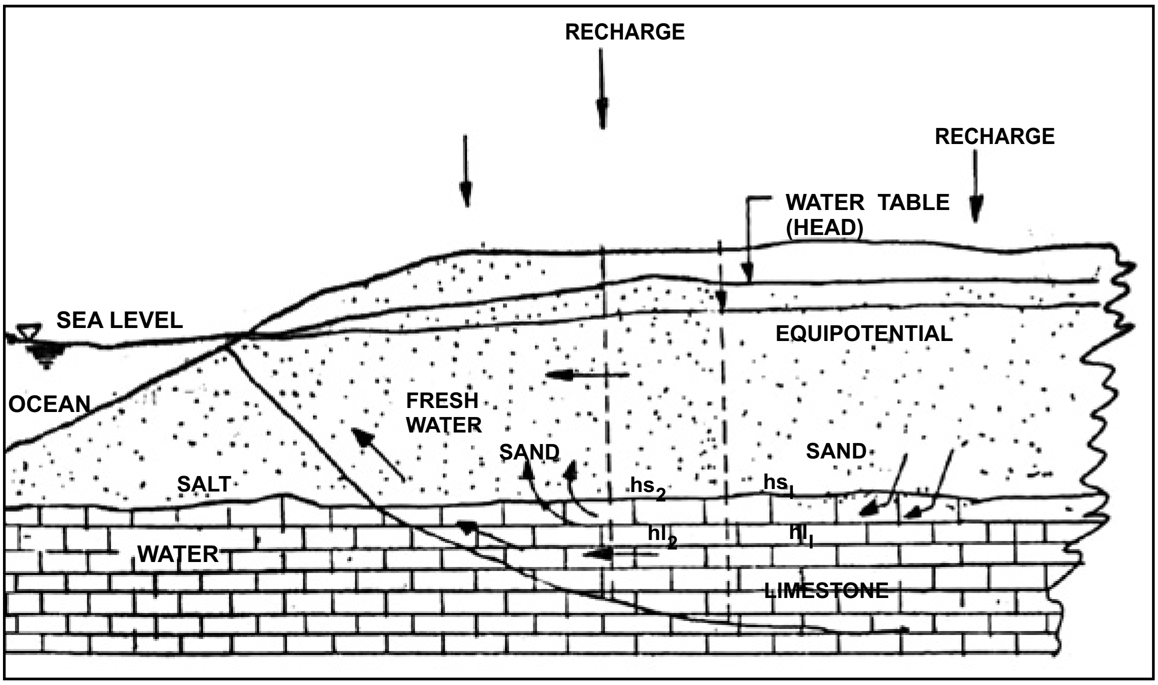


FIG. 11 FLOW BETWEEN LIMESTONE AND SAND

SOURCE : ENGINERRING - SCIENCE

The productivity of the sand-limestone aquifer is constrained by the cyclical nature of recharge, in which practically all infiltration occurs in three months (Oct-Dec) while leakage takes place constantly throughout the year. Low heads toward the end of the dry seasons determine the permissible continuous sustainable yield of potable water. Under natural, non-exploitation conditions, at the end of the dry season, heads descend to an average of about 0.5 m along the mid-line of the dunes from an initial and wet season head of about 0.8 m. Sustainable yield calculations are based on the low heads coupled with the constraint that the transition zone is never allowed to rise into the sand. Besides restricting the transition zone to the limestone, the quality of the water in the sand is protected, and a potable water supply ensues.

THENMARADCHI

The sand aquifer is the most important aquifer in the Thenmaradchi area. Although limestone underlies the sand throughout the area, the more permeable zones are generally too deep to consider for development by conventional drilled wall techniques without causing upconing.

In comparison to the sand aquifer in the Vadamaradchi area, the sand aquifer in the Thenmaradchi area is perhaps ten times less permeable. This is a result of the fine, clayey, silty sands that occur in this area compared to the medium to coarse sands that exist in the Vadamaradchi area. The hydraulic conductivity values determine from the test at ES-5 and 6, 3.0 and 2.0 m/d respectively, are characteristic of fine, silty sands. Characteristic and reliable specific yield values were not determinable. A value of 0.10 has been used to reflect the finer silty sands in this area compared to the Vadamaradchi area. Based on this figure, there is an estimated 140 million cu. m. of water stored in the sands of the Thenmaradchi study area.

Ghyben-Herzberg heads in this area show that leakage occurs in both the Vadamaradchi and Jaffna Lagoons. The steep gradient in the head near the lagoons reflects the less permeable nature of materials as the lagoons are approached.

ISLANDS

With the exception of the eastern portion of Kayts, the islands present little opportunity for additional development of significant groundwater supplies. The sands occurring over most of the islands are thin, non-existent, or present only in narrow bands along the southeast coast of each island. This set of conditions restricts groundwater accumulation to high permeability limestone and thus incurs rapid leakage to the ocean.

From the evaluation of the other groundwater areas in the Peninsula, it appears that infiltration or recharge is forty to fifty percent of the average annual rainfall if the conservative assumption is made that one fourth of this would be available for extraction distributed over the year, each of the larger islands may be able to yield several thousand cu. m. per day for domestic use.

Estimates attempted for the small islands of Eluvaitivu, Mandaitivu, and Analaitivu suggest that leakage rates prevent the formation of exploitable freshwater lenses. This implies that from the end of one wet season to the start of the next wet season, large amounts are lost from the shortage. It does not necessarily mean that no water is available. Skimming infiltration galleries of similar design [Original text unclear: Editor] could provide some relief for a short period after the wet season and perhaps help reduce the amount lost between monsoons.

The eastern half of Kayts offers a better chance for additional development because it contains a thick, 7.5-10 m cover of sand over the limestone. Because of the low permeability of these sands, a freshwater lens is able to form in this area.

Karainagar has a substantial potential volume available. But it is spread over a much larger area underlain by limestone. The resulting freshwater lens will therefore be much thinner and far more difficult to develop. This also applies to Delft, where a volume larger than indicated for Kayts is potentially available. Delft is one large, extremely flat fossil coral reef providing a minimal opportunity for water supply development.

The bulk of the island of Kayts is covered by silt and clay overlying the Jaffna limestone. The clay is as much as three metres thick but is very poorly permeable and does not serve as an aquifer. Dug wells must penetrate the clay to reach the limestone before yielding water. Where the island narrows as it changes direction to the east, however, the clay is replaced by fine sand to form a two-layer aquifer, sand on limestone, as in the Vadamaradchi dunes and Thenmaradchi. The Velanai water scheme exploits this condition and produces potable water.

The area of the exploitable aquifer system is small, about five km. It extends eastward from Velanai to about Cheddikadu, a distance of less than four km, and southward from the Jaffna Road to the coast, a distance of about one and a third km. Assuming a recharge area of 4.0 km and an annual average infiltration of 0.57 m, total recharge is about 2.3 million cu. m/y. About one third of this amount, by analogy with Thenmaradchi, which most resembles the Kayts Aquifer, can be safely extracted on a continuous basis. This is equivalent to approximately 2000 m/d.

The rate of withdrawal from the aquifer is constrained by the permeability of the sand and the thickness of the freshwater core. Employing the same analytical models as for Thenmaradchi and the Vadamaradchi dunes, the number of dug wells or length of infiltration gallery required to exploit the full safe yield of 2000 cu. m/d or a fraction of it can be calculated.

For dug wells, theoretical allowable production per well, based on the definition and hydraulic conductivity of 2 m/d, would be 15.1 cu. m/d per well, about half of what is currently being produced at the Velanai water scheme well. This well yields excellent quality water, and its average rate of production of about 30 cu. m/d is probably more realistic as an allowable rate than the theoretically derived one. In deriving the theoretical rate, conservative aquifer conditions were assumed.

C. FLOW CHARACTERISTICS

The groundwater flow characteristics in the Jaffna Peninsula depend on many hydrogeologic factors and require comprehensive techniques for a detailed analysis of the subject. The recent investigations by the Water Resources Board have provided water table contours and highly complex flow patterns, indicating the groundwater mounds and depressions generally as areas of discharge and recharge, respectively.

In the northwest zone of the Peninsula, the groundwater mounds under their hydraulic heads discharge rapidly into the surrounding depressions or directly into the sea through the anisotropic medium of carbonate rocks influenced greatly by the extensive karst zones. Along the northern coast, numerous coastal and possible offshore springs have been noticed, particularly from Kankesanthurai to Keerimalai, indicating rapid discharge through the Karstic limestone beds. Detailed investigation and study were carried out along the north coast during and immediately after the north-east monsoonal rains, and innumerable springs were seen along a certain stretch of the north coast, discharging one foot below mean sea level to 4 feet above mean sea level. From the month of November to January, springs at a level of 4 feet above mean sea level could be seen to discharge freshwater between a stretch of one-and-a-half-mile distance from Keerimalai to Kankesanthurai. However, these springs disappear by mid-January and do not seem to discharge at any level below 3.50 mean sea level or above, except the spring at Keerimalai, which is at an elevation of 1 to 2 feet below mean sea level. Between Kankesanthurai and Myliddi, freshwater could be seen bubbling up from the sea bed at an elevation of 1 foot below mean sea level, even during the dry months. The only places where perennial springs could be observed are Keerimalai and Myliddi. The rest of the springs disappear with the monsoon. The discharge data in Figure 12 will indicate the size and nature of springs along the north coast. This evaluates the fact that irrespective of the heavy rainfall and recharges, the aquifer discharges all the temporarily stored water through the numerous springs till a state of balance occurs in the saturated aquifer. To get an idea of the extent of Karstification, one may inspect the Kankesanthurai quarry, which cuts extensive solution cavities developed essentially along bedding and joint planes.

Many wells formed naturally by collapsing of the carbonate roof of solution caverns are found particularly in the northwest zone and in the northeast zone, where the limestone outcrops are covered by their soil covers. These are called 'freak' wells and may sometimes be compared with the sinkholes along the northwestern limestone terrain. The presence of such freak wells does strongly indicate the extent to which the carbonate rocks are karstic. With the presence of these extensive karst zones above and below zero mean sea level, the study of geohydrologic characteristics such as flow directions, saline freshwater interface, and the trend of seawater intrusion, etc., require special attention.

In the northwest zone, a few drill holes sunk in the central region by the irrigation department have indicated fresh to moderately freshwater up to depths around 10 to 120 feet. This shows that even under karst conditions of the aquifer, deep lenses of freshwater do occur under sufficient hydraulic heads.

The recharge of freshwater lenses, build-up of the 'mounds,' and a freshwater tongue forces itself laterally under a sufficient head overriding the coastal saline water regions. Flushing and diluting the mineralised water to some extent. Thus, the aquifers are discharged to the sea, depleting the maximum storage of some years by nearly 75% within less than three months.

D. FRESHWATER - SALTWATER INTERFACE FLUCTUATIONS

The Ghyben-Herzberg lens formation theory concerns the study of conditions due to saltwater intrusion in freshwater areas. This phenomenon occurs in sandy Islands or in Peninsula surrounded by or in close contact with the sea.

During rainy days, rainwater percolates downwards into the soil to join the freshwater that is supported by the heavier seawater, forming a shape - like a lens. This underground freshwater lens becomes thicker in rainy weather and flattens out as freshwater gets drawn out. The thickness of the lens 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 freshwater must balance the saltwater pressure at the bottom of the lens.

If the thickness of the lens in a vertical plane is H, and h its depth below sea level, and w and s the specific gravities of fresh and seawater, then

Hw = hs

H = w (H - h) / (s - w)

and if w = 1 and s = 1.025, then h = 40 (H – h).

So that if the water table is 2 feet above sea level, then theoretically, there should be 80 feet depth of freshwater below sea level in that locality.

When pumping is done, the depression by a foot of the freshwater table (above sea level) will reduce the thickness of the freshwater lens below sea level by 40 times. This would, in turn, cause the formation of a 40 times upward sea water bulge in the seawater-freshwater contact zone.

As the Jaffna Peninsula is surrounded by sea on all sides, it is susceptible to seawater intrusion from all directions; the freshwater occurs as a lens above the saltwater body underneath. The thickness of the lens varies with the fluctuation of the interface (or face of separation) of the saltwater and the freshwater surfaces.

With the view to observing the seasonal fluctuations of the level of saltwater-seawater interface, two drill holes, three inches in diameter, have been established by the Irrigation Department, one at Kondavil in the premises of the Jaffna Town Water Supply pumping wells where the ground level is 29.6 ft. and the other at Kankesanthurai in the Cement Corporation premises, ground level 14.9 ft. above mean sea level datum.

Observations of water levels and quality of water at various depths in the two drill holes have been carried out by the Geological Survey Department since 1965; the observations at the Kondavil drill hole are taken at 80 ft., 90 ft., 95ft., 105 ft., and 110 ft. below ground level and at Kankesanthurai 60 ft., 70 ft., and 80 ft. below ground level.

FIGURE 11a - Relation of Saltwater to Freshwater According to the Ghyben-Herzberg Principle

THE ENCROACHMENT OF SALT WATER INTO FRESH

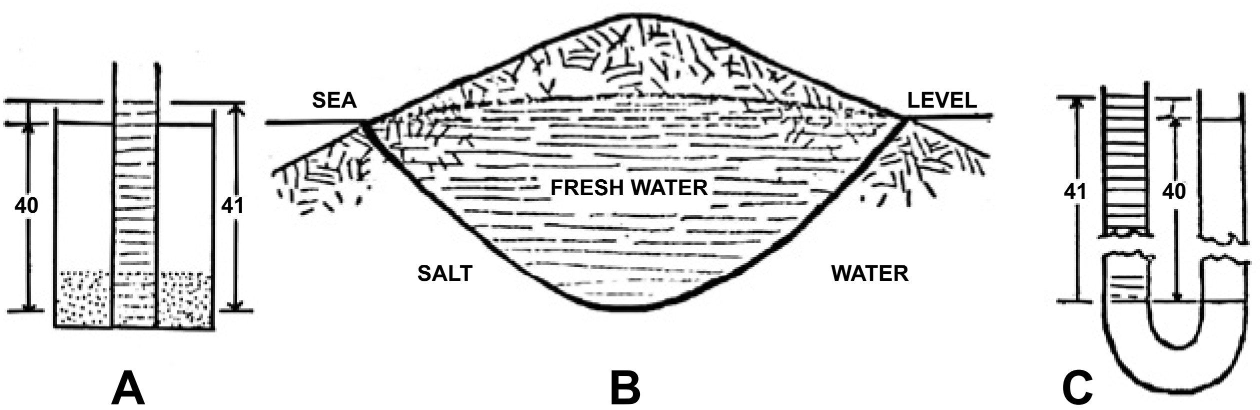


FIG. 11a - THE RELATION OF SALT WATER TO FRESH WATER ACCORDING TO THE GHYBEN - HERZBERG PRINCIPLE

The three diagrams in Figure 11a show the relation of saltwater to freshwater according to the Ghyben-Herzberg principle well explains the position in the Jaffna Peninsula. A small, open-bottomed tube containing freshwater is placed in saltwater and sand of a larger container. Freshwater is free to move out but does not move beyond a point of balance with heavier saltwater. On diagram C, the U tube contains freshwater on the left-hand side and saltwater on the right-hand side. As in A, the freshwater stands higher than the saltwater. 41 units high to 40 units high. B, an idealized cross-section of a permeable Island in the sea. Here the rainwater has seeped into the sand and produced a lens of freshwater that has depressed the heavier ocean water. The freshwater lens floats on the saltwater much as an iceberg floats on the ocean, with most of its mass submerged. Periodic rains replenish the freshwater lens.

In practice, dynamic conditions exist with movement towards and discharge to the sea and lower-lying areas. The position and character of the interface between the freshwater and saline water are further complicated by

i. the ocean tides, which cause a reciprocating motion in the groundwater reservoir,

ii. the abstraction of groundwater, and

iii. vertical and lateral variations in the hydraulic properties of the aquifer.

These factors may lead to gross discrepancies between the actual depth to the saline water interface and the depth indicated by the Ghyben-Herzberg relationship and lead to a thick transitional zone of brackish water being produced by hydrodynamic dispersion.

E. THICKNESS AND SHAPE OF THE FRESHWATER LENS

Before discussing the thickness and shape of the freshwater lens, it is well to define, somewhat arbitrarily, the terms 'fresh' and 'saline' water. A value of TDS (total dissolved solids) of 1000 ppm (parts for million) is taken as the upper limit of 'freshwater' and 10,000 ppm as the lower limit of 'saline water'. These values appear to correspond with Cl (chloride) concentrations of about 300 to 4000 ppm, respectively.

The thickness and shape of the freshwater lenses in the Jaffna Peninsula have not been adequately defined. Wijesinghe states that

"Good quality groundwater exists only in the form of scattered lenses ranging in depth down to about 80ft. in most parts of the Peninsula … even during the height of the drought".

Examination of data from the 14 boreholes drilled largely during a period of high-water levels provides additional understanding of the nature of the lenses and of the freshwater-saltwater interface. In most of the holes, a sharp increase in chloride concentration from less than 400 mg/l to more than 900 mg/l (usually more than 1000 mg/l) takes place with increasing depth. This has been called the freshwater-saltwater interface but is more precisely the upper boundary of the zone of diffusion. The thickness of the zone of diffusion can be identified in three wells as 20 to 25 feet.

In one of the Islands west of the Peninsula, the top of the zone of diffusion was typically 25 to 55 feet below mean sea level; at the time the water table was 9 feet below mean sea level. On an adjacent Island, the top of the zone of diffusion was 20 feet below mean sea level, and the water table was 0.3 feet above mean sea level. This latter position of the interface accords fairly with Ghyben-Herzberg's prediction. The seeming discrepancy between the two islands is probably a function of aquifer permeability, particularly the relation of lateral or vertical permeability and the additional complexity caused by the intermittent pumping of groundwater in the area. Furthermore, the freshwater head at the interface is unknown.

In the southwestern part of the Peninsula and at Thondaimanar in the north-central part of the location at the top of the zone of diffusion also accords reasonably well with Ghyben-Herzberg prediction. In the southwest, the interface was at or below 70 feet below mean sea level, and the water table ranged from 1 to 2 feet above mean sea level. The interface was located 33 feet below the mean sea level, and the water table altitude was 0.7 above the mean sea level, at Thondaimanar.

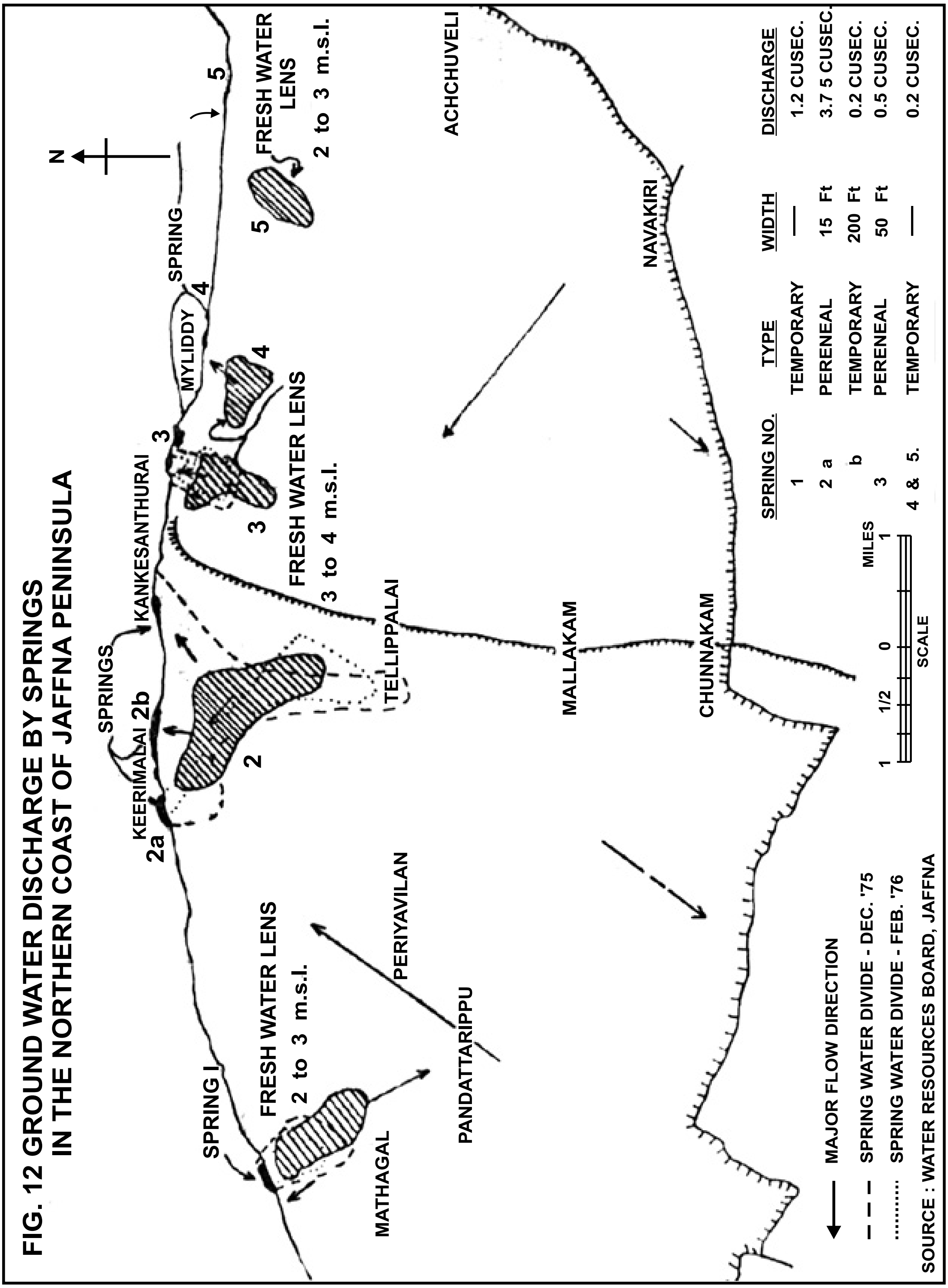
Data from four additional boreholes identifies the position of the interface ranging from 48 feet below mean sea level (water level unknown) at Kankesanthurai in the northwest, to deeper than 77 feet below sea level (water level was 3 feet below sea level) in an upland area Kopay (26 feet above mean sea level) west of the Uppu Aru Lagoon.

Salinity maps to be discussed in the next section show areas where the freshwater lens appears to be negligible, and water is being pumped from the zone of diffusion from shallow dug wells. Due to the Karstic nature of the aquifer and the unpredictability of both its vertical and horizontal permeability, additional subsurface borings are required to define the shape of the lenses and monitor fluctuations of the interface, particularly in areas of heavy pumping.

F. SALINITY CONDITIONS

As Jaffna is surrounded by sea on all sides, it is susceptible to seawater intrusion from all directions. During rainy days, rainwater percolates downwards into the soil to join the freshwater that is supported by heavier seawater, forming a shape like a lens. This underground freshwater lens becomes thicker in rainy weather and flattens out as freshwater gets drawn out. The thickness of the lens at any instant locality is dependent on the height of the water table above sea level, as the height of the column of freshwater must balance the saltwater pressure at the bottom of the lens. When pumping is done, the depression by a foot of the freshwater table (above sea level) will reduce the thickness of the freshwater lens below sea level by 40 times; this would, in turn, cause the formation of a 40 times upward seawater bulge in the seawater-freshwater contact zone.

FIGURE 12 - Ground Water Discharge by Springs in the Northern Coast of Jaffna Peninsula



The samples of water obtained from each of the 411 observation wells are chemically analysed in the laboratory by the Groundwater Investigation Unit to determine the following:

i. Chloride Ions, in parts per million

ii. Total hardness as calcium carbonate, in p.p.m.

iii. Total dissolved solids present, in p.p.m.

On the basis of the results obtained from such analyses, isochlor maps are prepared by the Irrigation Department; these show the distribution of salinity, in parts per million, as found in the well waters of the Peninsula at the end of the months of August, during each of the years 1967 and 1968 (see Fig. 12a).

By comparing the isochlor maps of successive years, areas which have consistently remained with the same degree or grade of salinity (i.e., either free, or moderately free, or completely saline) are obtained. Extents of each category, in the Peninsula remaining in the same category for successive years are shown in Table VI below.

FIGURE 12a - Jaffna Peninsula - Distribution of Salinity in the Month of August of the Years 1965, 1966, 1967

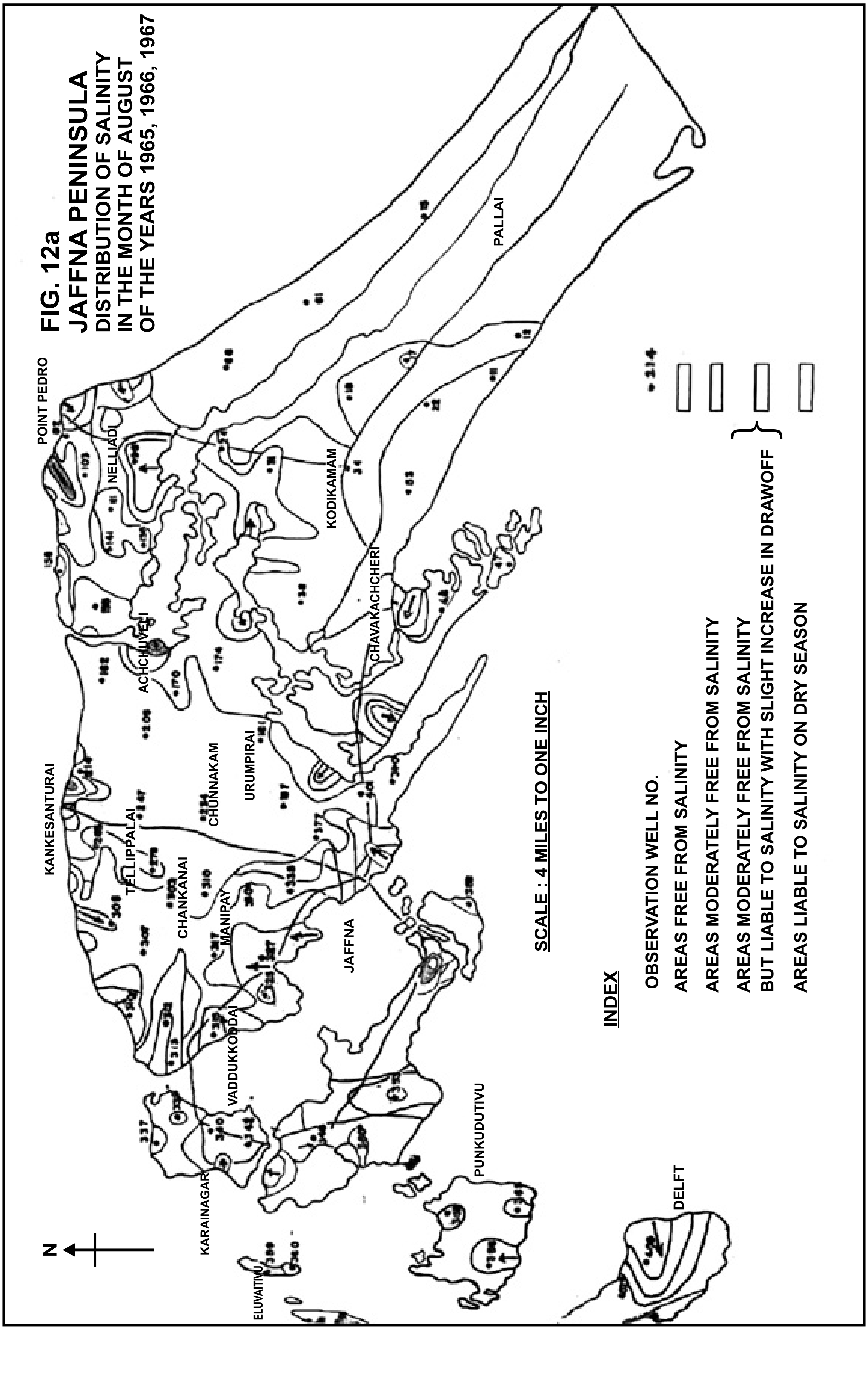


TABLE - VI			
Extents (acres) of saline areas in the Jaffna Peninsula			
Description and Salinity contents	**During the Years**		
	1965-66	**1966-67**	**1967-68**
Areas free of Salinity (less than 500 ppm)	128,100	142,780	155,780
Areas Moderately free (1500-2000 ppm)	64,200	64,000	58,500
Areas liable to be Saline (1500 - 2000 ppm)	46,480	43,800	37,300
Saline areas	17,290	11,000	14,000

(Source: Water Resources Board, Jaffna.)

Examination of the salinity distribution map shows two major areas of low salinity groundwater (less than 500 mg/l chloride) occur in the Jaffna Peninsula. One coincides with the southeastern part of the Peninsula and is approximately 150 square miles in size. The Jaffna limestone is overlain by sand in this area, and groundwater withdrawals are generally from the sand. The other area is centered in the western part of the Peninsula and is approximately 60 square miles in size. Smaller areas of low salinity groundwater also occur elsewhere in the Peninsula.

Areas of water with high chloride concentrations occur in several areas. Water with chloride concentrations of 1000 to more than 3000 mg/l occur at the western end of the Peninsula, along the southwest coast (near Jaffna) and northeast coast (near Point Pedro). Other, more local, areas of high salinity ranging from 500 to 2000 mg/l of chloride occur adjacent to the Uppu Aru Lagoon and the western part of the Thondaimanar Lagoon in an area (including) the lagoon of about 100 square miles. The areas of higher salinity generally occur in the proximity to bodies of saline water where the pumping of wells has caused upward movement of the lower boundary of a thin freshwater lens. Areas of salinity or those apt to be saline in the dry season amount to 23% of the total area.

A comparison of the salinity distribution map with that indicating the total estimated draw-off shows that a large area of the Peninsula is not exploited on any extended scale. Increased extraction from these areas should be possible such as, for instance, in the zone free from salinity in the centre of the Peninsula, where only 10,000 acre feet of water were drawn off from about 62,400 acres. In the eastern part of the Peninsula, in the Pallai sandy region, only 600 acre feet were drawn off in about 70,000 acres. In the islands, about 3,300 acre feet were extracted from about 12,000 acres. These rates, ignoring the Pallai area, vary from about one sixth to one fourth of an area foot per acre.

In the saline areas of about 12,450 acres, the estimated draw-off is 6,350 acre feet or about half an acre foot per acre. It becomes evident then, that these saline areas indicate a certain degree of over-extraction.

The above was computed on the presumption that the draw-off from an agricultural well is 1.5 acre feet per annum and from a domestic well 0.3 acre feet per annum.

The results of the regular monitoring of shallow wells by the Irrigation Department suggest a possible answer to the question of high salinity in the freshwater lens on the Jaffna mainland. Towards the end of the most severe drought for 20 years or more, and January 1976, after a monsoon carrying 1250-1400 mm (49.55 inches) of rainfall, 50% of which have infiltrated the main groundwater body. At numerous locations, which in August 1975 were experiencing salinity in the range of 50-300 ppm Cl, there were substantial increases by the end of the monsoon. It would thus appear that under a certain sequence of climatic conditions, the teachings of salts accumulated in the soils during prolonged irrigation with groundwater can be the cause of deterioration in the quality of the freshwater lens. No other explanation seems possible.

The extent of the build-up of groundwater salinity by such a process will depend primarily on the amount and sequence of infiltration (recharge) during successive Maha seasons and the rate of consumptive use of irrigation water. The latter, in turn, will depend on the types of crops grown, the potential evaporation, and the amount of inter-monsoonal rainfall. If we assume, for the sake of argument, that rainfall contains, on average, 20 ppm Cl and the shallow groundwater initially 50 ppm Cl, we can examine the salinity build-up in the groundwater system under simplified rainfall/ infiltration regions. Using many simplifying assumptions and estimates of the actual excess rainfall, a calculation for the period 1972 to 1975 can be made (see Table VII). The potential rate of build-up of salinity in the freshwater lens due to this mechanism is clearly established.

TABLE - VII

Hypothetical calculation to show potential build-up of salinity in groundwater recharge from irrigated land in Jaffna during 1972-75.

Year	Season	Rainfall		Irrigation Water		Ground Water Recharge	
		Inches	Cl ppm	Inches	Cl ppm	Inches	Cl ppm
1972	Yala	12	20	24	50	-	-
	Maha	26	20	-	-	9	220
1973	Yala	10	20	26	220	-	-
	Maha	27	20	-	-	8	800
1974	Yala	8	20	28	800	-	-
	Maha	16	20	-	-	0	-
1975	Yala	16	20	21	800	-	-
	Maha	52	20	-	-	32	1280

(Source: Water Resources Board, Jaffna.)

It should however be recognized that such build-up will only occur under the relatively small proportion of the land (about 10%) used for irrigated agriculture and that the infiltration through home gardens and wasteland should provide dilution. The situation in the paddy-growing areas (all non-irrigated) is less clear; where the water table is very shallow, it is possible that salinity build-up may occur naturally as a result of capillary rise and evaporation.

An additional contribution to the problem of salinity in the freshwater lens unquestionably must result from the very large number of septic tanks used for effluent disposal. An aquifer such as the Miocene limestone of Jaffna, when covered by only a thin mantle of permeable soil, must always be vulnerable to pollution from a variety of sources at the land surface. This will also include fertilizers and agrochemicals. Since very few full water analyses have been carried out on Jaffna groundwaters, it is impossible to assess the current extent of any such pollution. Analysis of the nitrate concentration in the pumped supplies from the Kondavil and Thirunelvely sources carried out gave values of 15 and 23 mg/l NO_3 and N, respectively: the corresponding values for Cl being 252 and 112 ppm. These nitrate levels are high, and it would be wise to undertake a more comprehensive chemical and bacteriological analysis of selected Jaffna groundwater supplies in the future from a public-health point of view (discussed in greater detail later in this report).

The widespread increase in the salinity of pumped water supplies from shallow wells since 1973 is, then, probably attributable in the greater part to salinity build-up in increasingly intensified irrigated agriculture during an unusually extended drought. Locally, however, especially in the areas of most concentrated groundwater abstraction, there is likely to have been some diminution in the thickness of the freshwater lens and up-coning of the saline water interface and transitional zone of brackish water.

Some indication of the extent of up-coning can be gained from the limited investigations undertaken at the Kondavil and Thirunelvely stations in 1976, clearly show the salinity of the groundwater pumped from the central well is considerably higher than that occurring in the corresponding depth range in observation bore-holes at lateral distances of only 100-125 m (330-410ft.). The investigations also reveal well-defined flow zones in the observation boreholes at both sites, identified by inflexions in the EC log and constantly fluctuating EC values. It would appear that the up-coning of higher EC values from one or more of these horizons in the immediate vicinity of the pumping well is the most likely origin of much of the salinity of the pumped water supplies. More observation boreholes would, however, be required to prove unequivocally that this was the case.

G. GROUNDWATER RECHARGE AND STORAGE

The recharge to groundwater in the Jaffna Peninsula is almost entirely from rainfall percolation; any significant contribution by lateral percolation from the basement is very unlikely. The behaviour of the groundwater table during the years 1965, 1966, 1967, and 1968 to January 1969 was computed by Arumugam (1970) and the results obtained are shown in Table VIII and in Fig. 13.

TABLE – VIII		
Rainfall and Recharge		
Period	**Rainfall**	**Recharge in ac. ft.**
Sept. '64 - Jan. '65	22 inches	50,000 (estimated)
Sept. '65 - Jan. '66	40 inches	90,000 (computed)
Sept. '66 - Jan. '67	36 inches	73,000 (computed)
Sept. '67 - Jan. '68	62 inches	177,000 (computed)
Sept. '68 - Jan. '69	27 inches	77,500 (computed)

(Source: Arumugam, 1970)

It is presumed that the groundwater storage is dependent on rainfall over the preceding past few months. However, the rainfall during the past month will have a much greater effect on the storage than the previous month and so on.

Arumugam has calculated what may be called the "Weighted Average Rainfall" for a particular month. This is obtained by multiplying each of the past few months' rainfalls by a geometrically diminishing coefficient, i.e., the value of the coefficient decreases as we go backward in time.

If m_t = weighted average rainfall for month t

and r_t = actual rainfall in month t

then $m_t = a_1 r_t + a_2 r_{t-1} + a_3 r_{t-2} + ... + a_n r_{t-n+1} + ...$

If the coefficients a_1, a_2, etc., from a geometric series, i.e., (each coefficient after the first is a constant fraction of the preceding coefficient), then m_t is an exponentially weighted moving average, and the sum of a_1, a_2, a_3, etc., up to infinity, is one.

By trial and error, a suitable series for "a" is,

$a = 0.3$, $a_2 = 0.21$, $a_3 = 0.147$, etc.

so $m_t = 0.3 (rt + 0.7 r_{t-1} + (0.7)^2 r_{t-2} + \dots)$

similarly, $m_{t-1} = 0.3 (rt_{-1} + 0.7 r_{t-2} + (0.7)^2 r_{t-3} + \dots)$

therefore $m_t = 0.3 r_t + 0.7 m_{t-1}$

To convert rainfall in inches to groundwater storage in acre feet, the find by comparison with the plotted values that a suitable multiplying factor is 1.25×10^4.

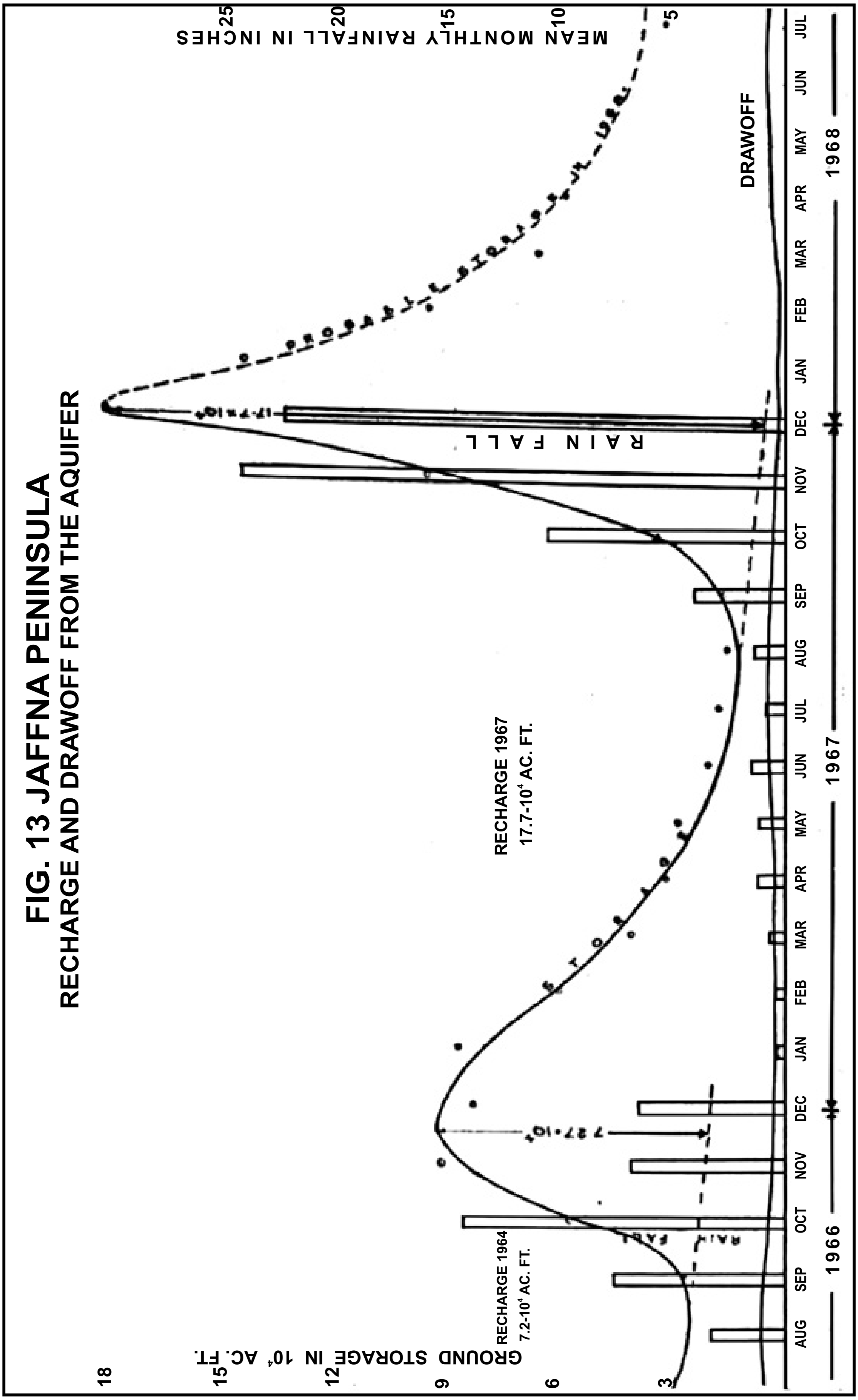
Therefore, groundwater storage in month t in acre feet

$= 1.25 \times 10^4$ (weighted average rainfall to month t in inches)

$= 1.25 \times 10^4$ (0.3 x rainfall in month t in inches + 0.7 x weighted rainfall to month (t-1))

The curve obtained from the above formula is shown in Figure 13.

FIGURE 13 - Jaffna Peninsula – Recharge and Draw-Off from the Aquifer



SOURCE : ARUMUGAM 1967

This formula has an empirical relationship derived from data obtained for the past four years. It attempts to estimate the groundwater storage in any month based on the actual rainfall figures of the previous few months. It can also be usefully used to predict groundwater storage during the next few months assuming of course that subsequent rainfall will be close to the long-term average. Groundwater contours enable the computation of the volume of water stored in the aquifer above mean sea level each month and assuming a storage co-efficient (effective porosity) of 0.15. The porosity of the Jaffna limestone has been found to vary between 4.5% and 27%, with a mean value of 15%. Thus, we get the results shown in Table VIII.

This computation has limitations for the following reasons.

1. Taking Jaffna Peninsula as a whole in one unit itself is a major drawback as this area is composed of three land masses and different aquifer characteristics (details given in previous discussion).

2. The level of the water table in the well was measured by tape from the benchmark established on top of the well apron. This method of measurement of levels is erroneous and can result in significant variation from the true value. However, considering the measurement from all the observation wells, the errors may partly compensate or can have a cumulative effect.

3. Measured water levels are not always representative of water table elevations. During the rainy season the wells are for the most part not pumped. Rainfall will temporarily create a water level greater than that of the water table because of the time required for the well water to flow out to the water table and restore equilibrium. On the other hand, during the dry season the consistent intermittent pumping lowers the water level below the actual level of the water table so that an equilibrium condition is rarely achieved.

4. It is apparent that only the water storage increase by the rise in water table level above mean sea level was considered. In these cases, a water table rise is followed by freshwater/seawater interface decline, which could be of the order of 40 times the water table rise, but in the actual situation it is much lesser magnitude because of the time lag in the response of the depression. However, whatever the magnitude of the depression of the interface it undoubtedly does add significantly to the freshwater storage volume and so the actual recharge was considerably greater than calculated.

5. The computation of the volume of water stored in the aquifer each month assuming a storage co-efficient (effective porosity) of 0.15 is considered to be a higher value. In other words, the porosity of the Jaffna Limestone was found to vary between 4.5 and 27% with a mean value of 15% but the formation and structure of limestone vary from place to place in the Jaffna Peninsula and hence, considering a mean value for the whole Peninsula has its limitations.

REFERENCES

Angie, C.M. : Groundwater Investigation in Ceylon, *UNESC/ECAFE Water Resources Series 33,* New York, 1967.

Arumugam, S. : Development of Groundwater and its Exploitation in the Jaffna Peninsula. *Institution of Engineers, Ceylon, Transactions*, 1970.

Brown, R.H., Konoplyanster, A.A., Inesonj., Kovalevsky : U.S. Groundwater Studies - An International Guide for Research and Practice, UNESCO, Paris, 1972.

Campbell (M.D) and Lehr (J.H.) : Water Well Technology, McGraw Hill, 1973.

Chorley, R.J. (Ed.) : Water, Earth, and Man. Methuen, 1969.

Davis, Stanley N., and De Wiest Roger, J.M. : Hydrogeology New York, Wiley, 1970.

Fernando, A.D.N. : The Groundwater Resources of Sri Lanka, Planning Division of the Ministry of Power and Highways, Sri Lanka. 1973;
Use of Aerial Surveys in the Investigation for Groundwater in Ceylon, *Transactions, Ceylon Association for the Advancement of Science*, 1968.

Foster, S.S.D. : The Problem of Groundwater Quality Management in Jaffna - Sri Lanka - (Unpublished Report), U.K. Ministry of Overseas Development, 1976.

Frink, John W. : Groundwater Conditions in Ceylon, Unpublished Report of the United States Operations Mission to Ceylon, 1958.

Furon, Raymond : The Problem of Water (Translated by Paul Barnes) – a World Study, Faber & Faber Ltd., 1963.

Goldberg, G.F.A. : Assessment of Groundwater Potentials in the Republish of Sri Lanka, Regional Mineral Resources Development Centre Advisory Service Report (Unpublished) HG 2, 1974.

Gunasegaram, T. : Groundwater Potential and Saline Water Intrusion in the Limestone Aquifer - Northwestern Zone - Jaffna Peninsula. Unpublished, 1978.

Hari Narain, Raghava Rao, K.V., Balakrishna, S. (Ed.): Exploration Techniques for Groundwater, Proceedings of a Workshop Organized by COSTED, Electron Printers, Bangalore. 1977.

Henry, H.R. : Interfaces Between Saltwater and Freshwater in Coastal Aquifers, USGS Water Supply Paper 16130, Washington D.C. 1964.

Hubbert, M.K. : The Theory of Groundwater Motion, *Journal of Geology*, Vol. 48, No. 8, pp. 785-944, 1940.

Huisman, L. : Groundwater Recovery, Mac Millan, 1972.

Ionides, M. : Shall We Run Short of Water Supply? *Ekistics,* pp. 254-9, Jan. 1977.

King, F.H. : Principles and Conditions of the Movements of Groundwater, *U.S. Geol. Survey 19th Annual Report,* pt. 2, pp. 55-294, 1899.

Kularatnam, K. : Geology and Water Supply in the North, 1964.

Linsley and Franzini : Water Resources Engineering, McGraw Hill, 1964.

Mather, J.D. : Development of the Groundwater Resources of Small Limestone Islands. *Q. J. Eng. Geol.* 8; 141-150, London, 1975.

Mahadeva, S. : The Hydrology of Jaffna with Particular Reference to the Jaffna water supply, *The Engineering Association of Ceylon, Transactions,* 1938.

Meinzer, D.E. : Outline of Groundwater Hydrology with Definitions, *U.S. Geological Survey Water Supply paper* 493. 1923.

Meisler, Harold : Groundwater in the Jaffna Peninsula - Republic of Sri Lanka (Unpublished Report), U.S. Geological Survey Report, 1977.

Nace, R.L. : Water Management Agriculture and Groundwater supplies, *Geological Survey Circular 415*, Washington D.C. 1964.

Rose, C.W. : Agricultural Physics, Pergamon Press, 1966.

Seniveratna, L.K. and Balendran, V.S. : Hot Springs of Ceylon, *Ceylon Association for the Advancement of Science Transactions,* 1968.

Sirimanne, C.H.L. : Ceylon's Water Resources and their development, *Journal, Soil Conservation Society of Ceylon*, 1962; Ceylon's Groundwater Resources, *Report of the working group on* Irrigation *and Land Development*, 1964.

Sirimanne, C.H.L and Vaidya, G.D. : The Occurrence of Groundwater in Ceylon, Proceedings of the Symposium on Groundwater, India, Central Board of Geophysics, Pub. No. 4, pp. 95- 108, 1958.

Teerink, John R. : Water Quality Pollution and Sea Water Intrusion Problems, Governors Dry Year Water Conference, Los Angeles, July 13, 1961, Mimeograph

Thevathasan, L.R.A. : Drilling for Groundwater, *The Institution of Engineers, Ceylon Transactions,* 1967.

Todd, David, K. : Groundwater Hydrology, John Willey & Sons. Inc. New York and London, 1959.

Tolman, C.F. : Groundwater, McGraw Hill, New York, 1937.

Wentworth, C.K. : The problem of Safe Yield in Insular Ghyben-Herzberg Systems, *Translations, American Geophysics,* Union 2, 739-742 Washington D.C. 1951.

Wijesinghe, M.W.P. : Underground Water Resources of the Jaffna Peninsula and the Islands, Unpublished Report in the Files of the Irrigation Department Jaffna 1975; Planning of Groundwater for Irrigation in Sri Lanka. Proceedings of the Second World Congress on Water Resources, New Delhi, India. 1975.

Wisler C.O. and Brater E.F. : Hydrology, John Wiley & Sons, 1959.

V. INTENSIVE STUDY AREA - NORTH WESTERN ZONE OF THE JAFFNA PENINSULA

The scope of this chapter is to furnish in detail the field data and analysis of the investigation in a particular zone of the Peninsula to show how the groundwater conditions occur in the entire study area.

The Northwestern region of the Peninsula was selected for this intensive study and detailed investigations since the above zone is characterized by numerous freshwater springs and saline water intrusion fronts. This region is approximately defined by a boundary through Moolai, Chankanai, Sandilipay, Chunnakam, Navakiri, Thondaimanar, and the North Coast. The area is approximately 55 square miles in extent and a well field of 725 was selected on an appropriate grid system, having a well field of 16 wells per square mile. Thus, the important geohydrologic features such as groundwater mounds, extensive sub-surface karst zones, main recharge-discharge zones, detailed geologic aspects of the aquifer, and areas of lateral saline water intrusions were encountered for detailed study and evaluation of data. The primary purpose is to establish as accurately as possible the state of balance between the groundwater replenishment and abstraction practices in the area to provide a comprehensive basis for the future management of this valuable resource.

From the investigations carried out so far from August 1973 to December 1976, it is now possible to describe the cause and extent of saline intrusion in some detail and the possible danger in the future. However, the investigations carried out by the Water Resources Board and the data available with them have the following deficiencies:

1. The few deep boreholes drilled for conductivity logging and depth sampling were non-effective, except for three or four holes, as they had collapsed or had been tampered with by the public. This curtailed the detailed investigation that was to be carried out to study the behaviour of the interface in the aquifer. It is therefore currently not possible to determine precisely either the location or the movement of the saline water interface through a time sequence of hydrological conditions.
2. There had been no actual records of abstraction figures available, and the abstraction data made use of in this chapter had to be obtained from the owners of private wells through field surveys of the entire intensive study area.

These data deficiencies would have to be satisfied before any major changes in the groundwater abstraction regime, or planned management of the resources could be enforced.

A. GEOLOGICAL AND HYDRAULIC CHARACTER OF THE AQUIFER

Jaffna Peninsula is split into three major land masses by the internal lagoons, namely Uppu Aru, Thondaman Aru, and the Elephant Pass, all of which open out to the sea. The upper surface of the Miocene limestone generally crops out in the east of the intensive area to an elevation of 25 to 30 feet above mean sea level. The upper surface of the limestone in the west of the area is in an elevation of 5 to 15 feet above mean sea level (see Fig. 16). The limestone is locally covered with a thin mantle of excessively drained latosol, approximately to a depth of 3 to 5 feet in the east of the area and 5 to 10 feet in the west with imperfectly drained clayey brown latosol (see Fig. 17)

The limestone of the intensive area comprises a varying sequence of highly decomposed and highly compact white limestone with a maximum vertical depth of 400 feet (as per Pallai drill hole), distinctly bedded and well jointed, often extensively karstic in the region of 2 to 4 feet above mean sea level. While there are some vertical variations in the physical properties of the limestone, both weathering and the presence of secondary structures may have induced modifications.

The extensive karst topography of the aquifer possesses very high porosity than its stratigraphic equivalents in the Mannar and Vannathavillu formations. Both flow and storage of groundwater in the saturated zone must be a factor of the physical discontinuities of the limestone mass, with fracture and Karst enlarged locally by solution.

FIGURE 14 - Intensive Area – General Geological Structure of the Limestone

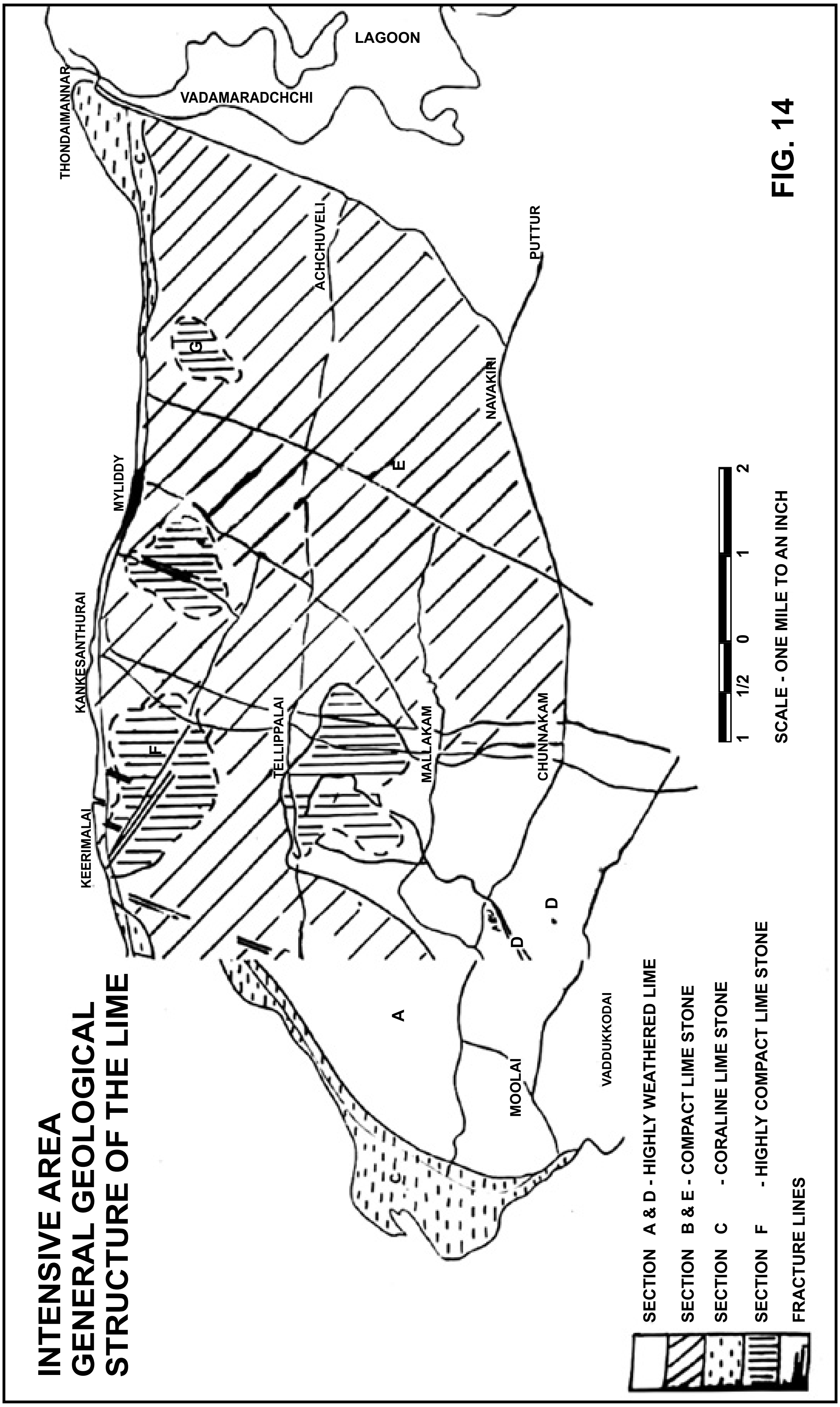


FIGURE 15 - Upper Surface Limestone Contour Map

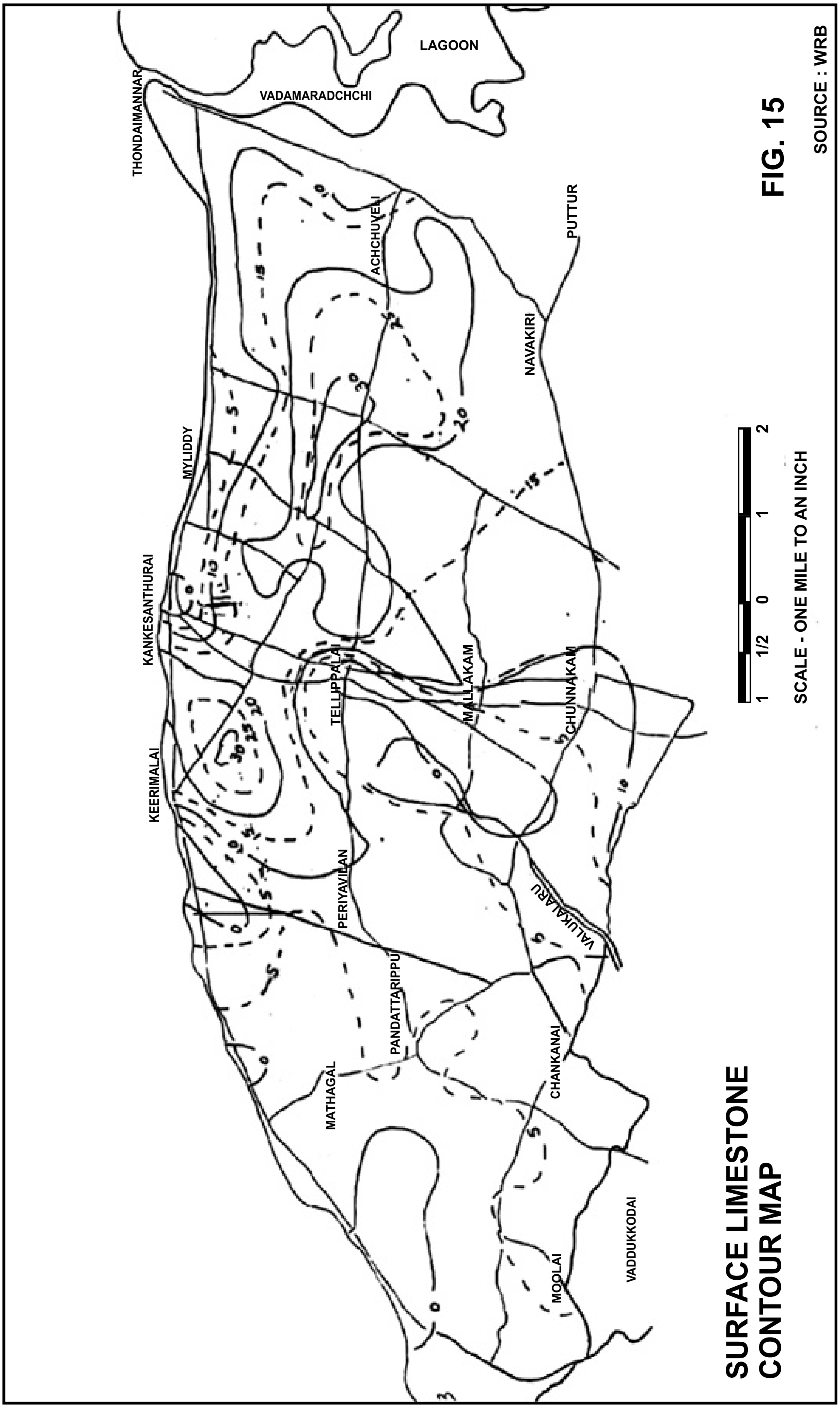


FIGURE 16 - Intensive Area – General Ground Contour Map

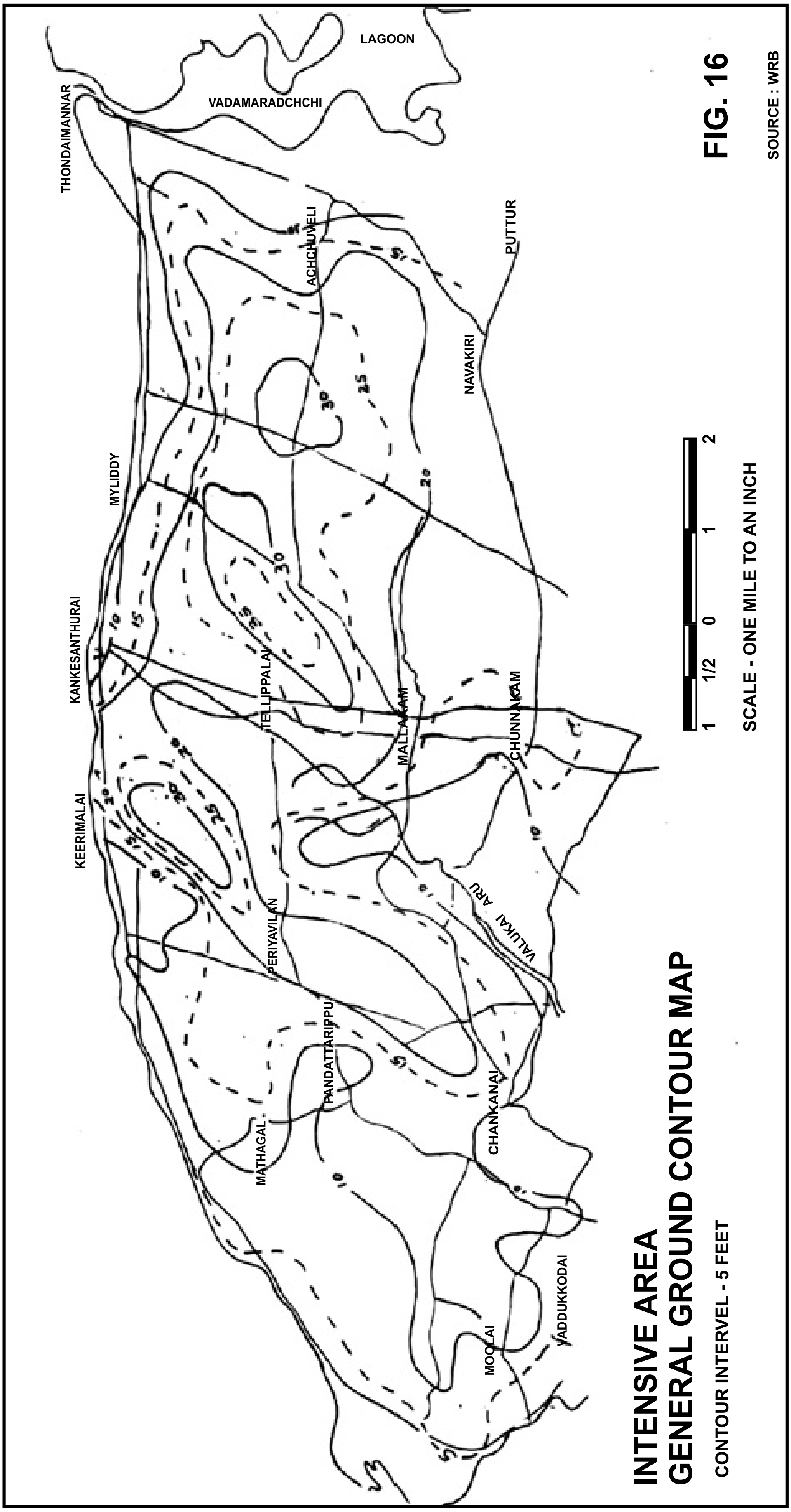
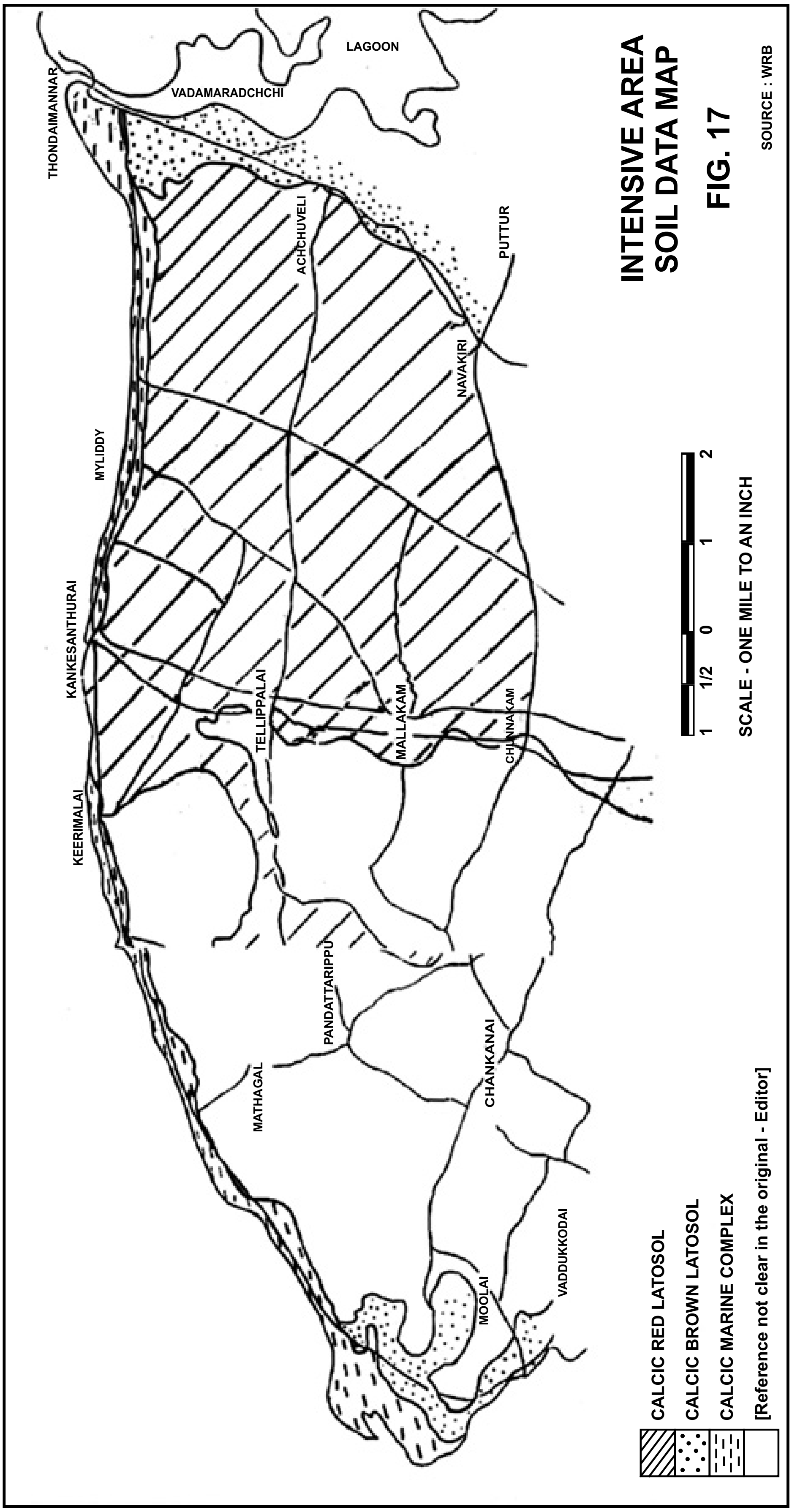


FIGURE 17 - Intensive Area – Soil Data Map



Based on field observations of the topography, limestone structure in the shallow wells of the area, core sample of a few deep boreholes, and the monthly water table maps, a general geological structure of the limestone in the intensive area had been evaluated. From the above data collected, there appears to be an evident disparity in the limestone structure of the intensive area. The east of the area appears to be of fine to coarse-grained white limestone, highly compact, with high permeability, high specific yield, with many fissures and karst, mostly above 2 to 3 feet mean sea level. West of the area appears to be composed of weathered and highly weathered limestone (chalky) when compared to the limestone of the east. The dividing section of the disparity zones of the limestone structure of the area appears to be approximately along the Jaffna-Kankesanthurai Road (south to north). It is interesting to note that the dividing boundary of the limestone structure appears to be the same boundary dividing the soil structure in the overburden above the limestone. The northern coastal belt from Moolai to Keerimalai and from Myliddi to Thondaimanar appears to be composed of coralline limestone to a distance of approximately a quarter of a mile inland from the coastal edge, covered with a thin mantle of calcic marine compels soil as overburden. In the central portion of the area and in a few isolated spots, there appears to be a composition of very highly compact limestone with low horizontal and vertical permeability portraying a very low specific yield. The fracture pattern and karst in the east section of the limestone appear to be in the direction of south-east to north-west, and in the western area appear to be from south-west to northeast and east to west.

FIGURE 17a - Intensive Area Water Level Contours Map - August 1975

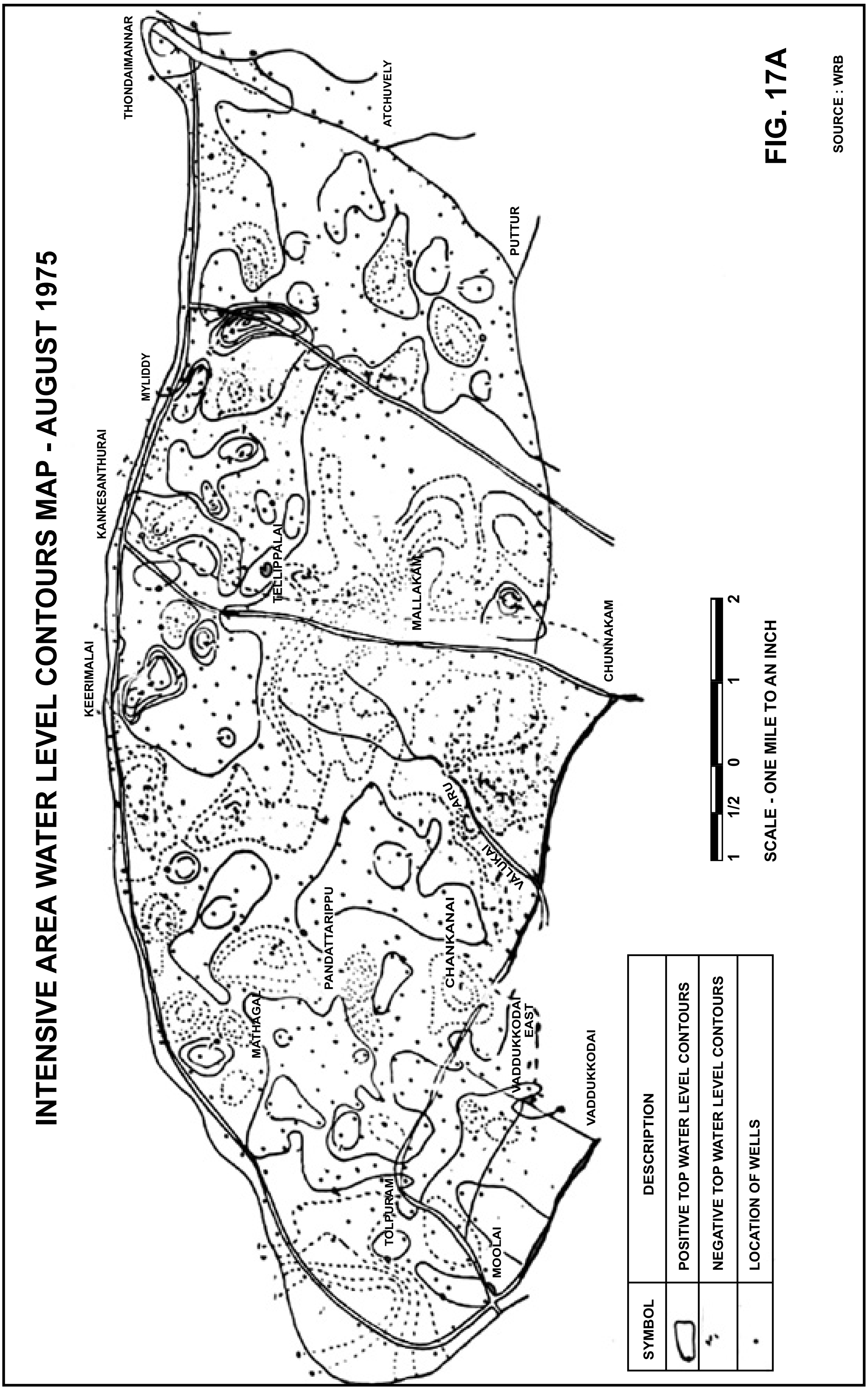
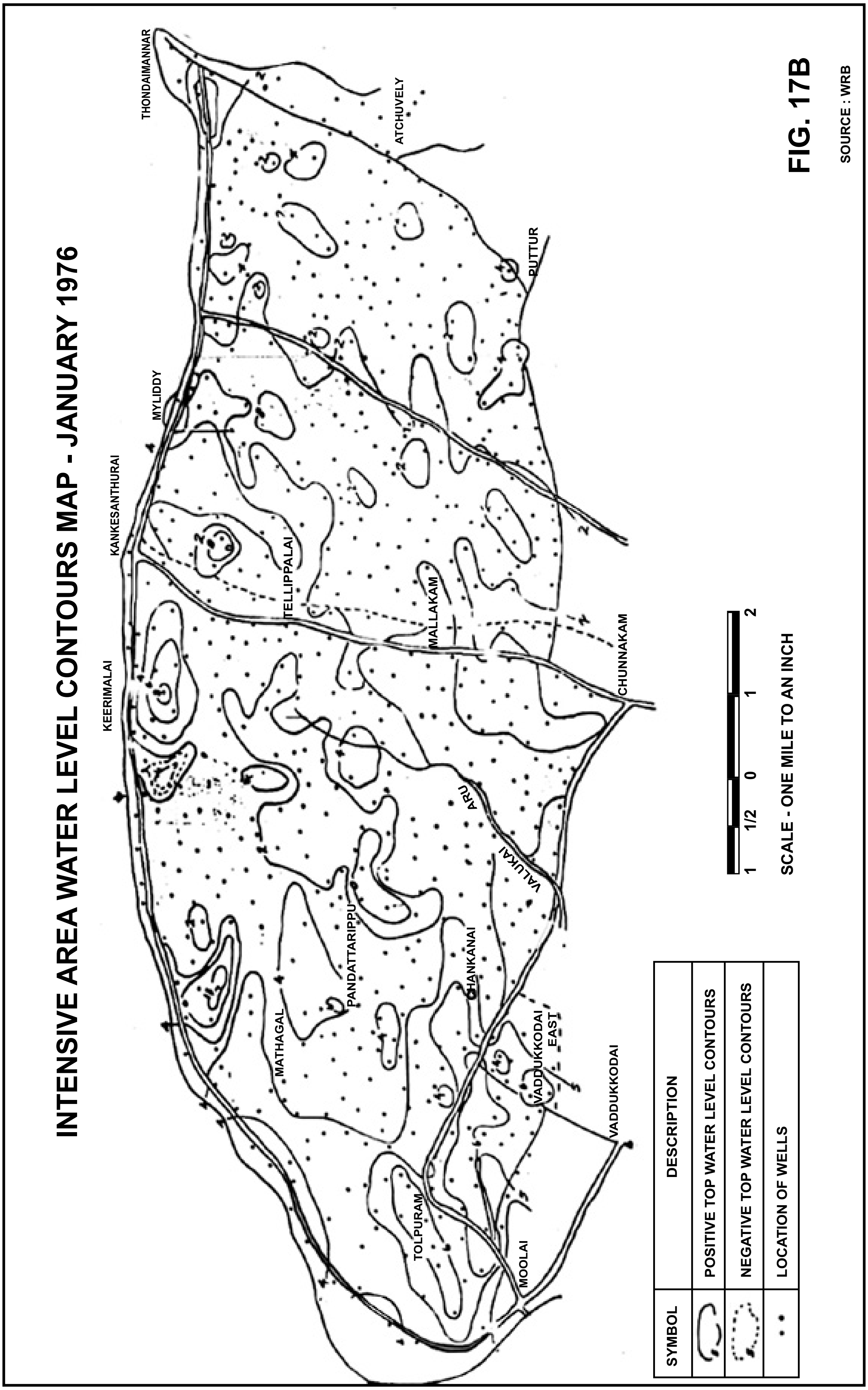


FIGURE 17b - Intensive Area Water Level Contours Map - January 1976



B. HYDRAULIC CHARACTER OF THE WATER TABLE

Water table fluctuations were observed by the Water Resources Board on the 1st and 15th of each month from the selected 725 shallow dug wells of the intensive area. The investigations commenced in August 1973 and continued until the end of December 1976. The monthly variation of the water table in the saturated aquifer was processed from the water table contour maps. The observation well density of around 16 wells per square mile gives a clear picture of the hydraulic character of the aquifer.

The occurrence of only a few scattered lenses of freshwater above mean sea level in the whole intensive area during the drought gives a clear indication of the hydraulic nature of the aquifer, its compactness and boundary parameters. The saturation and general recharge of the aquifer occurs during the period of October to January (N.E. Monsoon) by way of precipitation, with a slight recharge during the month of April, when the area experiences a very low rainfall.

The fresh groundwater is derived from precipitation, which infiltrates to the water table. Because of its lower density, this fresh groundwater will float upon the underlying saline groundwater, forming a lens-shaped body through the radial movement of freshwater towards the coast. Additionally, the thickness of a freshwater lens at any location is a function of the recharge, the distance from the coast, and the permeability of the aquifer. It is also possible that poorly permeable beach or lagoonal deposits may locally act as a cap rock and increase the thickness and areal extent of the lens. The variations in the aquifer permeability are probably more important, as seen from the investigations done than the other parameters in controlling lens thickness.

Figure 17b shows the areal extent of these few lenses in the month of January 1976. The areal extent of the above lenses is due to the heavy precipitation of 40 to 45 inches of rainfall. The thickness of these lenses above zero mean sea level varies from 4 feet to 8 feet above mean sea level. These lenses rapidly thin down to 3 to 4 feet above mean sea level in some areas of the aquifer during the drought months and to zero mean sea level in a major portion of the aquifer. This could be seen from all available groundwater maps. The occurrence of a few scattered lenses throughout the year is more or less confined to local areas of the general aquifer, giving the temptation to conclude that the above areas of the aquifer are less topographically karstic, have low transmissivity, and possibly less abstraction rates. The high permeability of a major portion of the zone of seasonal fluctuations can be attributed to preferential solutions increasing the karstic conditions of the aquifer, and its areal uniformity probably indicates that solution and flow had been concentrated on horizontal discontinuities in the directions southwest to northeast and southeast to northwest. A major portion of the flow could be possibly towards the north coast.

The east of the area is found to get saturated up to 2 to 3 feet above mean sea level, whereas the west of the aquifer gets saturated to 6 to 8 feet above mean sea level. There is an evident disparity in the saturation zones of the aquifer in this area. In general, the water level depletes to zero to 1 foot below mean sea level during the dry months, except for the few lenses mentioned earlier. The east and west of the aquifer appear to be having different permeability coefficients. In the central portion of the aquifer, between Mallakam and Tellippalai, the water table tends to be at a very low elevation. The water level is in the region of 8 to 10 feet below mean sea level during the major part of the year. This forms an unusual depression in the aquifer and appears to be a localised condition of the aquifer. The only evaluation that could be arrived at for this localized hydraulic character of this aquifer is that the limestone in this region could be very compact, less karstic with very low horizontal and vertical transmissivity, low specific yield, and possibly heavy abstraction area.

In general, the hydraulic character of the aquifer is such that due to its karstic topography and high permeability in a certain region of the aquifer, it cannot hold for long all the groundwater storage during and immediately after the monsoon. The water-retaining capability of the aquifer is limited. In the long term, all the recharge water infiltrating the lens must be discharged into the sea at its margin. Otherwise, the lens would continue to grow in extent year by year. Under natural conditions, the limestone aquifer appears to have been discharging in numerous sizeable springs all along the north coast. It is most likely that there could be some offshore springs at shallow depths of the sea bed, which could contribute to the depletion of the groundwater during and immediately after the monsoon. A detailed investigation and study were carried out along the north coast during and immediately after the northeast monsoonal rains, and innumerable springs were seen along a certain stretch of the north coast, discharging 1 foot below mean sea level to 4 feet above mean sea level.

From the month of November to January, springs at a level of 4 feet above mean sea level could be seen to discharge freshwater between a stretch of one-and-a-half-mile distance, from Keerimalai to Kankesanthurai. However, these springs disappear by mid-January and do not seem to discharge at any level below 3.50 mean sea level or above, except the spring at Keerimalai, which is at an elevation of 1 to 2 feet below mean sea level. Between Kankesanthurai and Myliddi, freshwater could be seen bubbling up from the sea bed at an elevation of 1 foot below mean sea level, even during the dry months. The only places where perennial springs could be observed are Keerimalai and Myliddi. The rest of the springs disappear with the monsoon. A reconnaissance survey and study of the springs and their discharges were carried out at Keerimalai and other places along the north coast. The discharge data in Figure 12 indicates the size and nature of springs along the north coast. This evaluates the fact that irrespective of the heavy rainfall and recharge, the aquifer discharges all the temporarily stored water through the numerous springs, until a state of balance occurs in the saturated aquifer. Considering that the spring discharge and abstraction remain constant during a particular hydrological cycle, the storage of the aquifer under this state of balance should be constant. The state of balance in storage is disturbed if the rate of abstraction is increased or the rate of discharge is reduced through the springs. At present, the state of balance in the aquifer storage is in the region of 1000 ac. ft. Above the mean sea level, irrespective of heavy rainfall, within the four hydrological cycles of observation. But at the moment, the state of balance in the aquifer storage below the mean sea level cannot be established due to insufficient data in hand. However, it appears that the water-holding capability of the aquifer is limited at present. During the four hydrological cycles of investigation, the year 1974/75 experienced a very low rainfall of 25 inches when compared to the rainfall of 42 to 50 inches during 1973, 1975, and 1976. Still, it could be seen that the state of balance in groundwater storage above the mean sea level had been in the range of 1000 ac. ft. during 1974/75. But there was a general depletion of the water table and salinity intrusion on a regional basis during the year 1975 due to the low precipitation in 1974.

The sub-surface water divide between the natural discharge area and groundwater flow (potential area of spring discharge) gradient could be established approximately from groundwater contours at any particular period, in addition to that flowing towards heavy abstraction areas. A general water divide for the springs and the flow directions of major flow paths were evaluated for the intensive area (see Fig. 12). Under maximum storage conditions, the hydraulic gradient was from northeast to southwest and southwest to northeast. Under minimum storage conditions, the hydraulic gradient was from west to east and northeast to southwest, which appears sufficient to satisfy the heavy extraction in the western portion of the aquifer. This occurs as a result of the expansion of the cone of depression associated with increased abstraction from groundwater storage in the area of heaviest development.

It is most important to recognise that sub-surface flow lines determined largely as a result of existing groundwater development (and possibly existing over-development) are not a suitable basis for the discussion and evaluation of the resources.

C. REGIONAL HYDROLOGICAL SYSTEM

While the seasonal rainfall exhibits a definite rhythmic pattern, there is, however, considerable variation in it from year to year. This variability of rainfall has always been a major hazard in agricultural enterprises on the Peninsula. The worst dry season since 1899 was recorded in 1918, when there were only 2.33 inches of rainfall from March to September. The poorest annual rainfall so far recorded for the last 95 years was in 1963, during which year there were only 24.6 inches of rainfall, which is only 50% of the long-term average.

The overall hydrological regime is determined by the regional rainfall, which in turn controls the storage of the aquifer depending on the geological formation of the aquifer concerned. The position of the permeable limestone, its confining beds, and the location of the recharge/discharge areas of the aquifer is controlled by the geological formation. Thus, the regional rainfall and the geological formation are two vital factors for the proper assessment of groundwater storage and planned management of the available resource.

The geological formation of a particular aquifer remaining nearly the same, the rainfall is the only variable factor involved in the proper assessment of the groundwater storage. The regional rainfall contributes a lot to the groundwater storage, and hence the study of the hydrological regime of the Peninsula forms the basis criterion for the planned management of the resources.

D. ASSESSMENT OF GROUNDWATER RECHARGE

Clearly, in an area of heavy development of groundwater resources, the assessment of the rate of groundwater recharge is of critical importance. Nevertheless, its determination as a long-term average or for individual years presents formidable problems. The bulk of the total groundwater recharge in the Peninsula originates from the infiltrating rainwater. The standard average for the period 1911 to 1940, as appearing on the report of Colombo observatory, is just under 52 inches. Unlike temperature and other climatic parameters, rainfall does show moderate seasonal differences. Any significant contribution by lateral percolation from the basement is most unlikely.

The water table oscillations of the saturated zone of the limestone aquifer, in relation to the rainfall and its depletion during the dry season, have been analysed from the groundwater table contour maps of this particular zone. The behaviour of the groundwater table during the years 1973, 1974, 1975, and 1976 enables the computation of the groundwater storage above mean sea level, and to study the variation of storage in relation to regional rainfall during each year of investigation. A long-term average recharge of the entire Peninsula in relation to the rainfall had been evaluated by Arumugam (1968) and Wijesinghe (1972). It is presumed that the storage figures arrived then for the volume of all water above mean sea level. But the fact remains that all groundwater storage above mean sea level is not freshwater (Any water whose quality is below 1000 p.p.m. is considered freshwater for storage computations in this Thesis), and all groundwater below mean sea level is not saltwater.

Hence, the storage computations for this 55 sq. mile area of the aquifer had been evaluated for freshwater above mean sea level only. All saline water above mean sea level had been omitted from storage. The volume of water stored in the aquifer was computed by way of integrating the increment layers of the saturated aquifer, as obtained from the water table contour maps of each month, with an assumption of a 10% storage co-efficient for the Jaffna limestone. It is evident that the maximum and minimum groundwater storage of the aquifer is during the months of January and August/September of a particular year. The maximum storage above mean sea level in January 1974 had been 15,840 ac. ft., which rapidly depleted to 3870 ac. ft. in February 1974. Approximately 12,000 ac.ft. of freshwater above mean sea level had escaped from the aquifer to the sea within a period of 30 days. (In addition to an unknown quantity from storage below mean sea level). The rate of discharge is in the range of 190 cusecs. The major springs (see Fig. 12) seem to discharge about 100 cusecs during the above periods. Since there is very little abstraction during the month of January, the balance 90 cusecs appear to have been discharged through the numerous seepage points noticed along the northern coast within the first 15 days of January. The storage drops down from 3870 ac.ft. to 1260 ac.ft. from the month of February to August 1974. The storage depletion (above mean sea level) of 44 ac.ft. per day occurred during the above period. But an average discharge of 2 ac.ft. per day takes place through the perennial springs at Keerimalai and Myliddi. The balance of 12 ac.ft. of freshwater above mean sea level seems to have been abstracted during the period of 180 days in addition to the quantity of freshwater abstracted during the period of 180 days in addition to the quantity of freshwater abstracted from storage below mean sea level. An average of 170 ac.ft. of freshwater (above mean sea level) is being abstracted daily from the 55 sq. mile area, in addition to an unknown quantity of water from storage below mean sea level. The analytical drought of 158 ac.ft./day is definitely from the storage below mean sea level.

The question then arises as to the quantum of storage below mean sea level, and the safe quantum of storage required as dead storage in the aquifer to keep the saline interface well away from causing any detrimental effects to the aquifer. Unfortunately, investigations could not be carried out to assess the actual storage below mean sea level during the above period of investigation.

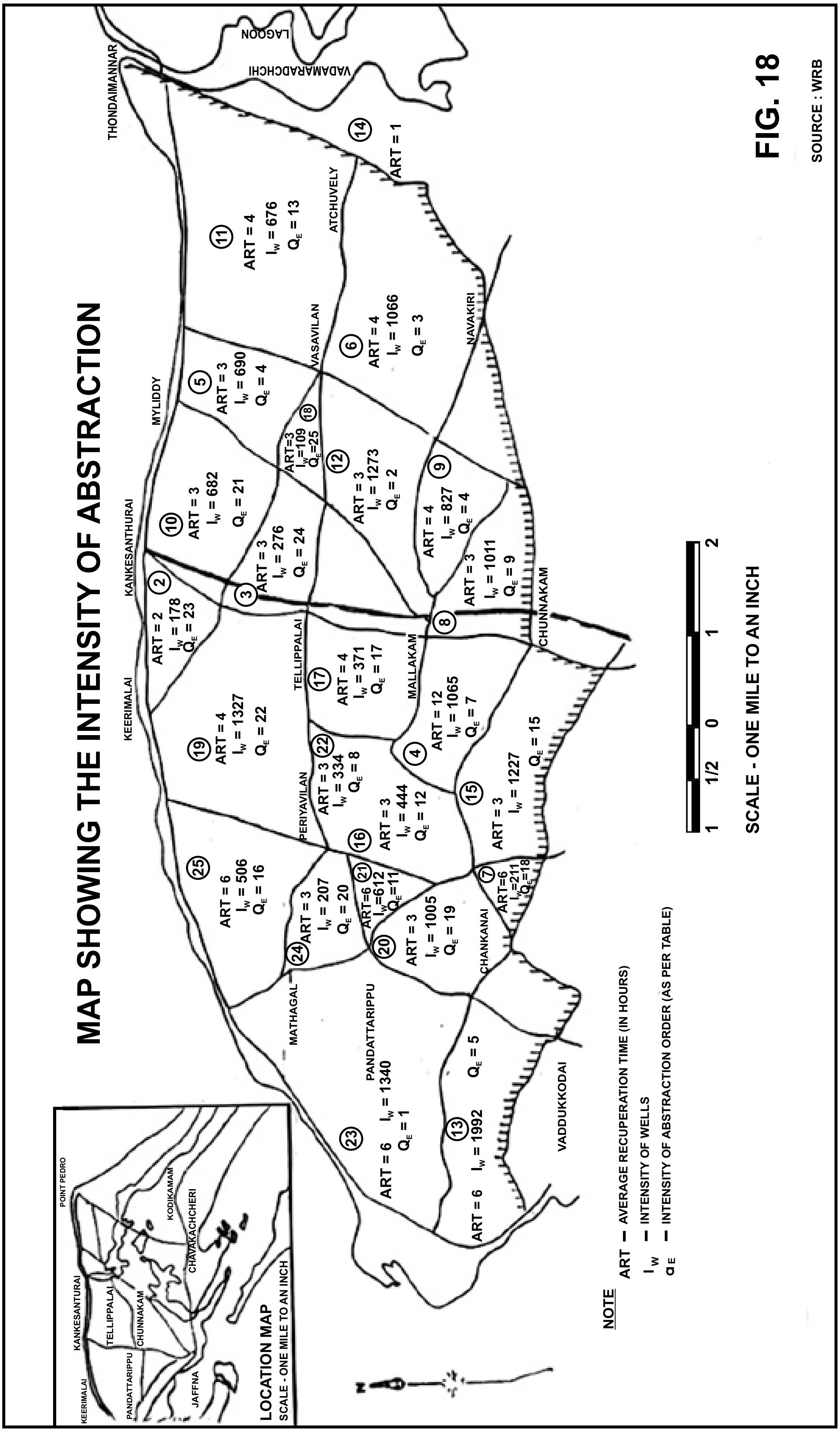
The maximum storage during January 1975 had been 5100 ac.ft., which depleted to 1700 ac.ft. in April 1975. From the above data, it is evident that comparatively, there had been very little discharge and depletion during 1975 than during the same period in 1974. The year 1974 experienced a very low rainfall of 22 inches (average) when compared to the rainfall of 42 inches during the year 1973. The year 1975 experienced a low recharge of the aquifer due to the North-East Monsoon of 1974 and hence the cause for regional depletion of water levels and rise in salinity of water on a regional basis during the year 1975. However, it is very interesting to see that the storage above mean sea level during the month of August 1975 had remained at 920 ac. ft, when compared to 1200 ac.ft. during August 1974. Also, it is very interesting to compare the storage value of the year 1976. There had been 52 inches of rainfall during North-East Monsoon of 1975, approximately 10 inches and 31 inches more than the rainfall in the years 1973 and 1974, respectively.

The maximum storage in January 1976 is in the range of 12,138 ac.ft., when compared to 15,840 ac.ft. and 5100 ac.ft. during the years 1974 and 1975 respectively. However, the storage had depleted to 920 ac.ft. in August 1976, being the same storage (above mean sea level) in August 1973, 1974, and 1975. From the above, it is evident that the cumulative storage during the driest period of a year remains the same, irrespective of the intensity of the precipitation.

E. GROUNDWATER ABSTRACTION

In order to make the best possible assessment of the state of development of groundwater resources, it is essential to have accurate data on groundwater abstraction. At present, the groundwater users of the Peninsula are not required by law to measure their abstraction. A comprehensive survey of all domestic and agricultural wells, acreage of land cultivated, rate of average recuperation of the wells, types of crops cultivated, and total number of saline wells and freshwater wells were carried out by the Water Resources Board in this area to assess the actual quantum of abstraction done during a hydrological cycle of 12 months. Appendix VII gives the data in detail in accordance with Figure 18. From Appendix VII, it is evident that only 25% of the available land is being cultivated. Leaving another 25% for the purpose of residence, yet another 50% of the land is available for further development. The amount of freshwater abstracted in this area amounts to 46,000 ac. ft. during a hydrological cycle of 9 months. This amount appears to be an overdraft when compared to the storage above mean sea level. The overdraft amount is definitely from the storage below mean sea level. The above abstraction figures were obtained in 1976 and appear definitely higher than in 1973. However, no abstraction data is available for comparison.

FIGURE 18 - Map Showing Intensity of Abstraction



The following summary is derived from the abstraction table:

Extent of this intensive study area	35,000 acres
Extent of Agricultural land cultivated	9,000 acres
Total number of saline wells (in number)	6,143
Total number of freshwater wells	13,862
Total number of wells	20,005
Intensity of wells per square mile	363
Percentage of saline water wells	30
Total Annual domestic and Agricultural abstraction	46,000 ac.ft.
Average abstraction per well	2.3 ac.ft.

F. SALINE WATER INTRUSION

Where an aquifer is in contact with the sea, salinity layering will occur, with the more dense saline water generally occupying the lower levels of the formation. Under static conditions, there will be a relatively sharply defined interface with the overlying freshwater, the result of the hydrostatic equilibrium between the two fluids of different densities. Where large-scale abstraction occurs from a coastal aquifer, water levels will be lowered, and the interface will become shallower. Prolonged heavy abstraction may eventually create an overall landward hydraulic gradient, causing lateral encroachment of the saline water interface into the aquifer. Under dynamic conditions, the usefulness of the Ghyben-Herzberg relationship is limited. Moreover, a thick zone of mixing will normally develop through the intermingling of different waters as a result of both density and hydraulic gradients in vertical and horizontal directions.

In the west of this area, the situation is further complicated by the localisation of the freer points of hydraulic communication between the aquifer and saline water. Perhaps the most important of all is the stratigraphy of the limestone in the above area.

G. HYDRO-CHEMICAL INVESTIGATIONS TO ASSESS THE EXTENT OF SALINE INTRUSION

Detailed groundwater sampling was carried out monthly from the selected 725 wells by the Water Resources Board in this intensive study area to assess the following:

1. Total chloride contents in parts per million
2. Total hardness in parts per million
3. Total dissolved solids in parts per million

The sampling and chemical analysis gives an indication of the areal extent of saline water intrusion. It is, however, essential to recognize that the problem is dynamic and three dimensional and that there are major limitations for a two-dimensional approach. The data obtained from the above sampling and chemical analysis is summarized under three categories on par with international standards:

1. Freshwater zone with chloride contents below 500 p.p.m.
2. Moderately freshwater zone with chloride contents between 500 to 1000 p.p.m.

3. Brackish water zone with chloride contents above 1000 p.p.m.

Iso-chlor/acreage graph (see Fig. 19) was drawn monthly for the data thus obtained from the hydro-chemical analysis and Iso-chlor maps. The Iso-chlor/Acreage graph was evaluated to study the areal extent of saline intrusion in the intensive area. Between August 1973 and December 1976, the high salinity front had advanced only very slightly, but significant changes appear to have occurred in the shifting of the area of salinisation in relationship to the recharge. From August 1973 to August 1976, an area extent of 1000 acres had become saline, out of the 35,000 acres under investigation. Although the spatial distribution of chlorides was not determined by any data prior to 1965, the groundwater resources of the Peninsula have had regular chemical analysis carried out for the last 10 years. From the chemical analysis of the North-West zone from 1973 to 1976, both seasonal and long-term variations in chlorides can be identified (see Fig. 19).

The seasonal variation in salinity is characterised by rising chlorides during the drought and lower chlorides after the rains. The seasonal variation is only noticed in the west of the intensive area and along the north coast, which has an area extent of 13 square miles. Ironically, the above areas of saline intrusion have a different formation of limestone in comparison to the rest of the aquifer. In comparing the limestone structure (Fig. 14) and the saline intrusion area (see Fig. 20), it is evident that uniform lateral saline intrusion is mainly taking place in the highly weathered limestone areas (West) and along the coralline limestone belt, which is at a very low elevation when compared to the rest of the aquifer and acting as a homogenous mass. In addition to the lateral intrusion of salinity, there is a definite upconing of the interface due to fairly heavy abstraction practices in the above areas.

It is now evident that the cause for this lateral saline water intrusion is mainly due to geological conditions and heavy abstraction taking place in the above area. The state of balance between the saline intrusion and freshwater storage could only be affected through carefully planned management of the available resources within the particular area without causing heavy extraction and subsequent landward hydraulic gradient. Since artificial recharge possibilities are remote for the Jaffna Peninsula aquifer, immediate planned management of the available resources within this area is warranted, before further damage is caused to the aquifer.

FIGURE 19 - Iso – Chlor / Acreage Graph

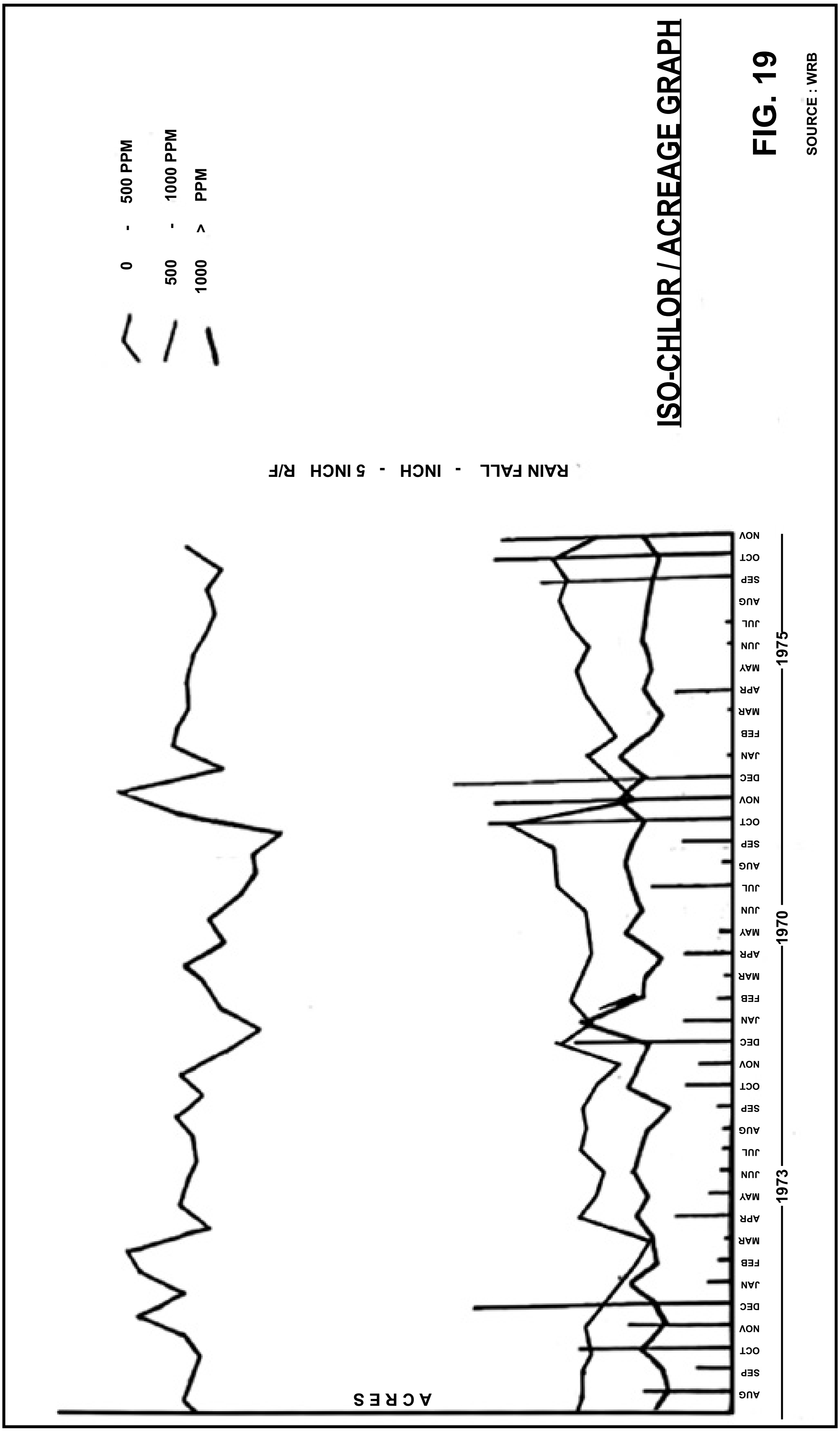
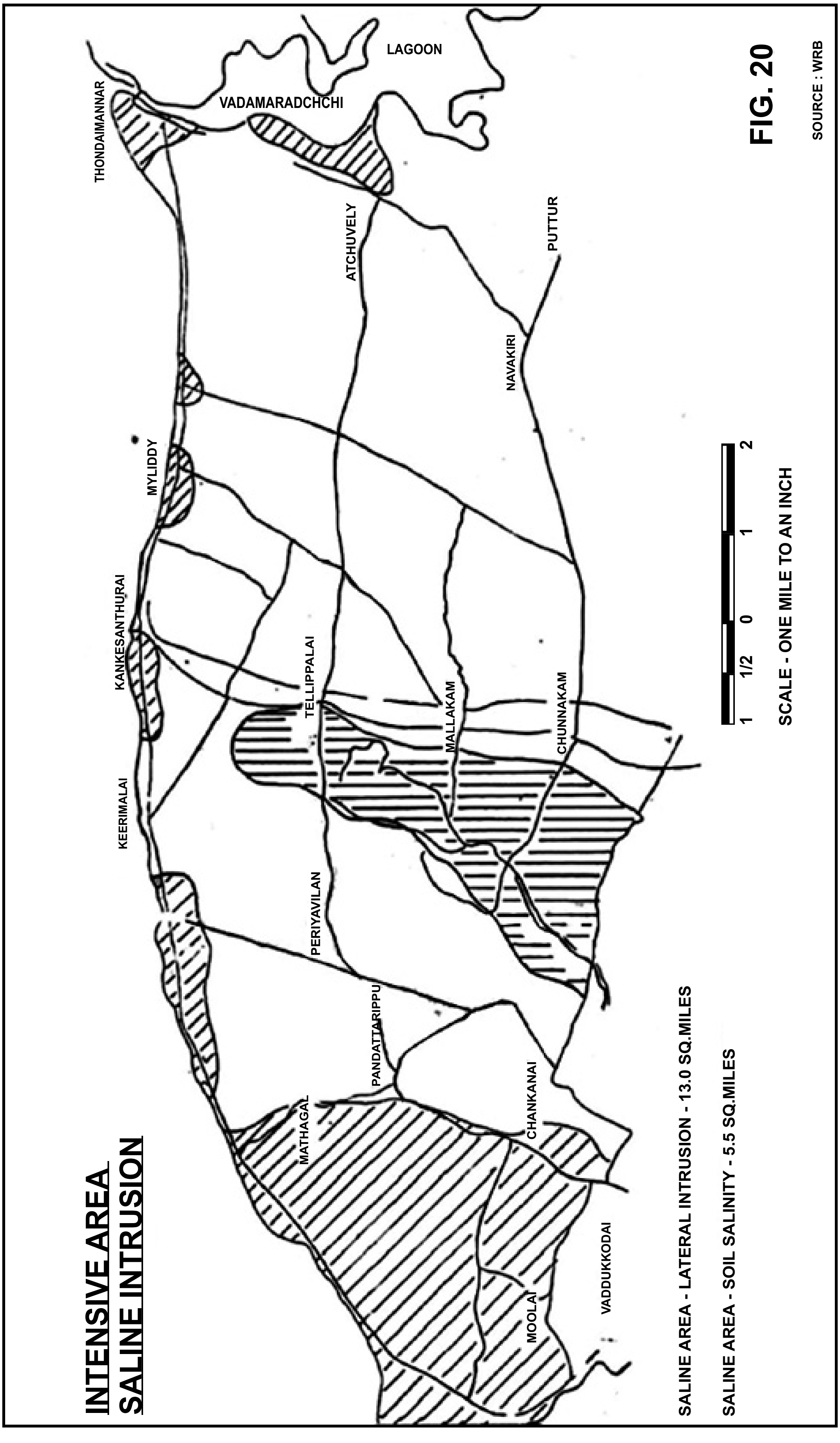


FIGURE 20 - Intensive Area Saline Intrusion



H. STATE OF GROUNDWATER RESOURCES OF THE INTENSIVE STUDY AREA

Using the estimated groundwater recharge together with the data on actual abstraction obtained, the current state of development of groundwater resources in this area can be assessed. It is important to appreciate fully the underlying assumptions employed. The recharge and storage in this zone had been computed in relation to the water table contours of the area, with the assumption that it is a self-contained basin. (But it is actually not so.) An analytical draught on this aquifer storage in the order of 30,000 ac.ft. per year is indicated from the freshwater storage above mean sea level, as the abstraction from the storage is considerably greater than the storage. This abstraction is inevitably associated with some undesirable side effects, provided the overdraft is balanced by sufficient storage from below mean sea level.

The side effects could be falling groundwater levels, well yields, competition for available groundwater storage, and advancement of the fronts of saline water intrusion. The non-uniform distribution of abstraction could induce the above side effects even in other parts of the groundwater basin, even with strong evidence to correlate the replenishment of groundwater to this portion of the aquifer, from the aquifer in the southern part outside the intensive area. It is interesting to note that the groundwater abstraction has exceeded the replenishment of this zone, and the groundwater resources of this zone could be regarded as having been overdeveloped with the cultivation of the 25% of the available land in this zone.

It is clear that there is no further room for conventional large-scale development in the zone though existing agricultural practices may be permitted. Further developments, if necessary, could be directed towards the area where appreciable lenses of freshwater are available, especially in the extreme north, where the lenses appear to be unexplored.

Higher groundwater development for agricultural purposes appears to be taking place in the rest of the aquifer of the Peninsula, and until such time as the groundwater storage and abstraction rates of these zones are established, one cannot assess the safety of the groundwater potential of the Peninsula from the undesirable side effects. Such assessment would require complex technical and economic studies to assess the feasibility of proper groundwater management of the Peninsula. The Peninsula experienced low North East Monsoonal rains during the years 1972, 1973, and 1974, when compared to 52 inches in 1975. This is a clear indication that all agricultural development in the Peninsula should be planned in relation to the rainfall intensity, as storage is directly proportional to rainfall. The extent of agricultural activities of a year should be based on the intensity of rainfall of the previous North East Monsoon. The planned management of the agricultural activity during a particular year is a must in the Jaffna Peninsula to avoid any overdraft of the groundwater resources. The groundwater resources of the Peninsula will be static, provided the rainfall and abstraction rates are static. But it is not so, since rainfall and abstraction are two varying factors from year to year.

VI. WATER UTILIZATION, DEVELOPMENT AND MANAGEMENT PROBLEMS

A. CROPPING PATTERN AND WATER MANAGEMENT

Agriculture is the most important occupation of the people of Jaffna, and the agricultural land use consists of the cultivation of food crops, cash crop, and tree crops. However, of the total of 617,360 acres, the cultivable extent of land is only 152,908 acres. This low percentage is owing to the nature of soils, distribution of sandy areas and limestone wastes, and lack of water for cultivation. The chief food crops are paddy, kurakkan, varagu, and yam. Paddy is grown as a rain-fed and an irrigated crop. Cash crops include chilies, onions, tobacco, and other miscellaneous crops. The cash crops grown in the Peninsula are cultivated with irrigated water from the well (see Table IX). The tree crops include the coconut, which is a plantation crop. Other tree crops are palmyra, mango, plantain, and arecanut. Definite forms of rotation of crops are practiced in the Peninsula. The land is manured heavily. Even tree crops are harvested in one year from the same land. The most common rotation is tobacco, then a cereal which is followed by a short- term legume - such as green gram.

TABLE - IX	
Estimated irrigated acreage under various crops in the Jaffna Peninsula in 1975	
Crops	**Acreage**
Chili	4,200
Onion	5,570
Potato	1,080
Manioc	1,250
All others	1,650
Probable total double-cropped Land	6,360
Probable total single-cropped Land	1,030

(Sources: Agriculture and Lands Office, Jaffna.)

Food and subsistence crops are mainly cereals. Rice is one of the chief crops as it is the staple food of the people. The cultivated extent of paddy lands is about 40,000 acres. There are a great many varieties of paddy, which are classified mainly according to the time they take to mature. They are two main paddy seasons in the Peninsula. The Maha crop, called Kalapokam, is sown in October and is reaped in March. The Yala crop, called Sirupokam, is sown in April and is reaped in September. In the Jaffna Peninsula, the full extent of paddy under cultivation is rainfed, and the paddy soils vary from sandy loams to grey loams. On the mainland, however, water is available for Irrigation. The process of rice cultivation in Jaffna is common in most parts of South East Asia. Each acre receives about 24 cartloads of composed or cattle manure. Weeding is an essential operation in the Peninsula, where the paddy is rain-fed. In areas where irrigation water is available, the weeds get smothered. The average yield in the Jaffna Peninsula for the Maha crop is about 33 bushels per acre, and in the Yala, 13 bushels per acre. The average extent of paddy land is saline due to its close proximity to lagoons and the sea.

Dry grains such as kurakkan and varagu are cultivated during periods of rain scarcity. They are usually grown in July, and yams occupy the land till December. The grains are cultivated in the red soil region and the grey loam paddy regions.

The tree crops cultivated are coconut, palmyra, arecanut, and mango plantation. The betel vine may also be included in the group. The only plantation crop cultivated in the Peninsula is coconut. It is grown under unfavourable conditions of soil and climate when compared to the coconut growing areas in the rest of Sri Lanka. The main areas of cultivation are distributed along the southern and eastern coasts of the Peninsula. Unlike other parts of Sri Lanka, it is grown mixed with the palmyra palm in some areas. At one time palmyra tree was almost exclusively grown in the Jaffna Peninsula. The palmyra is traditionally connected with the Sri Lankan Tamils of Jaffna and enters into the home life exactly the same way as the coconut with the life of Sinhalese. It yields several food products and various other articles adapted for different uses.

In the Jaffna Peninsula arecanut is not subject to any form of systematic cultivation as in India. They are found in the home garden only. Fruits are plucked when they are either very tender or of full nature. The Mango tree grows on a wide, deep well, drained sandy loams. But for the production of good crops, the soils should not be very rich clayey since the trees tend to run to leaf. A wet spell during the blossoming period is detrimental to fruit set because of defective pollination. Wet weather during ripening is also harmful since it is liable to cause fruit rot and attract fruit flies. The main season for mango in Jaffna is from May to August, with a small crop in December. There is rarely a home without at least one mango tree. Plantain trees are often grown on grey loam and are an important source of income for the peasants.

Cash crops such as tobacco, onion, chili and exotic vegetables are mainly grown in the red soil lands of the Peninsula. These are the best worked lands and show at their best of remarkable skill, patience, and industry of the Jaffna peasant. These garden lands are found west of the Vadamaradchi lagoon in the Peninsula in the Valigamam East, North, and West. These crops are also grown in the paddy lands of the Peninsula. After the harvest of one crop of paddy, the land is ploughed, and the roots of the paddy plant are buried deep. The land is then marked out into plots and manured. Crops are then planted. As the crops have to live there during the dry months of May and June, the peasant has to water the plant. Water is lifted from the well. Cultivation of chilis and onions are on the increase because of the great demand and the higher prices for them and better marketing facilities at present.

Thus, in every way, the Jaffna peasant makes much out of little. The land utilisation in the Peninsula is limited by two factors - the availability of water for cultivation and the extent of arable land.

The exploitation of groundwater by using open-dug wells has been one of the earlier forms of groundwater exploitation for agriculture, forming the basis of the economy. Most of the Peninsula is intensely cultivated. The area under cultivation has increased considerably in recent years as the Government launched an extensive program to encourage the cultivation of subsidiary food crops in order to save foreign exchange.

Paddy is mainly a water plant and is cultivated during the Maha season with the help of direct rainfall. However, in the case of subsidiary food crops, they cannot stand water stagnation around their roots, and their tolerance factor for inundation or water logging, as compared with that of paddy, is very low. This is probably the reason for these crops which are not cultivated during the rainy season in the Peninsula where this class of the crops is tradition.

Lift irrigation is the only form of irrigation that is practiced in the Peninsula. As pointed out in the earlier chapters, the source of water is the groundwater tapped in the underlying strata of Miocene limestone. Innumerable wells will be seen all over the area to tap the groundwater for irrigation as well as for domestic use. The very shallow wells along the coastal belt are mainly infiltration wells, while the wells in the interior go right up to the limestone strata to get the groundwater available. The water from these wells is lifted to the surface by means of well sweeps. Now mechanical pumps are steadily replacing these well sweeps. These have their advantages and disadvantages.

Generally, the water distribution to the crops is affected by the Ridge and Farrow system. The land is prepared with alternative ridges and farrows. The plants are planted on the ridges at specified intervals depending on the crop, and the water is led down the furrows. The length and the gradient of these furrows also vary with the type of crop. The water is led into each of these plots, and once it is full, water has to be turned on into the next plot.

As pointed out earlier, the cultivation of subsidiary food crops is confined mainly to the dry months of the year and is usually from about mid-January till about the end of September. It will thus be seen that the conveyance losses of water due to seepage and evaporation are very great.

It is evident from the discussion in the earlier chapters, the over-abstraction of water during dry months of the year using mechanical pumps results in the intrusion of saline conditions in the groundwater aquifer.

B. WATER UTILIZATION AND DEVELOPMENT PROJECTS

1. JAFFNA TOWN WATER SUPPLY SCHEME

The Jaffna Town Water Supply, which was originally commenced as a small undertaking to a small development area in the Town, has now been expanded into a proper Town Water Supply Project. A well situated in the Agriculture Department Farm at Thirunelvely was selected for the Town water supply - in particular to the Karaiyur Development Scheme in the Jaffna Town, over fifty years ago. Mahadeva reports (1938) that the well was deepened to 40 feet, i.e., about 11 feet below mean sea level; the well is said to have yielded 17,000 gallons per hour. It has been in commission ever since; the draw-off from it has been about 55,000 gallons per day for several years. This supply was used for serving 50 to 60 stand posts in the particular development scheme, drawn from a service reservoir tank capacity of 25,000 gallons constructed in the area.

The well is, however, capable of yielding more. Now the yield from this well is also utilised for the supply of about 75,000 gallons per day to the Jaffna General Hospital. Today, about 120,000 to 140,000 gallons are being drawn from this well daily by pumping.

A groundwater supply scheme to Jaffna Town, by pumping from wells at Kondavil, was taken up for construction by the Public Works Department in 1956. The Department of Water Supply completed the work, and the project was handed over in 1963 to the Jaffna Municipality, who are in charge and have been operating it ever since.

Arumugam (1971) commended the layout of the well system for extracting groundwater from the aquifer at Kondavil as a brilliant piece of work and serves as a pointer for similar undertakings in the Peninsula. By a provision of supplementary wells and connecting adits that intersect the general line of fissures of the limestone rock, collection is made of the utmost possible underground flow, and if the rate of extraction (pumping for Town water supply) is meticulously adhered to the ceiling limit given (viz 3,000,000 gallons per day) the system should work satisfactorily provided the rainfall pattern remains substantially unchanged. The only exception would be two consequent drought years of less than normal rainfall during both the years.

The whole area taken up for the project extends to 12 acres, within which the layout occupies a seven acre extent. The land is about 30 feet in elevation above mean sea level. By the central or pumping well, which is about 22 feet in diameter and 40 feet deep, is housed in the pumping machinery. Three subsidiary wells are sited, each about 285 feet away from the central well, in three very carefully selected directions so that the adits and galleries connecting them to the central well intersect the line of fissures in the area. The adits are 5 ft. high horseshoe-shaped on a 5 ft. wide base which carries a 2.5 ft. drainage channel.

Arnon Arad (1965), a visiting expert, commented that "The Galleries system of the Municipal Water Supply, although heavily pumped, has proved itself as a satisfactory method of exploitation of groundwater under the intricate Hydrological regime of the Peninsula.”

Before launching the project, various pumping tests were carried out by the Department of Geological Surveys to arrive at a safe figure of the maximum quantity of freshwater that can be extracted from the aquifer without causing adverse effects or the advent of salinity. The Government mineralogist advised the Director of Public Works to keep the limit of safe withdrawal to 350,000 gallons per day in the first instance.

The extraction of water for supply is done by means of two pumps, each pump is worked alternatively for a two hour period, and the pumping goes on from 6 a.m. to 10 a.m. and then from 2:30 pm onwards. The measuring gauge of the quantity of water pumped is assessed by the number of hours each pump has been working and assuming that the rate of pumping by each pump is 25,000 gallons per hour. The tendency is to pump till the service reservoir is full and back pressure is indicated in the pipeline gauge. Thus, extraction would lead to increase with consumption.

The arrangement is unsatisfactory. In the absence of any measuring meters, there is no check on the quantity pumped daily. This has to be rectified.

2. JAFFNA GENERAL HOSPITAL WATER SUPPLY

The Hospital in Jaffna used to be supplied with water from two wells situated on the premises and which was to have been further improved and augmented. But with the launching of a water supply scheme to Karaiyur with water pumped from the wells at Thirunelvely, the Medical Department asked for a temporary issue of 8000 gallons per day from the municipality for a short time in 1955 until the Hospital well supply scheme was improved. Unfortunately, however, no effort has been made to repair and improve its own Hospital Scheme, but an ever-increasing draw-off is being made by the Hospital from the Town water supply. Although at one stage, the Hospital drew off only 12,000 gallons from the town mains and supplemented it with about 15,000 gallons per day from their own wells, now no effort is being made at all to use any water from the Hospital wells. The precious high-quality water from the Town mains is used at about 500 taps, the bulk of it for washing drains, and lavatories, flushing sewerage systems, and general cleaning up.

It is totally unfair to meet the whole requirement of a major provincial Hospital like Jaffna from the meagre yields of the Thirunelvely-Kondavil aquifer. Today the Hospital requirement has risen from 8000 gallons per day in 1954 to 75,000 gallons per day in 1970, and now more than 100,000 gallons per day, taking a big share out of the Town water supply. This would further increase with more water being added to the newly created Medical Faculty Units of the University of Jaffna.

The remedy would be to have two separate systems for the Hospital - one for drinking water from the mains with a ceiling, say of 25,000 gallons per day, and the other a surface drainage and sewerage system for water obtained from wells in the Hospital premises. If this were not done, a critical situation will soon arise in the Jaffna Municipal water supply system, with saline conditions infiltrating into the system to the dismay of the rate payers of the Municipality and also causing the ruin of the farmers in and around Thirunelvely and Kondavil.

The commissioner of Local Government, by his letter No. CH 27 of 4.3.1960 informed the Medical Superintendent that:

> "Jaffna Town has not got a plentiful supply of water nor is it likely to have in the near future. The quantity of 50,000 gallons of water per day is a good portion of the supply to the Town, and you will therefore appreciate that the requirement of a major Provincial Hospital like Jaffna cannot be fully met from the town water supply scheme. The only remedy would be to have two separate systems for the Hospital - one is a drinking water scheme from water supplied by Municipality and the other a surface drainage and sewerage system from water obtained either from wells in the Hospital premises or even from the lagoon. In the alternative, the Department of Health should consider an independent Hospital water Supply scheme from some other source."

It is unfortunate that action in these lines has not been thought of. The situation is the difficulty in finding the quantity of water; payment for it does not obviate the difficulty in finding the water. In this connection it is of interest to note that a test was made by the Irrigation Engineer, groundwater Surveys in October 1970, of the four wells in the Hospital premises. These four wells served the needs of the institution but are not being used today, because of the ease in the availability of the piped Town Water Supply.

The main well, which is large, is reported to be capable of yielding 8000 gallons and the other three small wells about 1000 gallons each, making in all a total of 11,000 gallons. This should be utilised, easing the strain on the Town's sources of supply.

The supply from the wells at Kondavil is pumped to a service reservoir tank of capacity 125,000 gallons situated in the Town, and distribution is affected there from both by house connections and standpipes. These issue points have been steadily increasing as more and more areas of the town are brought under the water supply system. The following shows the positions:

Year	House Connections	Standpipes
1967	427	463
1969	550	500
1971	650	700
(Sources: Water Supply Office of the Jaffna Municipal Council.)		

Issues are made to houses from about 6:30 a.m. to 10:30 a.m., and from 3:30 p.m. to 5:30 p.m. There is always the demand for water and increases in connection are inevitable.

In addition, about 60 stand pipes serve the Karaiyur Development area, drawing supply from the wells at Thirunelvely.

Supply to the Hospital is made from both the sources viz. from Thirunelvely wells and Kondavil wells.

The position, therefore, may be summed up as follows. About 260,000 gallons are drawn from Kondavil wells and 140,000 gallons from Thirunelvely wells, and the total of 400,000 gallons is pumped daily to serve the 650 house connections, 700 standpipes in the Town, 60 standpipes at Karaiyur Development area and the Government General Hospital. The demand and the supply fluctuate with large quantities during the dry months and smaller during the wet season of the year.

Such an arrangement cannot be carried on indefinitely; it is ridiculous to presume that we can manage somehow. The increase in water demand and the increase in population are two factors that have to be met. The population of the Town today is over a lakh, and an urban population of this size would normally demand 3 million gallons per day as against the 4 lakhs gallons supplied today.

But the very important factor is that not more than 300,000 gallons should be drawn from the Kondavil wells in a day. Violation of this ceiling limit would result in the advent of salinity into the system. It would mean not only the supply of poor quality water for drinking to the Jaffna Town resident but also disastrous consequences to the extensive cultivation of chilies, onions and other cash crops in the Kondavil locality.

Very active steps, therefore, have now to be taken to institute, well additional systems like the complex Kondavil aquifer, and to augment the supply. Otherwise, the whole system would go into ruin with saline infiltration.

In this connection, the area along Raja Veethi provides suitable sites, which should now be investigated. The area is rocky, and the limestone is well-fissured, as was noticed in the wells in the area. Geologically the area corresponds very much to the Kondavil pumping station area; several such sites could be located along this road. A suitable site has to be located beyond the core of influence of the Kondavil area, and the next well complex commenced.

3. JAFFNA LAGOON SCHEME

This scheme has been given priority by the Ministry of Irrigation, Power and Highways in order to increase the groundwater potential in the Jaffna Peninsula, thereby relieve the acute shortage of water for cultivation and domestic use and also prevent saline intrusion into wells.

Jaffna Peninsula comprises a total area of 410 square miles and nearly 40 square miles of this extent is covered by two internal lagoons, namely the North (Vadamaradchi) and South (Uppu Aru) lagoons. An external lagoon of water spread area of 30 square miles called the Elephant Pass Lagoon lies between are not interconnected. The first one starts from Periya Pachilapalli as its eastern boundary enters the sea at Thondaimanar. The south lagoon originates from the lower plains of Kaputhu paddy lands and spreads abutting Sarasalai, Madduvil, Kaithady, and Navatkuli on the left; Puttur, Kopay, Irupalai, and Chiviyatheru on the right and link the sea at Ariyalai in the outskirts of Jaffna Town. The Elephant Pass Lagoon is the portion lying between the Peninsula and the mainland and enters the sea at Chundikulam on its eastern side and is isolated from the sea on the western side by Jaffna-Kandy Road.

a. PURPOSE OF THE SCHEME:

The major problems facing Sri Lanka are the increasing foreign exchange requirements and unemployment.

As a considerable amount of valuable foreign exchange is being spent for the import of food items, stepping up cultivation of rice and subsidiary food crops is a major economic objective. This will also increase the employment opportunities among educated youths. The people of the Peninsula have been constantly agitating to convert this lagoon into a freshwater lake for cultivation, domestic purposes, and replenishing the groundwater resources. Due to the over-exploitation of the aquifer, most of the wells which are in close proximity to the lagoons and sea have become brackish, and it is of paramount importance to have a supply source artificially to replenish the wells in order to meet the increased demands.

b. PROPOSALS:

i. ELEPHANT PASS LAGOON:

This will be used as a supply source for the internal (North and South) Lagoons in addition to improving the conditions along the fringe of the lagoons.

The present proposal is to provide a total spilling accommodation of 7000 feet length along the eastern closure with earthen dams on either side of the spill can causeway for a length of 4700 feet. The spill has to cater to the run-off from a catchment of 363 square miles. In addition, the highest flood level is controlled by the Jaffna-Kandy Road and the inundation of the developed land along the periphery. High tide levels etc., are also taken into consideration in deciding on the spill length.

ii. LINK CANAL:

This connects Elephants Pass Lagoon with North (Vadamaradchi) Lagoon and is 2 1/2 miles long. It is badly damaged and silted, as it runs in sandy material.

The channel section is now redesigned after a detail soil investigation, and the present proposal is to re-condition the existing channel as per the new design, excavate the balance length, provide an inlet regulator cum bridge, and provide a roadway along link canal.

iii. NORTH (VADAMARADCHI) LAGOON:

This project consists of a barrage across the outfall of the sea at Thondaimanar main gate. There are 18 bays of 20 feet width consisting of lower and upper gates. These gates are 20'0" in width x 4'0" in height and are made of steel.

There are subsidiary wooden gates 10'0" in width. The spill is at + 2.50 mean sea level, and the top level at + 4.00 mean sea level.

iv. SOUTH (UPPU ARU) LAGOON:

This project consists of a barrage which is located across the sea outfall at Ariyalai between 195 and 196-mile post along Jaffna-Kandy Road, two culverts 196/2 and 196/3 on Jaffna-Kandy Road and a separation bund of 2.75 miles isolating the lagoon from Chemmani Salterns and paddy fields.

The barrage consists of a series of controlled bays flanked on both sides by two clear overfall gravity sections. Controlled bays are 42 in number, out of which 18 are fitted with screw operated wooden gates each 5' 6" in width and 5' 0" in height. The balance of 24 bays are centrally situated and are controlled by planks, each having a width of 5'6" and a height of 5' 0".

The separation bund will be improved according to the new design determined after an investigation of the soils available in the area.

c. BENEFITS:

i. Underground storage will be recharged, thereby benefitting the brackish wells along the fringe of the lagoons. There may be a possibility of suppressing the interface of fresh and saltwater below the existing level and thereby increasing the storage potential of groundwater to meet the increased demand for irrigation and domestic consumption.

ii. Reclaim about 11,000 acres of non-arable land along the fringe of the lagoons by leaching the salt content of the soil.

iii. Supplement 20,000 acres of presently cultivated rain-fed lands along the fringes.

iv. Cultivation of lake bed during the dry season when the bed is free of salinity.

v. Cattle grazing during the dry season in the lake bed.

The extent of 11,000 acres of reclaimed land, along with the 20,000 acres of existing cultivable land, could be provided with water for the cultivation of paddy, chilies, onions, yams, and other crops. The construction is planned to be completed in two years, and the full development is anticipated in ten years.

If this scheme is successfully implemented, its impact on groundwater management in the Peninsula could be significant. In addition to the availability of surface water directly for irrigation, the lagoons could be a source of water for artificial recharge in areas of heavy pumpage and a relatively thin freshwater lens. If sufficient freshwater head can be maintained by importation or enough water from the mainland into the lagoons, improvement in the water quality of areas adjacent to the lagoons should occur. However, significant subsurface discharge to the sea may also occur and such water loss must be weighed against the expected gains.

C. ECOLOGICAL IMPLICATIONS

The activities of man upon the earth may affect the quality of groundwater in two major ways:

i. by accelerating the rate of buildup of compounds or ions normally found in groundwater, and

ii. by adding or increasing the concentration of dissolved solids during the beneficial use of water.

The first results from the plowing of fields, denuding of forest lands, construction of highways and similar actions which expedite the normal movement of water into soils containing soluble compounds. The second results from discharging to the water which water may move, inorganic chemicals, biological agents, and organic compounds associated with municipal and industrial use of water.

The activities of the groundwater users have shown clear signs of natural contamination as well as man-made contamination of the fresh groundwater body of the Peninsula.

The natural contamination of the fresh groundwater in the Peninsula evolved out of the unplanned extraction practices that are being carried out at the moment. The overall effect of this activity has already shown signs of natural contaminants polluting the groundwater body in the form of more salty waters lying around and underneath the freshwater lens encroaching into the groundwater body, either laterally or vertically in the form of upconing. A second problem of contamination to the fresh groundwater body could result from the discharge of inorganic chemicals, biological agents, and organic compounds associated with the Municipal, Industrial and Agricultural use of water, and the residues entering the aquatic ecosystem through the process of leaching to the substratum by irrigation practices or by rainwater percolation.

Manmade hazards to the groundwater body of the Peninsula caused by way of:

i. Contamination by wastes from human life processes.

ii. Contamination by wastes from Industrial processes.

iii. Contamination by Agricultural Inputs.

By far, the greatest concern for contamination of water, especially the groundwater, has been directed to human wastes in the form of sewage. Curiously enough, such concern has not generally been expressed over the septic tank efficiently discharged directly underground. At least, such concern is so recent in origin, especially in urban areas. This is being clearly observed by the Water Resources Board within certain areas of the Jaffna Peninsula. However, from the viewpoint of contamination hazards from wastes matters, whether the percolating liquid comes from subsurface leaching or from operations involving surface application of sewage effluents, as well presently be noted.

In the practical case, Municipal sewage contains both domestic and industrial waste products. From the domestic fraction comes nitrates from human body grease, ground garbage, and residues from commercial products such as soap and detergents. Industrial production normally includes a variety of biochemically unstable organic matter and a wide spectrum of common chemicals as well as more organics and toxic ions, generally in concentrations below but critical to waste treatment processes. Therefore, in evaluating contamination hazards involved in Municipal Sewage, the fate of several standards of materials in soil systems must be considered:

i. Organic and inorganic particles other than living organisms.

ii. Microorganisms, including bacteria and viruses.

iii. Chemical products of degradation of organic matter.

iv. Chemicals from industrial wastes or from industrial products in commercial use.

v. Leachings from landfills.

Of this group, the organic degradation products may be generated either by using aerobic or anaerobic conditions and so develop a variety of intermediate products. All of the groups are generated by either aerobic or anaerobic conditions and so develop a variety of intermediate products. All of the groups are generated or commonly discarded by man at the earth's surface, with a few rare exceptions, and hence are initially separated from the groundwater by the soil mantle of the earth. They are further separated from the user of groundwater by the extent of the aquifer between the point of outcrop or withdrawal of water. Further, the soil mantle of the earth is geologically active. Under these circumstances, the question of man-made hazards to groundwater involves two basic considerations:

i. The nature of contaminants in each of the general classes of material.

ii. The fate of each contaminant in water percolating downward through the biologically active mantle of the earth or in water translated laterally as groundwater in saturated aquifer sands and gravels.

In addition to the above, the contaminants in water moving through fractured strata or dissolution channels should be considered. However, in this latter case, the hazards of manmade pollution may be directly assumed from the nature of the contaminants in the five classes of material listed. For a while, phenomena such as sedimentation absorption, decay, and the like may reduce the concentration of contaminants, but the hazard remain.

1. NITRATE POLLUTION IN GROUNDWATER

Foster (1976), a Hydrogeologist of the British overseas Development Mission, visited the Jaffna Peninsula on a very short-term study of the groundwater problems of the Peninsula (Report No. JD/05/76/3 of Dec. 1976 - British ODM). He carried out a few sample analyses on the Thirunelvely and Kondavil Municipal water supply wells (tested at the Department of Agriculture, Peradeniya) and found the nitrate levels as 66 mg/l and 101 mg/l, respectively. He found that these levels are rather high for the groundwater quality and sounded a warning to look out for fertilizer pollution.

In 1977, Prof. Bently, Soil Scientist in the USA, came to Jaffna Peninsula on a private visit, and the Resident Engineer of the Regional Water Resources Board, Jaffna, had the opportunity to discuss with him the fertilizer pollution based on the findings of Foster. He confirmed the observations made by Foster and wanted further studies to be carried out to estimate the regional nitrate level in the groundwater of the Peninsula. In a few of the seminars given by Prof. Bently, he stressed the ill effects of using excessive chemical fertilizers, especially the nitrogen-rich 'Urea'. However, no serious thought was given to this problem, probably due to the inadequate laboratory facilities for a detailed study in Jaffna.

In Dec. 1979, the Water Resources Board, Jaffna, was able to obtain equipment for the laboratory to handle any type of water analysis in the Peninsula. Initially, random sampling was carried out to determine the nitrate levels in the water, especially in the drinking water wells and agricultural wells. As the preliminary tests indicated and confirmed higher levels of nitrates in Jaffna groundwater, the Water Resources Board embarked on a broad-based regional nitrate study incorporating many agricultural, domestic, and public wells spaced throughout the Peninsula and the islands. The colorimetric method, as well as the Micro-Kjeldahl method, were used jointly to establish the correctness of the results and confirm the nitrate levels analysis.

2. EVALUATION OF POLLUTION

Since this analysis is very laborious and time-consuming, one hundred and twenty wells were tested in the Peninsula covering the entire Valikamam, Vadamaradchi, and Thenmaradchi divisions. Twenty-one wells were tested in the islands of Kayts, Punkudutiva, Karainagar, Analaitivu, and Mandaitivu. Of these observed 141 wells, [Text missing: Editor] in agricultural lands, and the wells beings used in water for agricultural purposes. 50% of the agricultural wells indicated nitrate levels exceeding the permissible level of 45 mg/l and ranging up to 150 mg/l of nitrates, thus indicating the potential danger of nitrate build-up in the groundwater body. Out of the balance of 61 domestic wells, 16 wells indicated nitrate levels higher than 45 mg/l and a few even up to 250 mg/l, thus indicating localised sewage pollution.

The nitrate levels in the groundwater during September 1980 (prior to the monsoonal rains) were estimated in order to assess the build-up of nitrates at the end of the drought season. The obtained data was mapped to assess the potential danger zones and to evaluate the causes of higher nitrate levels in such areas of high contamination.

The concentrated nitrate level zones in the groundwater body were studied in relation to the present land-use pattern of the Peninsula as well as the geology of the area. This exercise revealed the fact that higher concentrations of nitrates did occur in areas where intensive agriculture is taking place.

Other observed areas of high nitrate levels (where agricultural practices are not in force) indicated the extent of sewage pollution due to concentrated input of sewage into the underground from residential areas. Table X seems to support the position that nitrate concentration problems are confined to wells in high-intensity irrigated produce-raising areas.

The result of mistakes on the part of man in his agricultural activities or his ignorance of the laws of salinisation. (e.g., salinisation or irrigated lands during the rise of groundwater already saline or irrigation with already saline water etc.) Especially, the use of already saline water for irrigation saline continues the cycle of salinisation. The irrigated saline water is brought above near the zone of aeration by the capillary movement of water during dry months, which deposits the salt due to evaporation during the dry spells of the season. Subsequent leaching causes the immediate increase in chloride contents of the groundwater, which subsequently gets diffused with freshwater recharges to the aquifer.

TABLE - X

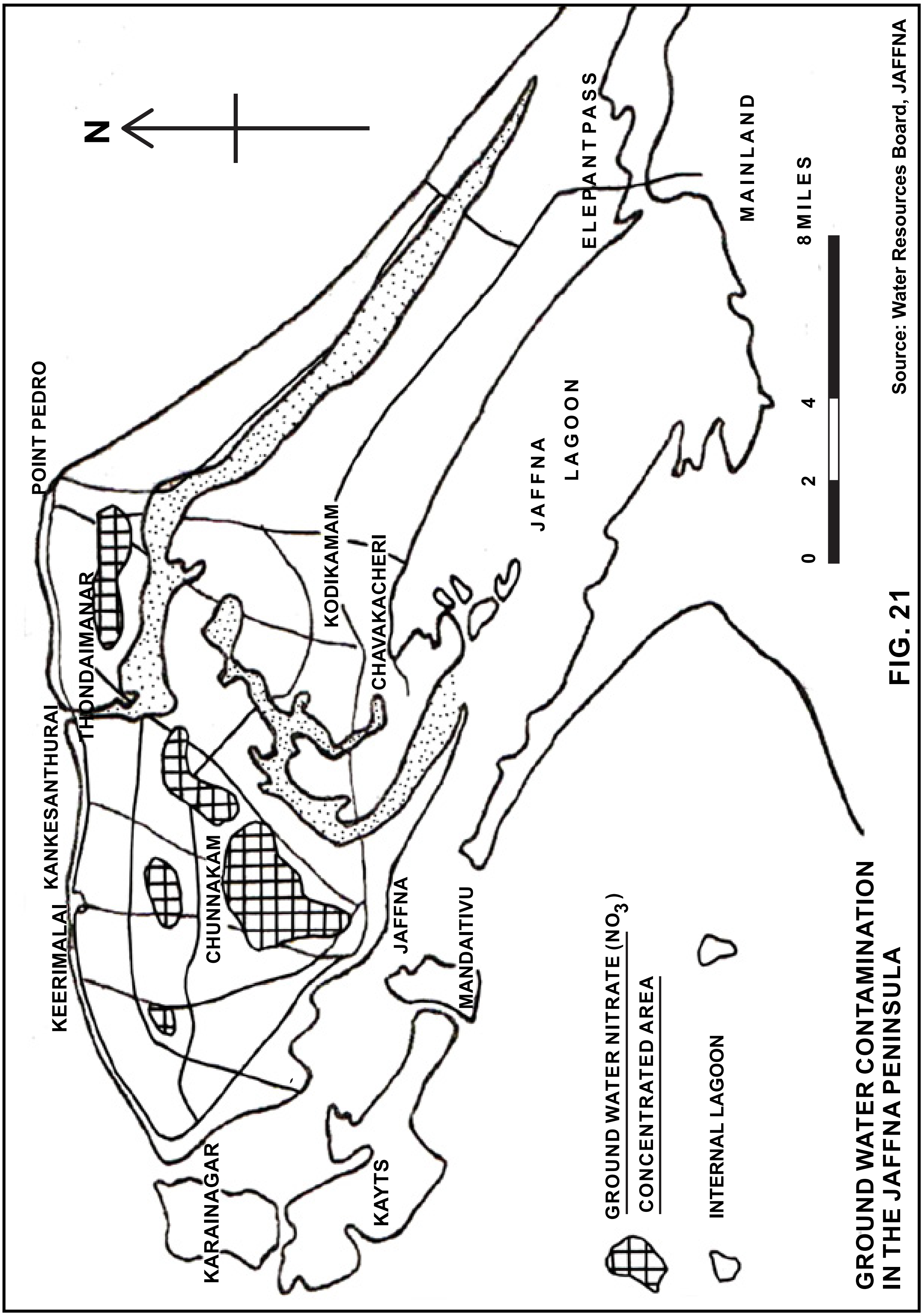
Nitrates in certain areas of the Jaffna Peninsula outside municipal council limits

Place Names	NO_3 - Mg/l
Karaveddy WSS - 19 miles from Jaffna	1.0
Kallady (Near Cement Plant)	0.3
Araly North WSS - Well, in non- irrigated paddy	0.57
Chunnakam WSS (Nov. 1980)	0.34
Kallady WSS (Nov. 1980)	0.3
Kondavil (Nov. 1980)	Trace
Araly South	0.2

(Source: Senn 1982.)

On super-imposing the concentrated groundwater nitrate map to the freshwater availability map, the highly impermeable red soil area map, and the highly intensified agricultural area map, it is clearly evident that higher nitrate levels existed in the intensively farmed agricultural area. The cause of the high nitrate level rise in these areas cannot be attributed to sewage pollution as only a very few houses are situated in the agricultural centre, contributing to sewage pollution.

FIGURE 21 - Groundwater Contamination in the Jaffna Peninsula



The following table indicates the percentage of available nitrogen in various fertilizers that are being used in the Peninsula during a period of six to eight months of a year.

Nitrogen percentages of various fertilizers	
Fertilizers	**Percentage N**
Human night soil	1.2 to 1.5%
*Cow dung	0.3 to 0.4%
Town refuse	0.6 to 0.7%
*Farmyard manure	0.5 to 0.6%
*Compost	0.5 to 0.6%
*NPK mixture	3.0%
** Ammonium Sulphate	20.5%
** TDM, Mixture	38.64%
**Urea	46.0%

* Used in Jaffna for Agricultural purposes.

** Possible over-usage in Jaffna for Agricultural purposes.

(Source: Gunasegaram, 1978)

The above nitrogen percentages of the various fertilizers clearly indicate the famous 'Urea' to contain the highest value of 'N'. A field reconnaissance survey by the Water Resources Board, Jaffna, to obtain statistics from the farmers on the amount of fertilizer usage per acre, revealed that the farmers use on an average 5 cwt. of fertilizers per acre during a crop season. Since chillies and onions are the main intensively cultivated crops in the Peninsula, the input of nitrogen-rich chemical fertilizers to these crops could be the source for the presence of excess nitrate in the area concerned.

The high build-up of groundwater nitrate contents in this area clearly indicates the over-usage and leaching of the easily soluble 'Urea'. Of the agricultural chemicals, commercial fertilizers are perhaps the most significant. In these activities, the farmers have attempted to ignore the capacities and characteristics of their ecosystem. The agricultural ecosystems in which they produce their food have been loaded with products of chemical technology while thinking of only maximizing food yields. In the process, the nutrient and non-nutrient chemicals, which he has added, have had repercussions beyond the ecosystem to which they were applied. In time, this can cause such an increase in aquatic photosynthesis that the aquatic ecosystems can be completely changed.

The soil mantle of the area is relatively thin and acts as an infiltrative surface from which the groundwater aquifer normally derives its annual recharge. It is evident that undue the concentration of chemical fertilizer application in such area would create a local pocket of potential contaminant overlying the groundwater body, which invariably gets leached down to the groundwater.

3. NITRATE LEVELS IN THE JAFFNA TOWN WATER SUPPLY WELLS

The two major source wells for the Jaffna Town Water Supply System at Thirunelvely and Kondavil are situated invariably in an intensively farmed area. The effect of intensive cultivation and application of chemical fertilizers in those areas has not only polluted the groundwater underneath but has shown signs of pollution mobility to non-agricultural areas.

The study of nitrate pollution in the Jaffna Municipal water supply scheme wells (Table XI) indicates the concentration of 149.0 mg/l (NO_3) and 141.0 mg/l (NO_3) at Kondavil and Thirunelvely respectively, as on 9.10.1980.

TABLE - XI				
Nitrates in the Jaffna Municipal water supply wells				
Jaffna Municipal Well	**mg/l**		**NO_3**	
	Dec. 1976	Early 1980	Nov. 11, 1980	Nov. 20, 1980
Thirunelvely (Hospital etc.)	66	141		
Kondavil (Public Well)	101	149	129	131
Kondavil (Tap)			134	

(Source: Senn, 1982)

This clearly indicates the potential danger of nitrate levels in a single drinking water supply scheme, supposed to provide safe drinking water supply scheme, supposed to provide safe drinking water to a population of nearly a hundred thousand.

The concentrated intake of palatable water from these agricultural areas would not only endanger the health of the population consuming the water supplied, but also would aggravate natural contamination (intrusion of salty water) of the freshwater body, thus endangering the agriculturists too. We are thus wedged between the needs and development hazards. Proper planning and management of both agricultural and aquatic ecosystems are very essential for the Peninsula. The groundwater resources are almost like a self-contained water basin, from which water is drawn daily and the balance water is allowed to seep underground with more and more of the pollutants. This recycling of the already polluted water with more and more pollutants, depends on the fact that the yearly monsoonal rains would carry away the wastes and pollutants, allowing the underground water resources to start the contamination cycle once again. It is suggested that this is a dangerous exercise to be carried out in the groundwater basin of the Peninsula, and timely action is necessary to curtail this ignorant activity in the Peninsula. It may be that this would pose challenges to politicians and administrators, but the fact remains that water is the primary need for any living being and it is the duty of everyone to safeguard this essential commodity for the better and safe use of everyone, either in water-rich or water-deficit areas.

However, the ill effects of all these contaminations yet remain to be identified in relation to the human health of the inhabitants of the Jaffna Peninsula. Much research and correlation of data in this field remains to be done, and it is where medical research could contribute for a successful solution to the water problems of the Peninsula.

D. PRESENT WATER USE

1. DOMESTIC

There is very little data on present water use in the Jaffna Peninsula. For Jaffna Town, there is limited data on the number of direct connections, the number of standpipes, and total water production. There is no metering data to determine leakage or wastewater levels or for estimating actual demand according to consumer type. There are several other standpipe systems located in the study area, but similarly, the available data provides an indication of the amounts supplied but not the amount consumed.

Therefore, little can be determined about present per capita demand or even about the difference in usage between various levels of service. It is believed that present usage is far below what the demand would be given a reliable water supply with safe water and a convenient method of distribution.

2. AGRICULTURAL

Actual water use by agriculture has not been directly measured or computed with field data for the Jaffna Peninsula in the past. Meisler has estimated water withdrawals for agriculture on the basis of his investigation of a 142 sq. km area to be, on average, 0.391 mm/yr. Extrapolating proportionality to the entire 1065 sq. km study area, this amounts to 416 million cu. m/y. The following preliminary estimate of the present water requirement for agriculture is based on the fundamental factors involved in determining water use by crops.

For the purposes of this preliminary estimate of agricultural water demands, readily available data from local sources were used. Some of these data have yet to be fully verified and further refined. Therefore, the computation present below should be viewed as preliminary.

The estimated cropping pattern based on available data is summarized in Table XII. Sixty percent of the cropped area during the first half of the year is in home gardens where miscellaneous vegetables, fruits, and tree crops are grown, primarily for home consumption. Visual observation of these gardens indicated that they are nearly totally irrigated, except where only trees are being grown. A detailed analysis of water use in these gardens would be extremely difficult because of their highly varied characteristics and the very large numbers of home gardens involved. Home gardens have therefore been lumped together and treated as potentially one unit with regard to agricultural land use and water demand.

The next major category of crops is paddy, with 22 percent of the cropped area during Maha (Wet season). Irrigated paddy culture in the study area is almost nil. Chilies (7 percent of the cropped area), onions (5 percent) and Coconuts (8 percent) comprise the other major crops grown. Smaller areas of potato, tobacco, banana, kurakkan, maize, sorghum, green gram, black gram, manioc, gingelly (sesame) yam, mango, and a large variety of vegetables are also grown.

TABLE XII - Estimated Present Cropping Pattern in the Jaffna Peninsula by Month

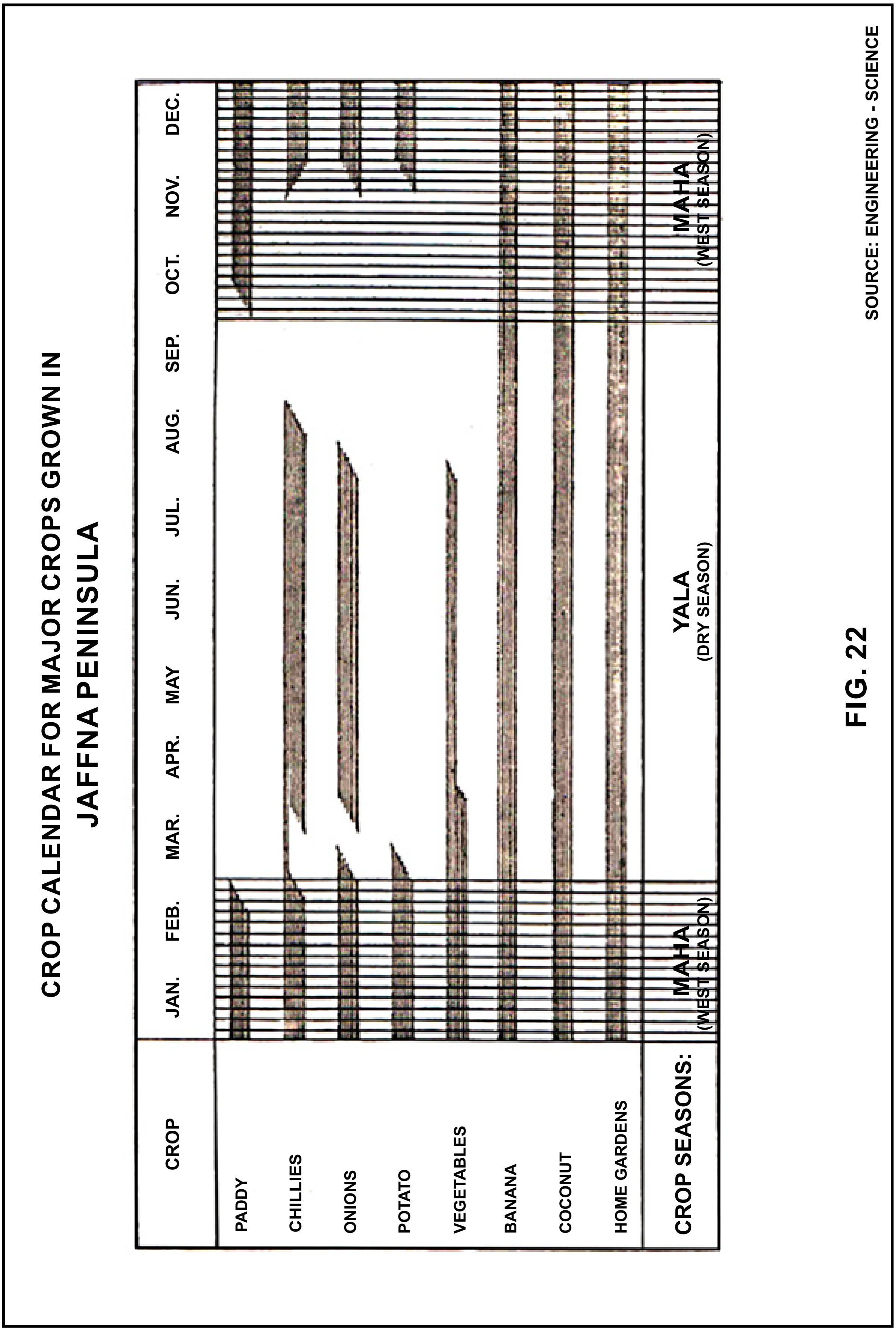
TABLE - XII

ESTIMATED PRESENT CROPPING PATTERN IN THE JAFFNA PENINSULA BY MONTH (In Hectares)

	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Present of Cropped Area (3)**
Paddy	11,720	11,720	0(1)	0	0	0	0	0	0	11,720	11,720	11,720	22
Chillies	30	30	30	3,960	3,960	3,960	3,960	0(2)	0		11,720	11,720	7
Onion	1,920	1,920	0	2,560	2,560	2,560	2,560	0(2)	0				5
Potato	590	590	0(2)	0	0	0	0	0	0				1
Tobacco	340	340	0(2)	0	0	0	0	0	0				1
Miscellaneous Vegetables	2,170	2,170	2,170	670	670	670	670	0(2)	0				1
Banana	130	130	130	130	130	130	130	130	130	130	130	130	0.2
Coconut	4,180	4,180	4,180	4,180	4,180	4,180	4,180	4,180	4,180	4,180	4,180	4,180	8
Home Gardens	32,180	32,180	32,180	32,180	32,180	32,180	32,180	10,000	10,000	10,000	10,000	10,000	60
TOTAL	**53,260**	**53,260**	**38,690**	**43,680**	**43,680**	**43,680**	**43,680**	**14,310**	**14,310**	**26,030**	**26,030**	**26,030**	**-**

1. After paddy harvest, it is assumed that the paddy land will be diverted thusly: 2,000ha to various crops, 3,000ha to natural vegetation and 6,720ha to uncropped or waste land.
2. Uncropped in period shown, i.e. waste land
3. Percentage for each crop was computed by dividing the maximum monthly extent of the crop by 53,260, maximum total crop land.

FIGURE 22 - Crop Calendar for Major Crops Grown in Jaffna Peninsula



For preliminary water demand assessments, the computations were made for the major crops and private home gardens. Obviously, any effect on agricultural water use reduction must concentrate on these categories of crops. The impact of rice on the total water demand is indirect because rice is grown in Jaffna almost entirely during the wet season and is totally rainfed. The paddy basins act as storage areas, and, in normal water years, carry enough water through the months of January and February for the crop to mature. In exceptionally dry years, the crops suffer significant yield reductions or even fail. A crop calendar for the major crops is presented in Figure 22.

Essentially, crop water requirement is determined by

a. Local climatic factors,

b. Crop factors, and

c. Local conditions and agricultural practices.

To estimate local climatic Factors, a "reference" ET or ETO is calculated and defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground, and not short of water. Four methods for computation of ETO are in common use – the Blaney-Criddle, Radiation, Penman and Pan evaporation methods. Mean climatic data are used to compute ETO for monthly periods. ETO is expressed in nine per day or month and represents the mean value over that period. Each of the four methods rely on a different combination of climatic factors and has its inherent accuracy. The Penman method can be accurate within ±10 percent, the Pan method ±15 percent (assuming the proper location of the pan), the radiation method ±20 percent, and the Blaney-Criddle up to ±25 percent.

K_p is a factor called pan coefficient, and is used to convert pan evaporation data into reference ET data. It is selected separately for each month depending on wind speed, fetch and mean humidity. Tabulations of K_p are produced from many years of measurement of ETO and pan evaporation data at the same locations and correlating them with local conditions.

The reference ET or ETO must be adjusted for each crop and for each month during its growing season to reflect particular crop morphology, physiology, and state of growth. Experience with a large number of crops of a very wide geographical distribution has provided an inventory of crop factors that account for these parameters. Applied to the ETO values, these coefficients result in the [Text missing: Editor] evapotranspiration of the specific known [Text missing: Editor]. A summary of crop factors for the major crops grown [Text missing: Editor] study area is presented in Table XIII.

Using these crop factors, ET crop minus effective precipitation is applied to the area under each crop during each month, and an estimate of water use by major crops is obtained, as shown in Table XIV.

In this tabulation, a 75 percent efficiency of Irrigation is assumed. This may be overly optimistic. Recent observations indicate that current irrigation efficiency may be as low as 50 percent. Thus, the estimated total present water requirement for agriculture of 318 million cu. m/y (Table) may well be on the lower side. Indications are that actual water demand may be considerably higher, possibly double the figure.

FIGURE 23 - Monthly Distribution of Crop Water Demand in Jaffna Peninsula Under Existing (1981 - 1982) Cropping Pattern

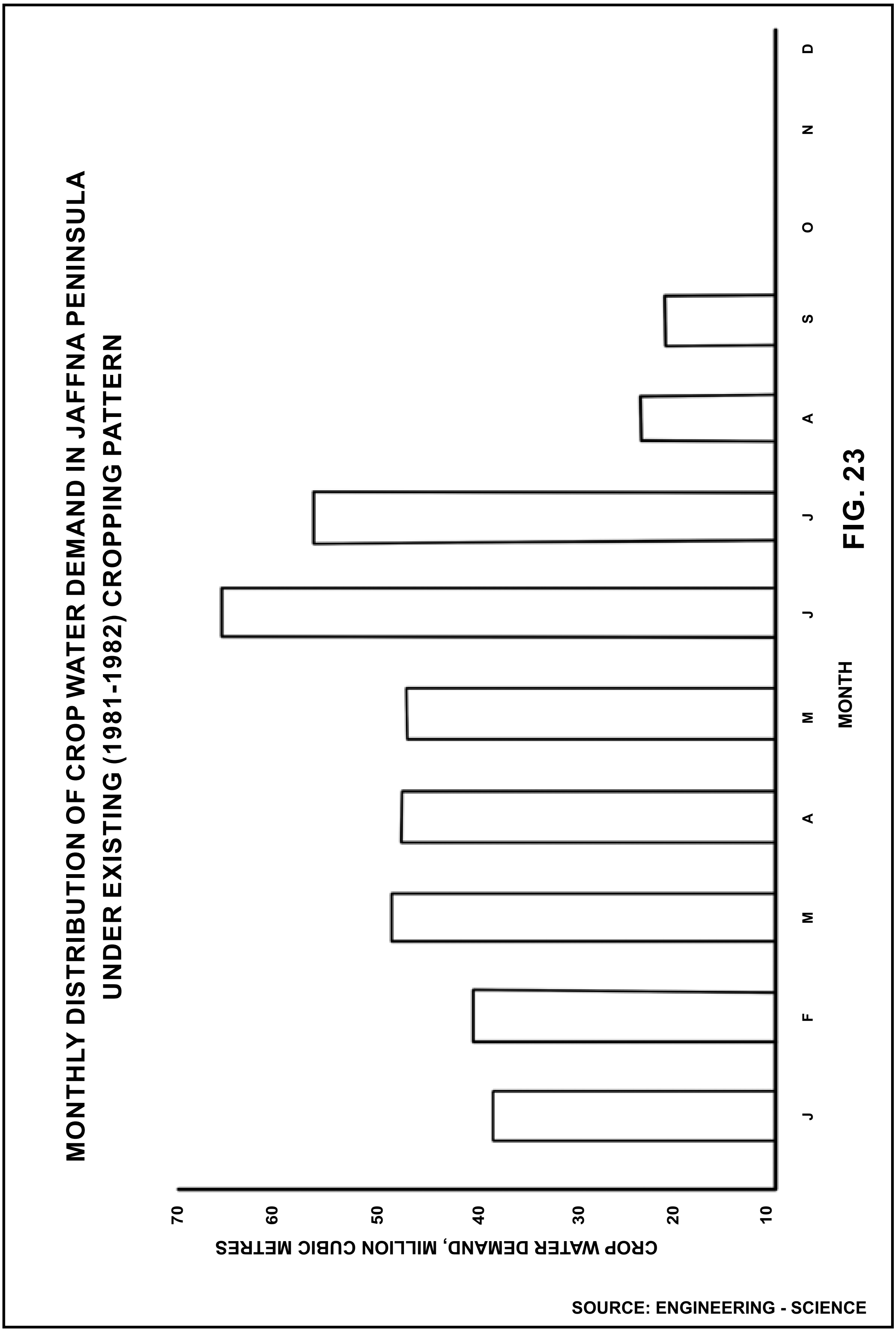


TABLE XIII - Crop Factors Used for Estimating Evapotranspiration in the Jaffna Area

TABLE - XIII

CROP FACTORS USED FOR ESTIMATING EVAPOTRANSPIRATION IN THE JAFFNA AREA

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Rice	1.0	0.95	-	-	-	-	-	-	-	E	E	E
Chillies	0.95	0.95	0.95	0.85	0.85	0.85	0.85	-	-	E	E	E
Onion	0.95	0.85	0.9	0.9	0.9	0.9	0.9	-	-	-	-	-
Potato	1.1	0.7	-	0.9	1.1	0.1	0.7	-	-	-	E	E
Tobacco	0.9	0.9	-	-	-	-	-	-	-	-	E	E
Miscellaneous Vegetables	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	-	-	-
Banana	1.0	0.8	0.75	0.7	0.7	0.8	0.95	1.1	1.1	E	E	E
Coconut	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	E	E	E
Citrus	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	E	E	E
Private Gardens	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	-	-	-

TABLE XIV - Estimated Water Use by Major Crops in the Jaffna Peninsula

TABLE XIV

ESTIMATED WATER USE BY MAJOR CROPS IN THE JAFFNA PENISULA (million cubic metres)

CROP	MONTH												TOTAL	PERCENT
	J	F	M	A	M	J	J	A	S	O	N	D		
Paddy	13.0	5.8	0	0	0	0	0	0	0	-	-	-	18.8	5.5
Chillies	0	0	0	4.3	4.2	4.3	3.8	0	0	-	-	-	16.6	4.8
Onions	1.8	1.7	0	2.9	2.9	2.8	2.6	0	0	-	-	-	14.7	4.3
potatoes	0.6	0.4	0	0	0	0	0	0	0	-	-	-	1.0	0.3
Tobacco	0.3	0.3	0	0	0	0	0	0	0	-	-	-	0.6	0.2
Miscellaneous Vegetables	2.0	2.0	2.3	0.8	0.7	0.7	0.7	0	0	-	-	-	9.2	2.7
Banana	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-	-	-	0.9	0.3
Coconut	3.0	2.6	2.9	4.0	4.7	3.1	2.9	2.6	2.9	-	-	-	28.7	8.3
Home Gardens	28.9	29.7	33.9	36.7	35.9	35.7	32.9	10.5	9.3	-	-	-	253.5	73.7
Total Evapotranspiration	49.7	42.6	39.2	48.8	48.5	46.7	43.0	13.2	12.3	-	-	-	344.0	100
Effective rainfall	21.3	11.7	10.8	20.9	21.0	5.2	7.9	2.8	3.6	192.7	258.9	918.38		
Net Evapotranspiration	28.04	30.9	28.4	27.9	27.5	41.5	35.1	10.4	8.7	-	-	-	238.8	
Losses (75 Efficiency)	9.5	10.3	9.4	9.2	9.1	13.7	11.6	3.4	2.9	-	-	-	79.1	
Total water Demand	37.9	40.9	37.8	37.1	36.6	55.2	46.7	13.8	11.6	-	-	-	317.9	

SOURCE : WRB

REFERENCES

Arad, Anon : Groundwater in the Jaffna Peninsula, Unpublished Report in the Files of the Irrigation Department Colombo, 1965.

Arumugam, S. : A Memorandum on the Jaffna Town Water Supply, An Unpublished Paper in the Files of the Municipal Council, Jaffna, 1971.

Barton Worthington, E. (Ed.) : Arid Land Irrigation in Developing Countries, Pergamon Press, 1977.

Behrman, A.S. : Water is Everybody's Business - The Chemistry of Water Purification.

Bingham, F.T., Davis, S. and Shade. E. : Water Relations, Salt balance and Nitrate Leaching Loss of a 900 Acre Citrus Watershed, *Soil Science* 112, 1971.

Foster, S.S.D. : Groundwater Conditions in the Jaffna Peninsula, Unpublished Report (JD/05/76/3) British Overseas Development Mission, 1976.

Gunasegaram, T. : Groundwater Pollution in the Jaffna Peninsula, Unpublished Report in the files of the Water Resources Board, Jaffna, 1980.

Kampen, J.E. : Soil and Water Management in Semi-arid India Agriculture Irrigation, pp. 258-283, May, 1977.

Mahadeva, S. : The Hydrology of Jaffna. *The Engineering Association of Ceylon, Transactions,* 1938.

Mc Gauhey, P, H. : Engineering Management of Water Quality, California, Mc Graw Hill, 1969.

Mc Naughton, G. : Aspects of Water Pollution Control, WHO Public Health Papers No. 13, 1962.

Pavoni, Joseph, L. (Ed.) : Handbook of Water Quality Management Planning, New York, Van Nostrand, 1977.

Simmons, I.G. : The Ecology of Natural Resources, Arnold, 1974.

Thorne, Waynne : Land and Water Use, Pub. No. 73 of the American Association for the Advancement of Science, Washington, D.D. 1963

Van Dynes George, M. (Ed.) : The Ecosystem Concept in Natural Resource Management, Academic Press, New York, 1969.

Part Three

IMPLICATIONS OF THE STUDY

A. DEVELOPMENT AND PLANNING OF WATER RESOURCES IN THE JAFFNA PENINSULA

We are rapidly moving on to a world water shortage. Each one of us is affected by the water problems now before us. Looking ahead into our Peninsula's distant future, with its increasing population growth, the gradually expanding acreage under cultivation, added to which also must be taken into account some industrial establishments of all sorts springing up here and there, the industrial estate, higher educational Institutions like the University, the demand of our water resources would naturally turn out to be more and more as the years roll by. Though water is supposed to be infinite, the current rate of use and the modifications to the quality of water in making freshwater a scarce commodity in restricted areas.

Water resource development means the exploitation of water to benefit society by meeting the basic needs of individuals. Considering the limitations, the Peninsula has had to face in augmenting water availability, far greater efficiency and the strictest economy in use become imperative. There is no shortage of freshwater in the Peninsula at present; only there is over-drawing in certain places while large quantities are flowing out to the sea at other places. What has been available will always be available (however, subject to a minimum monsoonal rainfall of 40 inches), and the Peninsula need never become a desert, as commended by Arad, a visiting Hydrologist from Israel in the year 1965.

The urgency to plan and develop all available water resources in the Peninsula to meet the rapid increase in demand for water has to be acknowledged as a regional priority. It is imperative to embark on both short-term and long-term schemes now. In any overall water planning study, invariably two vital factors – yield and demand – need to be considered. Unfortunately, both these factors involve a number of variables and are in turn influenced by other variables. To achieve any degree of precise accuracy, it is extremely difficult and indeed to some extent may prove superficial. This is especially so in the case of surface water scarcity in rapidly developing regions like the Jaffna Peninsula. Therefore, development and planning of water resources in the Peninsula needs to call for studies and collaborations from a number of other disciplines involving Geography, Ecology, Biology and Limnology, Microbiology, and Physiology. The last mentioned discipline is thought valuable in assessing the long-term cumulative effects on human health of some minerals and compounds existing in water, the precise physiological effects of which are not fully known at the moment. The planning policy is nothing more than a "to collect drops to become a pond" concept. Water is simply too valuable to be allowed to go to waste in the Peninsula. To enable the Peninsula's available water resources to be stretched to the maximum for various uses, water conservation and wastage reduction are very much a part of good water management. The amount of water wasted daily because of inconsiderate use-habit and conventional irrigation methods can be appreciable. Effective methods to reduce wastage in the agricultural sector, apart from educational efforts, should be actively implemented.

The problem as considered in this study mainly contains three elements: recharge occurs during a three-month monsoonal period each year; part of this water is lost to the sea through a network of solution channels in the limestone aquifer; and, saltwater intrusion and upconing of the freshwater-saltwater interface occurs at many locations with over-abstraction.

The development of a water management plan is needed in order to control saltwater intrusion and upconing of the saltwater-freshwater interface while maximizing the amount of water that can be safely extracted. In areas of high salinity, the pumping rates of individual wells are too great to achieve a stabilization of the interface beneath the well. The quality of the water being pumped could be improved by the reduction of pumping from each well. Maximum utilisation of the aquifer in such areas could be accomplished by pumping a larger number of shallow, large diameter wells at lower rates per well.

Concentration of wells has caused deep holes in the water table and, in some places, has even reversed the normal direction of the underflow. These deep holes in the water table are actually great cones of depression; so much water has been extracted that a general lowering of the water table over many miles has resulted and the annual rate of replenishment cannot equal to the extractions. Such conditions require aquifer-wide action to obtain outside supplemental supplies, limitation of pumping, or rearrangement of well-spacing within the aquifer.

The basic hydrologic equation of a groundwater aquifer is: recharge equals discharge. Where pumping occurs, the draft must be over a long period at the expense of natural discharge plus artificial discharge. When, over a long period, natural plus artificial discharge exceeds recharge, the excess is supplied from accumulated storage and a condition of overdraft exists. Obviously, the only solution is to increase the recharging side of the equation or reduce the discharge side to bring about a balance.

An increase of recharge may be accomplished by importing water to the area either for direct consumption to relieve the pumping craft or for artificially recharging the groundwater aquifer, as through water spreading or injection of water into wells.

A decrease in the discharge side of the equation may be accomplished by eliminating waste in consumptive use and evaporation losses from uneconomic plants and conveyance methods.

Preventing run-off, and thereby inducing deep percolation of precipitation, helps to bring the recharge and discharge into balance. Also, proper use of water in irrigation reduces evaporation and transpiration losses.

Planned utilization of the groundwater aquifer will require competent investigations and plans for groundwater development of the common supply of interconnected surface and groundwaters. When the aquifer is operated under a planned program, the full use of the water will be obtained, and no permanent overdrafts should be expected. That appears to be the only way to avoid the results of the haphazard exploitation of groundwater that has occurred in many localities.

The problem of salinity build-up in irrigated soils and subsequently in groundwater recharge is something of a secondary problem. It will create difficulties for domestic and public water supplies, but the suitability of the groundwater for use in irrigation itself does not depend on its chemistry alone. In the Jaffna Peninsula, the salinity resistance of the crops being grown, the …

[Manuscript damaged, original text unclear: Editor]

… there is finally the need for integrated water resources planning on the basis of surface and groundwater, taking into account the inter-relationship of agricultural and other development and the various form of water development with the view to achieving optimum benefits. Groundwater, as the lifeblood of farming and other activities in the Peninsula, can spell abundance if managed and pursued towards the right direction.

B. CONCEPTUALIZATION

The foregoing discussion of the state of groundwater resources with the widespread observation of quality deterioration during dry months is sufficient to cause concern about the long-term position in the Jaffna Peninsula. Clearly, the groundwater resources of the region need positive and careful management.

From the observation and analysis of the data, it is established that the groundwater table declines faster from the months of March onwards as the dry spell begins. The average groundwater table during the wet months is in the region of 4 to 8 feet above mean sea level during the dry months of the year. Hence, variability in rainfall reflects in the fluctuation of the water table, and fluctuation of the water table affects the cropping pattern in the Peninsula.

It is also identified that the freshwater-saltwater interface is between 80 to 120 feet below mean sea level. A rough estimation of the total groundwater storage in the Peninsula indicates an average of 100,000 ac. ft. of water availability in the aquifer for an average annual rainfall of 48 inches, leaving allowances for the negative parameters, a safe withdrawal of 50,000 ac.ft. of the storage could be abstracted annually for domestic and agricultural purposes. However, saltwater intrusion and the upconing of the freshwater-saltwater interface occurs at areas of over-abstraction and localities near the sea water and lagoons. The seasonal variation in salinity is characterised by rising chlorides during the dry months and lower chlorides after the rains. The seasonal variation is only noticed in the west of the Valigamam area and along the north coast, which has an areal extent of 13 square miles. Ironically, the above areas of saline intrusion have a different formation of limestone in comparison to the rest of the aquifer. In comparing the limestone structure and the saline intrusion area, it is evident that uniform lateral saline intrusion is mainly taking place in the highly weathered limestone areas (west) and along the Coraline limestone belt, which are at a very low elevation when compared to the rest of the aquifer and acting as homogenous mass. In addition to the lateral intrusion of salinity, there is a definite upconing of the interface due to fairly heavy abstraction practices in the above areas.

It is now evident that the cause for this lateral saline water intrusion is mainly due to geological conditions and heavy abstraction taking place in the above area. The state of balance between the saline intrusion and freshwater storage could only be affected through careful planned management of the available resources within the particular area without causing heavy extraction and subsequent landward hydraulic gradient. Since artificial recharge possibilities are remote for the Jaffna Peninsula aquifer, immediate planned management of the available resources within this area is warranted, before further damage is caused to the aquifer. As such, it is evident that over abstraction in certain localities in the aquifer promotes salinity conditions and brings forth ecological damage.

An unusual seasonal variation in salinity is characterized by rising chlorides after the rains and a fall in chlorides during the drought, within the central portion of the aquifer, in the Vadamaradchi area. A belt of the aquifer, approximately 1.5 miles in width and 5 miles in length along the centre of Valigamam area, within the Valukkai Aru basin, characterised this phenomenon. A careful observation and study of the monthly Iso-chlor maps show that this distribution of salinity in the above area does not occur as lateral intrusion or as vertical upliftment of the interface.

The following possibilities are suggested as the cause for this unusual salinity:

i. Deposition of salt on the surface of the soil during the drought months, which is subsequently leached down by the first few downpours of rain. This is evident by the rise in chloride contents immediately after precipitation and the diffusion of salinity by the subsequent rains. The deposition of salt on the solid could be from one or two of the following: The result of mistakes on the part of man in his agricultural activities or his ignorance of the laws of salinisation. (e.g., Salinisation of irrigated lands during the rise of groundwater already saline or irrigation with already saline water etc.) Especially the use of already saline water for irrigation continues the cycle of salinisation. The irrigation continues the cycle of salinisation. The irrigated saline water is brought above near the zone of aeration by the capillary movement of water during dry months, which deposits the salt due to evaporation during the dry spell of the season. Subsequent leaching causes the immediate increase in chloride contents of the groundwater, which subsequently get diffused with freshwater recharged to the aquifer.

ii. The stratigraphy of the limestone shows a buried stream directly under and along the Valukkai Aru drainage stream, which is incidentally falling within the region of the unnatural salinization zone. It is possible that the salts of the surrounding soil get leached and is carried down to the valley immediately after the rains, which in turn changes the freshwater of the area with higher chloride contents.

It is clearly evident that the above unusual salinity is due to the salinity in the soil. A detailed investigation of the soil during the drought and wet period is necessary to eliminate the possibilities of the above suggestions. A vast area of the aquifer is getting affected due to this salinisation process, and a careful investigation of the above area is very necessary, as it is causing a hydro-geological division of the aquifer.

Some Chemists and Engineers have suggested that the leaching of human and animal waste deposition could have been the cause of this unnatural phenomenon. Even though a small percentage could be attributed to the above source, it cannot be understood why such a source has not affected the rest of the aquifer and only to this portion of the aquifer to such an areal extent. As such, a careful investigation of the soil should give a substantial solution to the above salinisation. Localised unnatural salinisation of well water within a freshwater zone could be attributed to localised conditions of salt deposition by the anthropogenic cycle and its subsequent leaching by rainwater.

The salinisation of the soil starts not only as a result of its enrichment by soluble salts sedimented from groundwater and soil solution when the concentration of the latter increases, but from the exchange absorption process between water and soil as well. In summary, the hydro-chemical investigations provide strong evidence of saline intrusion, apparently from localised points along the western and northern coasts, but are on mere balance due to the recharge of the aquifer. Recharge being a limited and unpredictable factor, the hazards of saline intrusion could be carefully controlled by planned management of the abstraction practices.

The uneven distribution of groundwater abstraction in the Peninsula induces side effects such as falling groundwater levels, well yields, competition for available groundwater storage, and advancement of the fronts of saline water intrusion. Even with strong evidence to correlate the replenishment of groundwater to the intensively cultivated Valigamam area from the aquifer in the southern part outside this area, it is interesting to note that the groundwater abstraction has exceeded the replenishment of this zone and the groundwater resources of this zone could be regarded as having been over developed with the cultivation of one quarter of the available land in this zone. It is clear that there is no further room for conventional large-scale development in this zone, though existing agricultural practices may be permitted. Further developments, if necessary, could be directed towards the areas where appreciable lenses of freshwater are available, especially in the extreme north, where the lenses appear to be unexploited.

The fluctuation of rainfall in the Jaffna Peninsula is a clear indication that all agricultural development should be planned in relation to the rhythm and rainfall intensity, as storage is directly proportional to rainfall. The extent of agricultural activities of a year should be based on the intensity of rainfall of the previous N.E. Monsoon. The planned management of the agricultural activity during a particular year is a must in the Jaffna Peninsula to avoid any overdraft of the groundwater resources. The groundwater resources of the Peninsula will be static, provided the rainfall and abstraction rates are static. But it is not so since rainfall and abstraction are two varying factors from year to year. The time has come for planned management of the available resources of groundwater and for modern engineering techniques to be utilised for measures to increase the storage of the aquifer by arresting the free flow of freshwater from the aquifer to the sea. A rough estimate of about two-thirds of the aquifer storage is lost within a month immediately after the northeast monsoonal rains when the water requirement for cultivation is very low. Only about one-third of the storage is being used for any development, out of which a small portion is lost to the sea by way of spring discharge. Hence, roughly one third of the storage is being utilised for a period of eight months of a year when the peak abstraction takes place at the risk of saline intrusion.

An average of 40 inches of rainfall is more than sufficient for the Peninsula to recharge the aquifer for the annual requirement of groundwater, provided measures are taken to arrest at least a portion of the freshwater discharge to the sea. Hence, it is found that the aquifer of the Jaffna Peninsula cannot hold all the water that percolates into it from the rainfall.

The conception of storing rainwater in the shallow ponds in the Peninsula amounts to only 6350 ac. ft. of water, and the deepening of these shallow ponds to increase groundwater storage is only a temporary measure to retain water due to the climatic and hydrogeologic parameters of the Peninsula.

Proposals for the closure of saltwater lagoons of the Peninsula and the creation of freshwater bodies are under consideration within the Irrigation Department. The proposals call for the importation of fresh surface water from the mainland to the Peninsula. If such a scheme is successful, its impact on a groundwater management plan could be significant. In addition to the availability of surface water for irrigation, unlike the ponds, the lagoons could be a source of water for artificial recharge in areas of heavy pumpage and a relatively thin freshwater lens during dry months of the year as the ponds go dry during the dry months due to evaporation. If sufficient freshwater head can be maintained by the importation of enough water into the lagoons even during dry months, improvement in the water quality of areas adjacent to the lagoons should occur. Consideration also should be given to interconnecting some wet-zone rivers with the rivers which fall into the Jaffna lagoon for a perennial supply of water, especially during the dry months when the wet zone rivers get much precipitation by the South West Monsoon during this period. However, significant subsurface discharge to the sea may also occur, and such water loss must be weighed against the expected gains.

C. CONCLUSIONS AND RECOMMENDATIONS

The foregoing discussion of the state of groundwater in the Jaffna Peninsula, especially during the dry months of the year, coupled with the widespread observation of quality deterioration during the last few years, is sufficient to cause concern about the long-term position in Jaffna. Clearly, the groundwater resources of the Peninsula need positive and careful management.

However, in trying to draw up a water management plan, many difficulties and uncertainties are encountered. Many areas in the Peninsula are subject to seasonal and long-term variations in salinity. The seasonal variation in salinity is characterised by rising chlorides during the drought and lower chlorides after the rains. These areas are subject to direct seawater intrusion which is held back by the recharge during the rainy season. With the rapid depletion of the recharge, however, the hydraulic head and the corresponding outward lateral pressure are reduced, and the seawater advances inland. This variation of intrusion can be correlated with the occurrence of rainfall and drought.

The coastal zone from Kankesanthurai up to the Thondaimanar lagoon and that in the extreme south are generally free from saline intrusion up to the water table. This is an indication that the central lens of freshwater is discharging steadily along this direction into the sea. It is evident, that in areas like the southern end of the east coast with a relatively thick sand cover overlying the limestone, the depletion of freshwater from these sandy beds is occurring at a lower rate due to the higher capacity of those more or less homogenous layers to retain water. Furthermore, no salinity has been detected near water table levels, even in areas close to the shoreline. Therefore, the cause for this lateral saline water intrusion is mainly due to geological conditions, and due to heavy abstraction taking place in some areas. Unusual seasonal variation in salinity is characterised by the deposition of salt on the surface of the soil during the drought months, which is subsequently leached down by the first few downpours of rain. This is evident by the rise in chloride contents immediately after precipitation and diffusion of salinity. There is a definite upconing of the interface due to fairly heavy abstraction practices in some areas of the Peninsula. The state of balance between the saline intrusion and freshwater storage could only be affected through carefully planned management of the available resources without causing heavy extraction and subsequent landward gradient. An additional contribution to the problem of salinity in the freshwater lens unquestionably must result from the very large number of septic tanks used for effluent disposal. An aquifer such as the Miocene limestone of Jaffna, when covered by only a thin mantle of permeable soil, must always be vulnerable to pollution from a variety of sources at the land surface. This will also include fertilizers and agrochemicals.

The data on an extensive testing and studies of nitrate contamination of groundwater in the Jaffna Peninsula by the Water Resources Board, Jaffna, shows clear indications that high nitrates were associated with areas of intensive cultivation. There is sufficient data of high nitrates associated with areas of dense population and subsurface excreta disposal. The existing data definitely shows a very sharp rise in nitrate concentration is taking place in the area of intensive irrigated agricultural activity. The nitrate levels in Jaffna groundwater have reached 125 to 150 mg/l, when compared to the permissible limit of 45 mg/l. The levels of nitrate fertilization recommended by the Department of Agriculture would result in acceptable groundwater nitrate levels. However, test data clearly indicate that the amount of nitrogen fertilizer applied is much higher than is recommended and is in the range indicated by farmers who actually apply fertilizers and who know how much they and their neighbours apply. It is suggested that careful studies be made of all available data on fertilizer consumption and application to more definitely answer the question of current rates of application and the amount needed for good crop yield. There is doubt that it is possible to do intensive well- water irrigated produce farming on high-value land, without excessive nitrate contamination in the aquifer. For this reason, it is important that planners of public, potable water supplies seek aquifers on lands. Such a policy is also supported by the growing health concern associated with the potentially carcinogenic properties of various agricultural chemicals which are applied, such as pesticides, weedicides, and herbicides.

For the foreseeable future, then, it would seem that groundwater quality management is a must to prevent the elimination of the freshwater lens in any part of the Peninsula.

In areas of high salinity, the pumping rate of individual wells is too great to achieve a stabilization of the interface beneath the well. The quality of the water being pumped could be improved by the reduction of pumping from each well. Maximum utilization of aquifers in such areas could be accomplished by pumping a large number of shallow large, diameter wells at a lower rate per well. Efforts should be made to determine optimum well spacing and pumping rates based on local hydrologic conditions. It will be particularly vital to prevent the construction of deep water-supply boreholes equipped with large-capacity pumps. Efforts should be made to discourage the deepening of existing wells and to avoid the further concentration of abstraction in any limited area.

When considering the economical use of available freshwater in the Peninsula, one approach that deserves considerable study is the dual water supply system, especially to Municipal and Hospital uses such as toilet flushing, lawn and park watering, laundering, firefighting, public fountains and the like. The existing town water supply should be utilized strictly for drinking, cooking and other uses that demand high purity. Therefore, consideration should be given to having a dual water supply system with fresh and brackish water, especially in public water supply schemes such as Municipality, Hospitals, Hostels and other public institutions in the first instance. The efficiency of such a dual system has been successfully demonstrated in many parts of the world.

Another aspect of economising the available freshwater supply is to educate and demonstrate the farmers of the Peninsula on irrigation methods which will eliminate the conveyance losses of water due to seepage and evaporation.

Finally, some form of surface impoundment or containment of monsoonal rainfall on land or in a lagoon is also superficially attractive, but the low relief, land scarcity, and high permeability of Jaffna soils could render any such project both expensive and experimental. However, efforts should be taken to de-saline the internal lagoons of the Peninsula with the monsoonal rainfall and importing water from the mainland to these lagoons, by way of converting and reclaiming the existing larger lagoons into smaller ones like a ribbon arrangement. Such a scheme would help to recharge the groundwater aquifer artificially, especially during the dry months when the abstraction is high in the Peninsula. Mention has been made in the previous section to get the needed water for artificial recharge of the groundwater aquifer, by way of interconnecting wet zone rivers with the rivers which flow into the Jaffna lagoon. If sufficient freshwater head can be maintained by the importation of enough water into the lagoons, improvement in the water quality of areas adjacent to the lagoons should occur.

In an overall assessment, there is no shortage of freshwater in the Peninsula at present; only there is over-abstraction in certain places, while large quantities are flowing out to the sea at other places. What has been available will always be available (subject, however, to a minimum monsoonal rainfall of 40 inches), and the Peninsula never needs to become a desert, as commented by a visiting Hydrologist.

D. RESEARCH FINDINGS

1. The groundwater resources of this region need positive and careful management. The urgency to plan and develop all available water resources to meet its rapid increase in demand has to be acknowledged as a regional priority. It is imperative to embark on both short-term and long-term schemes now. In

any overall water planning, invariably two vital factors – yield and demand – need to be considered. Both these two factors involve a number of other variables and are in turn influenced by other variables. To achieve any degree of precise accuracy is extremely difficult and indeed to some extent may prove superficial. This is especially so in the case of surface water-scarce, rapidly developing regions like the Jaffna Peninsula. Therefore, development and planning of water resources in the Peninsula need to call for studies and collaborations from a number of other disciplines involving geography, ecology, biology, limnology, microbiology, and physiology. The last mentioned discipline is thought valuable in assessing the long- term cumulative effects on human health of some minerals and compounds existing in water, the precise physiological effects of which are not fully known at the moment. The planning policy is nothing more than a "to collect drops to become a pond" concept. Water is simply too valuable to be allowed to go to waste on the Peninsula. To enable the Peninsula's available water resources to be stretched to the maximum for various uses, water conservation, and wastage reduction are very much a part of good water management. The amount of water wasted daily because of inconsiderate use-habit and conventional irrigation methods can be appreciable. Effective methods to reduce wastage in the agricultural sector and in public water supply schemes, apart from educational efforts, should be actively implemented.

2. Another aspect of the water management plan is to control saltwater intrusion and the upconing of the saltwater - freshwater interface while maximizing the amount of water that can be safely extracted. In areas of high salinity, the pumping rates of individual wells are too great to achieve a stabilization of the interface beneath the well. The quality of the water being pumped could be improved by the reduction of pumping from each well. Maximum utilisation of the aquifer in such areas could be accomplished by pumping a larger number of shallow large, diameter wells at lower rates per well.

3. The uneven distribution of groundwater abstraction induces side effects such as falling groundwater levels, well yields, competition for available groundwater storage, and advancement of the fronts of saline intrusion. It is interesting to note that in some areas, the groundwater abstraction has exceeded the replenishment of those areas and the groundwater resources of this area could be regarded as overdeveloped. Therefore, there is no room for conventional large- scale agricultural development in these areas, though existing agricultural practices may be permitted.

4. The fluctuation of rainfall is a clear indication that all agricultural development should be planned in relation to the rainfall rhythm and intensity, as storage or replenishment is directly proportional to rainfall. The extent of agricultural activities of a year should be based on the intensity of rainfall of the previous northeast monsoon. Planned management of agricultural activity during a particular year is a must in the Jaffna Peninsula to avoid any overdraft of the groundwater resources. The groundwater resources will be static, provided the rainfall and abstraction are two varying factors from year to year. But it is not so since rainfall and abstraction are two varying factors from year to year.

5. The conception of storing rainwater in shallow ponds to increase groundwater storage is not possible due to climatic and other hydrogeologic parameters of the Peninsula. But the fact remains, if, for instance that there are no surface depressions or Kulams (tanks), the rainwater would flow

off to the sea as surface drainage and would be lost completely to man in December itself, whereas when stored even temporarily in the tanks and induced into the ground or subsoil. There is a time lag; it would take some time to permeate through the limestone to the aquifer and then to the sea, during which period it is available for use by man, such as for pumping during February and March when wells recuperate much more than later on in the year. Thus, the Kulams (Tanks) of Jaffna perform a critical function in the hydrological cycle of the Peninsula by both detaining and percolating the drainage of the area.

6. Groundwater contamination takes place in intensively cultivated areas due to the overuse of chemical fertilizers and in residential areas due to human wastes in the form of sewage to the underground by way of septic tanks. According to the data obtained from the Water Resources Board Jaffna, for each month of 1980 and 1981 definitely show a very sharp rise in nitrate concentrations taking place in areas of intensive irrigated agricultural activity. There were clear indications from the data available that high nitrates were associated with Jaffna Town Water Supply wells which are situated at Thirunelvely and Kondavil. Therefore, it is very necessary to educate the public on the ill effects of the overuse of chemical fertilizers and the disposal of effluent into the underground.

7. Wherever possible, especially the public institutions should be provided with a dual water supply system in which freshwater is for drinking and brackish water for other than drinking and cooking purposes. It should be noted this kind of dual system has been implemented successfully in many other countries.

8. Saltwater exclusion of the internal lagoons of the Peninsula should actively be implemented in order to reclaim the alkaline areas around the internal lagoons and to safeguard the groundwater potentials by way of artificial recharge in order to maintain sufficient freshwater head around the internal lagoons to improve the groundwater quality of the adjacent areas.

9. Agricultural land use is probably close to maximum development in terms of total area, but substantial improvements in crop production and water use efficiency should be possible with the introduction of more efficient cropping patterns and water management practices.

10. The open wells from which the bulk of the population obtain their water supply are commonly contaminated, a fact which is reflected in statistics for water-related diseases such as cholera, dysentery and hepatitis.

11. Although high nitrate levels are common in many groundwater source areas, no adverse effects upon young babies have been observed by local health authorities to date. High chloride and iron concentrations are present in many areas.

12. The responsibility for and control of water resources in the study area is shared by a number of agencies. Overlapping jurisdictions and lack of effective coordination between the involved agencies characterize present institutional arrangements for water resources management. A clearer definition of Agency responsibilities to control groundwater resources in the study area is essential to the successful management of the available water resources in the future. This would also eliminate errors for future investigations and regular groundwater monitoring. Effective management of groundwater resources in the study area is extremely difficult, because none of the institutions involved

are empowered to manage groundwater resources of the Jaffna Peninsula. No legal provision for control of the extraction of groundwater presently exists. Free use of groundwater is permitted throughout the year for irrigation purposes. Construction of hand-dug wells in the Peninsula is freely permitted and the use of land for agricultural purposes is essentially uncontrolled. More and more land is used for the cultivation of cash crops during both the Maha and Yala seasons and this has resulted in over-extraction of groundwater. Paddy lands is being converted for the cultivation of cash crops. Proper control of the use of land for agricultural purposes in the Peninsula is essential as neglect of this will aggravate the water resources problems on the Peninsula. An agency for the overall direction, determination of priorities for water resources, and for coordinating the efforts of the concerned agencies does not presently exist.

E. VALIDITY OF HYPOTHESIS

An attempt is made here to find out whether the hypotheses formulated earlier are proved, partly proved or disproved in this study.

The first hypothesis, "the variability in the rainfall will reflect in the fluctuation of groundwater table" has been proved. From the observations and analysis of the data, it is established that the groundwater table declines from the month of March onwards as the dry spell begins. The average groundwater table during the wet months is in the region of 4 to 8 feet above mean sea level and rapidly fall down to one foot above mean sea level during the dry months of the year.

The second hypothesis "the aquifer in the Peninsula cannot hold all the water that percolates into it from the rainfall" has been proved. Careful observations were carried out immediately before and after the monsoon along the north coast of the Peninsula through which much of the groundwater from the aquifer is escaping to the sea (see Fig. 12). A rough estimate of about two-thirds of the aquifer storage is lost within the month immediately after the northeast monsoonal rains when the water requirement for cultivation is very low. Only about one-third of the storage is being used for any development, out of which a small portion is lost to the sea by way of spring discharge. Hence, roughly one- third of the storage is being utilized for a period of eight months of a year when the peak abstraction takes place at the risk of saline intrusion.

The hypothesis "fluctuation in the water table will affect the cropping pattern" has also been proved. While the seasonal rainfall exhibits a definite rhythmic pattern there is, however, considerable variation in it from year to year. This variability of rainfall has always been a major hazard in agricultural enterprises on the Peninsula. Water table fluctuations were observed by the Water Resources Board, and monthly variation of the water table in the saturated aquifer was processed from the water table contour maps. The behaviour of the groundwater table during the years 1973, 1974, 1975, and 1976 enable the computation of the groundwater storage in relation to regional rainfall during each year of investigation. The Peninsula experienced low northeast monsoonal rains during the years 1972, 1973, and 1974, when compared to 52 inches in 1975. There is a clear indication to say that the cropping pattern in the Peninsula in those years has been geared in relation to the rainfall intensity, as storage and water table fluctuation is directly proportional to rainfall. Hence, the cropping pattern of an area is based on the rainfall of the previous North East Monsoonal rains, which influence the aquifer storage and water table fluctuation.

The next hypothesis "over-abstraction of the water in the aquifer promotes salinity conditions in the wells and perhaps due to over- pumping more wells in future will turn into brackishness or saline conditions," has also been proved correct in this study. As the Jaffna Peninsula is surrounded by sea on all sides except where it connects to the mainland, it is susceptible to seawater intrusion from all directions. The freshwater occurs as a lens above the saltwater body underneath. The thickness of the lens varies with the fluctuation of the interface or face of separation of the saltwater and the freshwater surfaces. This groundwater lens becomes thicker in rainy weather and flattens out as the freshwater gets drawn out. The thickness of the lens at any instant locality is dependent on the height of the water table above sea level as the height of the column of freshwater must balance the saltwater pressure at the bottom of the lens. When pumping is done, the depression by a foot of the freshwater table above sea level will reduce the thickness of the freshwater lens below sea level by 40 times; this would in turn cause the formation of a 40 times upward sea water bulge in the seawater-freshwater contact zone. An examination of salinity distribution maps shows two major areas of low salinity groundwater (less than 500 mg/l chloride) occur in the Jaffna Peninsula. One coincides with the southeastern part of the Peninsula and is approximately 150 square miles in size. The Jaffna limestone is overlain by sand in this area and groundwater withdrawals are generally from the sand. The other area is centered in the western part of the Peninsula and is approximately 60 square miles in size. Smaller areas of low-salinity groundwater also occur elsewhere in the Peninsula. Areas of water with high chloride concentrations of 1000 to more than 3000 mg/l occur at the western end of the Peninsula, along the southwest coast near Jaffna, and the northeast coast near Point-Pedro. Other, more local, areas of high salinity ranging from 500 to 2000 mg/l of chloride occur adjacent to the Uppu Aru Lagoon and the western part of the Thondaimanar lagoon in an area including the lagoon of about 100 square miles. The areas of higher salinity generally occur in close proximity to bodies of saline water where the pumping of wells has caused upward movement of the lower boundary of a thin freshwater lens. In comparing the limestone structure and the saline intrusion area, it is evident [Text Missing: Editor] saline intrusion is mainly taking [Text missing: Editor] the highly weathered limestone areas in the west and along the coralline limestone belt, which are at a very low elevation when compared to the rest of the aquifer. In addition to the lateral intrusion of salinity, there is a definite upconing of the interface that occurs in the intensively cultivated market gardening areas where fairly heavy abstraction practices take place with modern water lifting devices. The widespread salinity in the pumped samples of the agricultural wells also makes us arrive at this conclusion. If this kind of over-abstraction continues, it is evident that more wells will turn into brackishness or saline conditions in the future.

The fifth and last hypothesis, "there exists a correlation between land use and the quantity of water available", has been proved, but only partially due to the inadequacy and reliability of related data. However, with the available data, it has been established that the cropping pattern in the Peninsula largely depends on the quantity of rainfall of the previous year, which in turn determines the quantity of groundwater recharge to the aquifer on which the cultivation practices are dependent.

F. FUTURE RESEARCH FRONTIERS AND PROSPECTS

Despite the conclusions stated above, future research and further study are still necessary for resource development in the Jaffna Peninsula. The following observations may prove beneficial.

1. To locate the points of major submarine groundwater discharge, an air-borne infra-red line scan survey could be undertaken, and a large number of boreholes and associated investigations would be required to establish the depth at which the major seaward groundwater flow was occurring.

2. It is essential that careful studies be made of all available data on fertilizer consumption of application to more definitively answer the question of current rates of application and the amount needed for good crop yield. Then, current studies should be expanded to get data for former educational programs to show:

    a) How to obtain maximum crop yield with "optimum" rather than "excessive" application of nitrates.

    b) The economics which can result from "optimum" rather than "excessive" application rates.

3. Research is needed on improved methods of irrigation, including the lining of field channels to prevent conveyance and evaporation losses.

4. Research pertaining to a dual water supply with fresh and brackish water to the Jaffna Town water supply scheme is necessary in order to restrict the uses of freshwater supply for uses other than drinking and cooking purposes.

Water resources development is a team job involving not only civil engineers but also agricultural scientists, agricultural economists, geographers, geologists, meteorologists and others, and one weakness in the past has been the lack of close cooperation in research between these disciplines in this country. One reason is the fact that no single University in this country is strong in all these fields. A common meeting ground for research workers is being provided by the National Science Council of Sri Lanka and the Ceylon Association for the Advancement of Science, but meetings are too infrequent to be really effective and lack interdisciplinary sessions. Perhaps the recent developments in the newly established Jaffna University probably would lead to more frequent opportunities for liaison between these disciplines and the water authorities in the near future.

In the investigation, development, and operational work on water conservation and use, as distinct from research, another weakness is that the water authorities are content to use teams comprised only of civil engineers without the inclusion of specialists in other relevant fields. Therefore, it is essential to include the services of various scientists also in the planning team for round development and planning of water resources in this region.

REFERENCES

Davis, Kenneth P. : Land Use, McGraw Hill, 1976.

Douglas James L., Robert R. Lee : Economics of Water Resources Planning, Tata Mc Graw Hill Bombay, New Delhi, 1971.

Doxiadis, C.A. : Global action for Man's Water Resources, *Ekistics* Vol. 37. No. 218 (Jan. 1974). pp. 390-393.

Guy. Harold Smith (Ed.) : Conservation of Natural Resources, John Wiley & Sons, 1950.

Humlum, J. : Water Development and Water Planning in the South Western United States, Aarhus Univ. Denmark, 1969.

Koenig, L. : Economics of Groundwater Utilization, J. Am. Water Works Assoc. V. 55, No. 1, p.61. 1963.

Scott, Verne H. : Sprinkler Irrigation, Circular 456, *Agricultural Experimental Station*, University of California, Davis, 1956.

Sen, C.L. : Nitrates in Jaffna Water Supplies and Effects on Human Health, Jaffna Market Town Water Supply paper, 1982.

Thaker, M.S. : Natural Resources and Their Planned Utilization, The Maharaja Sayaji Rao, University of Baroda, 1963.

Thomas, H.E. : The Conservation of Groundwater, Mc Graw Hill Book Company, Inc. New York. 1951.

Thomas, R.O. and others : Groundwater Development: A Symposium, *Trans. Am. Sic. Civil Engrs*. Vol. 122. 1957.

Valantine, V.E. : Groundwater Management for the Nation's Future: Effecting Optimum Groundwater Basin Management, *Proc. Am. Soc. Civ. Eng.* V. 90. No. hy. 4, pp. 97-105, 1964.

INDEX

GLOSSARY

Kulam	--	Small water body on the surface
Kurakkan	--	Food grain
Lacham	--	A measure of Land
Legum	--	Food grain such as green gram
Pond	--	Small water body on the surface
Varagu	--	Food grain
Yam	--	Thick tubers usually larger than potatoes from the roots of a particular variety.

BIBLIOGRAPHY

1. BOOKS

Adams, F.D. : Geology of Ceylon, *Canadian Journal of Research* Vol. 1, pp. 425-511. 1929; The Birth and Development of Geological Science, Baltimore, 1938.

Altovsky, M. and Konoplyantsev, A. (Ed.) : Manual for the Systematic Study of the Regime of Underground Waters, Foreign Language Publishing House, Moscow, 1959.

Balendran, V.S., Sirimanne, C.H.L., Arumugam, S. : Groundwater in Jaffna, Water Resources Board, Colombo, 1968.

Barton Worthington, E. (Ed.) : Arid Land Irrigation in Developing Countries, Pergamon Press, 1977.

Beardmore, Nathaniel : Manual of Hydrology, London, 1850.

Brohier, R.L. : Ancient Irrigation Works in Ceylon, 3 Vol. Govt. Press, Colombo, 1934

Brown, R.H., Konoplyantsev, A.A., Inesonj., Kovalevsky, U.S. : Groundwater Studies - An International Guide for Research and Practice, UNESCO, Paris, 1972.

Campbell (M.D) and Lehr (J.H.) : Water Well Technology, Mc Graw Hill, 1973.

Chorley, R.J. (Ed.) : Water, Earth and Man, Methuen, 1969; Introduction to Physical Hydrology, Methuen & Co., 1973.

Cooray, P.G. : An introduction to the Geology of Ceylon, Museum Publication, Ceylon, 1967.

Darcy, Henry : Les Fontaines Publique de la ville de Dijon, Paris, 1856.

Davis, Kenneth P. : Land Use, Mc Graw Hill, 1976.

Davis, Stanley N., and De Wiest, Roger, J.M. : Hydrogeology, New York, Wiley, 1970.

Douglas James, L/Robert R. Lee : Economics of water Resources Planning, Tata Mc Graw Hill, Bombay, New Delhi 1971.

Farmer, B.H. (Ed). : Pioneer Peasant Colonization in Ceylon A Study of Asian Agrarian Problems, Oxford University Press London, 1957; Ceylon: A Divided Nation, Oxford University Press, London, 1963; Green Revolution? London, Macmillan *(Cambridge Commonwealth Series)*, 1977

Fernando, A.D.N. : The Groundwater Resources of Sri Lanka, Planning Division of the Ministry of Power and Highways, Sri Lanka, 1973.

Garg, S.P. : Groundwater and Tube Wells, Oxford and IBM Pub. Company, New Delhi, 1978.

Guy - Harold Smith (Ed.) : Conservation of Natural Resources, John Wiley & Sons, 1950.

Hari Narain, Raghava Rai, K.V., Balakrishna, S. (Ed.) : Exploration Techniques for Groundwater, Proceedings of a workshop organized by COSTED Electron Printers, Bangalore, 1977.

Huisman, L. : Groundwater Recovery, MacMillan, 1972.

Humlum, J. : Water Development and Water Planning in the South Western United States, Aarhus Univ. Denmark, 1969.

Kampen, J.E. : Soil and Water Management in Semi-arid India Agriculture Irrigation, pp. 258-283, May, 1977.

Kazmann (R.G.) : Modern Hydrology, Harper & Row Pub. 1965.

Kendrew, W.G. : The Climate of the Continents, Oxford University Press, New York, 1942.

Linsley and Franzini : Water Resources Engineering, Mc Graw Hill. 1964.

Mc Gauhey, P.H. : Engineering Management of Water Quality, California, Mc Graw Hill, 1969.

Mainzer, O.E. : The History and Development of Groundwater Hydrology, Washington Acad. Sci. Jour. Vol. 24, 1934.

Meyer, A.F. : The Elements of Hydrology, 1st Ed. New York. 1917.

Nefedov, K, E., Popova, T.A. : Deciphering of Groundwater from Aerial Photographs, Amerind Publishing Co. Pvt. Ltd., New Delhi, Bombay, Calcutta. 1972.

Pavoni, Joseph L. (Ed.) : Handbook of Water Quality Management Planning, New York, Van Nostrand, 1977.

Raymond Furon : The Problem of Water (Translated by Paul Barnes) - a World Study, Faber & Faber Ltd, 1963.

Rose, C.W. : Agricultural Physics, Pergamon Press, 1966.

Simmons, I.G. : The Ecology of Natural Resources, Arnold, 1974.

Teerink, John R. : Water Quality Pollution and Sea Water Intrusion Problems, Governors Dry Year Water Conference, Los Angeles, July 13, 1961, Mimeograph.

Thaker, M.S. : Natural Resources and their Planned Utilization, The Maharaja Sayaji Rao University of Baroda, 1963.

Thomas, H.E. : The Conservation of Groundwater, McGraw Hill Book Company, Inc. New York, 1951.

Thomas King : Water - Miracle of Nature, Collier Books, New York, 1961.

Todd, David, K. : Groundwater Hydrology, John Wiley & Sons, Inc. New York and London. 1959.

Tolman, C.F. : Groundwater, McGraw Hill, New York. 1937.

Van Dyne George, M. (Ed.) : The Ecosystem Concept in Natural Resource Management, Academic Press, New York. 1969.

Walton, W.C. : Groundwater Resources Evaluation, McGraw Hill Book Co., New York, 1970.

Ward (R.C.) : Principles of Hydrology, Mc Graw Hill, 1967.

Warran Viessman Jr., Terance E. Harbaugh, John W. Knapp : Introduction to Hydrology, Intext Educational Publishers, New York, 1972.

Wisler/Brater : Hydrology, John Wiley & Sons, 1959.

2. PERIODICALS

Adams, F.D. : The Origin of Springs and Rivers - A Historical review, *Fennia 50*, No.1, Helsingfors, Finland, 1928.

Jayamaha, G.S. : A Summary of the Meteorological Characteristics of Ceylon. Bulletin of the Ceylon Geographical Society, Vol. 9, No. 1, 1955.

King, F.H. : Principles and Conditions of the Movements of Groundwater, U.S.Geol. Survey, 19th Annual Report pt. 2, pp. 55-294. 1899.

Koenig, L. : Economics of Groundwater Utilization. J.AM, Water Works Assoc. V. 55, No. 1, p. 61, 1963.

Mahadeva, S. : The Hydrology of Jaffna, *The Engineering Association of Ceylon, Transactions,* 1938; The Hydrology of Jaffna with Particular Reference to the Jaffna Water Supply, *The Engineering Association of Ceylon, Transactions,* 1938.

Mather, J.D. : Development of Groundwater Resources of Small Limestone Islands, Q.J.Eng. Geol. 8: 141-150, London. 1975.

Seniveratna, L.K. and Balendran, V.S. : Hot Springs of Ceylon, *Ceylon Association for the Advancement of Science, Transactions,* 1968.

Somerville, B.T. : The Submerged Plateau Surrounding Ceylon; Some Considerations Regarding the Formation of the Coastline, *Spolia Zeylanica,* 1908.

Sirimanne, C.H.L. : Geology for Water Supply - Proceedings of the Eighth Annual Session of the *Ceylon Association for the Advancement of Science, Transactions,* 1952; Ceylon's Water Resources and Their Development, *Journal, Soil Conservation Society of Ceylon,* 1962; Groundwater Resources in Dry Zone. *Ceylon Association for the Advancement of Science Proceedings,* Colombo, 1967.

Thambyahpillay, G. : Climatic Controls in Ceylon. University of Ceylon Review, Vol. XI, Nos. 3 and 4, 1963.

Theis, C.V. : Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage, *Trans. Am. Geophys.* Un.pt.2, pp. 519-524, 1935; The Significance and Nature of the Cone of Depression in Groundwater Bodies, *Econ. Geology.* Vol. 33, pp. 889-902, 1938.

Thevathasan, L.R.A. : Drilling for Groundwater. *The Institution of Engineers, Ceylon, Transactions*, 1967.

Thomas, R.O. and others : Groundwater Development: A Symposium, *Trans. Am. Soc. Civil Engrs.* Vol. 122, 1957.

Thompson, B.W. : An Essay in the General Circulation of the Atmosphere Over S.E. Asia and the West Pacific, *Quarterly Journal of the Royal Meteorological Society,* Oct. 1951.

Valentine, V.E. : Groundwater Management for the Nation's Future: Effecting Optimum Groundwater Basin Management, *Proc. Am. Scc. Civ. Eng.* V. 90, No. Hy 4, pp. 97-105, 1964.

Water : The Yearbook of Agriculture 1955, The United States Department of Agriculture, Oxford IBH Publishing Company.

Wayland, E.J. : Outlines of the Stone Ages of Ceylon, *Spolia Zeylanica*, Vol. II, pp. 85-125. 1921.

Wayland, E.J. and Davies, A.M. : The Miocene of Ceylon, Quarterly Journal Geological Society, Part 4, LXXIX, 1923.

Wentworth, C.K. : The Problem of Safe Yield in Insular Ghyben-Herzberg Systems, *Transactions, American Geophysical Union* 32, 739-742, 1951, Washington D.C.

Wijesinghe, M.W.P. : Groundwater Hydrology, *Ceylon Association for the Advancement of Science. Transactions,* 1973, Colombo.

3. REPORTS/UNPUBLISHED WORKS

Arad, Anon : Groundwater in the Jaffna Peninsula, Unpublished Report in the Files of the Irrigation Dept. Colombo, 1965.

Arumugam, S. : A Memorandum on the Jaffna Town Water Supply, An Unpublished Paper in the Files of the Municipal Council, Jaffna, 1971.

Dolcini, Albert J. : Groundwater Resources Planning, Biennial Conference on Groundwater Research, Development and Management at the University of California, Los Angeles, Sept. 1, 1965, CDWR Sacramento, 1965, (Mimeograph); Groundwater Resources Planning, Biennial Conference on Groundwater, Recharge, Development and Management at the University of California, Los Angeles Sept. 1, 1965, CDWR Sacramento, 1965, (Mimeograph).

Foster, S.S.D. : The Problem of Groundwater Quality Management in Jaffna - Sri Lanka (JD/05/76/3) Unpublished Report, U.K. Ministry of Overseas Development, 1976.

Frink, John W. : Groundwater conditions in Ceylon, Unpublished Report of the United States Operations Mission to Ceylon. 1950.

Goldberg C.F.A. : Assessment of Groundwater Potentials in the Republic of Sri Lanka, Regional Mineral Resources Development Centre Advisory Services Report (Unpublished) HG 2, 1974.

Gunasegaram, T. : Groundwater Potentials and Saline Water Intrusion in the Limestone Aquifer- North Western Zone - Jaffna Peninsula Unpublished Report, 1978; Groundwater Pollution in the Jaffna Peninsula Unpublished Report in the files of the Water Resources Board, Jaffna, 1980.

Henry, H.R. : Interfaces Between Saltwater and Freshwater in Coastal Aquifers, USGS Water Supply Paper 16130, Washington D.C. 1964.

Jeyasingham, W.L. : Urban Geography of Jaffna Town, Unpublished Ph.D. Thesis, Clark University, 1958.

Mc Naughton, G. : Aspects of Water Pollution Control, WHO Public Health Papers No. 13, 1963.

Meiszer, D.E. : Outline of Groundwater Hydrology with Definitions, U.S. Geological Survey Water Supply Paper 493, 1923.

Meisler, Harold : Groundwater in the Jaffna Peninsula - Republic of Sri Lanka, Unpublished U.D. Geological Survey Report, 1977.

Nace, R.L. : Water Management, Agriculture and Groundwater supplies, Geological Survey Circular 415, Washington D.C. 1964.

Patkunan, V.R. : General Hydrogeologic Reconnaissance Survey of Freak Wells and Coastal Springs in Jaffna Peninsula, Unpublished Report in the Files of the Irrigation Department, Colombo, 1974.

Rao, K.N., George, C.T. and Ramasastri, K.S.: India, - Meteorological Department Scientific Report No. 136, New Delhi.

Report of the Colombo Observatory, Sri Lanka, 1967.

Report of the Colombo Observatory, Sri Lanka, 1968.

Scott, Verne, H. : Sprinkler Irrigation, Circular 456 Agricultural Experiment Station, University of California, 1956.

Sen, C.L. : Nitrates in Jaffna Water Supplies and Effects on Human Health, Jaffna Market Town Water Supply paper, [Year unclear in original text: Editor].

Slichter, C.S. : Field Measurements of the Rate of Underground Water. U.S. Geol. Survey Water Supply paper 140,1905; Theoretical Investigation of the Motion of Groundwater H.S. Geol. Survey 19th Ann. Report. pt. 2, pp. 295-384, 1897.

Sirimanne, C.H.L. : Ceylon's Groundwater Resources Report of the Working Group on Irrigation and Land Development, 1964.

Sirimanne, C.H.L. and Vaidya, G.D. : The Occurrence of Groundwater in Ceylon, Proceedings of the Symposium on Groundwater, India, Central Board of Geophysics, Pub. No 4, pp. 95-108, 1958.

Thorne, Wynne. : Land and Water Use Pub. No. 73 of the American Association for the Advancement of Science, Washington D.C. 1963.

Wijesinghe, M.W.P. : Underground Water Resources of the Jaffna Peninsula and the Islands, Unpublished Report in the Files of the Irrigation Department, Jaffna, 1975; Planning of Groundwater of Irrigation on Sri Lanka. Proceedings of the Second World Congress on water resources, New Delhi, India, 1975.

INVESTIGATIONS AND ANALYSIS REPORT: Market Town Water Supply, Jaffna Project, The National Water Supply and Drainage Board, Sri Lanka.

FINAL FEASIBILITY STUDIES REPORT: Part I and Part II, Market Town Water Supply, Jaffna Project, The National Water Supply and Drainage Board, Sri Lanka.

PRELIMINARY STUDIES REPORT: Market Town Water Supply, Jaffna Project, The National Water Supply and Drainage Board, Sri Lanka.

AUTHOR'S APPENDIX

APPENDIX - I

OBSERVATION WELLS

A.G.A's Division

Well Location No.	Well Location No.
PACHILLAI PALI (16 Wells)	25. Varany North
1. Chundikulam	26. Varany North
2. Mulliyan	27. Idaikurichy
3. Mulliyan	28. Idaikurichy
4. Koil Vayal	29. Varany, Thavalai
5. Koil Vayal	30. Varany, Thavalai
6. Muhavil	31. Navat Kadu
7. Soran Pattu	32. Iyattalai Sarasalai
8. Ittavil	33. Manthuvil
9. Puloppallai	34. Kodigamam
10. Puloppallai	35. Meesalai North
11. Kilaley	36. Manthuvil
12. Kilaley	37. Meesalai North
13. Muhamalai	38. Iyattalai, Sarasalai
14. Chempian Pattu	39. Madduvil North
15. Champian Pattu	40. Kaithady
16. Maruthankerni	41. Kaithady
THENMARACHCHY (44 Wells)	42. Koilakandy
17. Eluthumaduvil	43. Koilakandy
18. Eluthumaduvil	44. Maravan Pulam
19. Usan	45. Maravan Pulam
20. Mirusuvil	46. Thanan Kilappu
21. Mirusuvil	47. Thanan Kilappu
22. Usan	48. Madduvil North
23. Kodigamam	49. Meesalai South
24. Mavat Kadu	50. Meesalai South

Well Location No.
51. Chavakachcheri
52. Kachchai North
53. Kachchai North
54. Madduvil Nunavil
55. Chavakachcheri
56. Chavakachcheri South
57. Chavakachcheri South
58. Nunavil
59. Nunavil
60. Madduvil Nunavil
VADARARACHCHY (100 Wells)
61. Nagarkovil
62. Nagarkovil
63. Nagarkovil
64. Nagarkovil
65. Kudathanai Karaiyoor
66. Kudathanai Karaiyoor
67. Kudathanai Karaiyoor
68. Ampan
69. Ampan
70. Kudathanai karaiyoor
71. Ampan
72. Ampan
73. Thunnalai North
74. Thumpalai
75. Kalkovilam
76. Kalkovilam
77. Kalkovilam
78. Thumpalai
79. Thumpalai

Well Location No.
80. Thumpalai
81. Point Pedro
82. Point Pedro
83. Point Pedro
84. Alvai North
85. Puloly West
86. Puloly West
87. Puloly East
88. Puloly East
89. Puloly East
90. Thumpalai
91. Puloly East
92. Puloly East
93. Puloly South
94. Puloly South
95. Thunnalai North
96. Thunnalai South
97. Thunnalai North
98. Thunnalai North
99. Thunnalai South
100. Alvai North
101. Alvai West
102. Alvai South
103. Alvai South
104. Puloly West
105. Alvai North
106. Puloly West
107. Puloly South
108. Puloly South
109. Alvai South

Well Location No.	Well Location No.
110. Alvai South	140. Plokandy
111. Alvai South	141. Valvetty
112. Thunnalai South	142. Udupiddy
113. Thunnalai South	143. Valvetty
114. Karaveddi West	144. Valvetty
115. Karaveddi West	145. Udupiddy
116. Karaveddi West	146. Udupiddy
117. Karaveddi East	147. Udupiddy
118. Karaveddi West	148. Kerudavil
119. Karaveddi East	149. Udupiddy
120. Karaveddi East	150. Thondaimanaru
121. Alvai West	151. Udupiddy
122. Karanawai North	152. Kerudavil
123. Alvai West	153. Thonda Manaru
124. Polikandy	154. Thonda Manaru
125. Karaveddi North	155. Kerudavil
126. Karaveddi North	156. Udupiddy
127. Karaveddy North	157. Udupiddy
128. Karaveddy North	158. Valvettithurai
129. Karaveddi West	159. Udupiddy
130. Karanawai North	160. Valvettithurai
131. Karanawai South	**VALLIKAMMAM EAST (40 Wells)**
132. Karanawai North	161. Pathaimany
133. Karanawai South	162. Pathaimany
134. Karanawai North	163. Pathaimany
135. Karanawai South	164. Pathimany
136. Karanawai Sourth	165. Atchuvely
137. Karanawai South	166. Atchuvely
138. Polikandy	167. Atchuvely
139. Polikandy	168. Atchuvely

Well Location No.
169. Puttur West
170. Puttur West
171. Puttur East
172. Puttur East
173. Puttur West
174. Puttur East
175. Puttur East
176. Sirupiddy
177. Sirupiddy
178. Sirupiddy
179. Sirupiddy
180. Neervely
181. Nerrvely
182. Neervely
183. Urumpirai
184. Urelu
185. Urumpirai
186. Urumpirai
187. Urumpirai
188. Kopay North
189. Kopay North
190. Neervely
191. Kopay South
192. Kopay North
193. Kopay South
194. Kopay South
195. Kopay South
196. Kopay South
197. Urumpirai
198. Urelu

Well Location No.
199. Urelu
200. Puttur West
VALIKAMAM NORTH (100 Wells)
201. Palaly
202. Palaly
203. Palaly
204. Palaly
205. Vasavilan
206. Vasavilan
207. Vasavilan
208. Vasavilan
209. Punnalaikadduvan
210. Punnalaikadduvan
211. Punnalaikadduvan
212. Punnalaikadduvan
213. Myliddy East
214. Myliddy East
215. Myliddy North
216. Palaly
217. Myliddy South
218. Myliddy South
219. Myliddy South
220. Myliddy South
221. Vasavilan
222. Kadduvan
223. Kuppilan
224. Kuppilan
225. Punnalai Kadduvan
226. Kuppilan
227. Kuppilan

Well Location No.	Well Location No.
228. Kuppilan	258. Maviddapuram
229. Earlalai	259. Palaly Veemankaman
230. Earlalai	260. Maviddapuram
231. Earlalai	261. Tellippalai North West
232. Earlalai	262. Maviddapuram
233. Earlalai	263. Tellippalai North West
234. Chunnakan	264. Tellippalai North West
235. Myliddy East	265. Maviddapuram
236. Myliddy East	266. Maviddapuram
237. Myliddy East	267. Tellippalai South West
238. Kankesanthurai	268. Tellippalai North West
239. Myliddy North	269. Tellippalai North West
240. Myliddy North	270. Tellippalai South West
241. Myliddu North	271. Tellippalai South West
242. Palaly Veemankaman	272. Tellippalai South West
243. Palaly Veemankaman	273. Tellippalai South West
244. Myliddy North	274. Tellippalai East
245. Kadduvan	275. Tellippalai East
246. Myliddy South	276. Tellippalai East
247. Tellippalai East	277. Alaveddy
248. Kadduvan	278. Alaveddy
249. Kadduvan	279. Alaveddy
250. Kadduvan	280. Mallakam
251. Tellippalai East	281. Mallakam
252. Kankesanthurai	282. Alaveddy
253. Kankesanthurai	283. Mallakam
254. Kankesanthurai	284. Mallakam
255. Kankesanthurai	285. Mallakam
256. Palaly Veemankaman	286. Chunnakam
257. Palaly Veemankaman	287. Chunnakam

Well Location No.
288. Chunnakam
289. Uduvil
290. Uduvil
291. Uduvil
292. Chunnakam
293. Inuvil
294. Inuvil
295. Uduvil
296. Uduvil
297. Inuvil
298. Inuvil
299. Inuvil
300. Alaveddy
VALLIKAMMAM WEST (36 Wells)
301. Periyavilan
302. Periyavilan
303. Sandilipay
304. Mathagal
305. Mathagal
306. Pandaitharippu
307. Pandaitharippu
308. Chankanai West
309. Chankanai East
310. Sandillipay
311. Chulipuram

Well Location No.
312. Chulipuram
313. Chulipuram
314. Chulipuram
315. Chankanai West
316. Chankanai East
317. Vaddu East
318. Moolai
319. Moolai
320. Vaddukoddai West
321. Vaddu East
322. Vaddukoddai
323. Araly North West
324. Araly North West
325. Araly South East
326. Araly South East
327. Araly North West
328. Manipay
329. Navaly
330. Manipay
331. Suthumalai
332. Suthumalai
333. Anaikoddai
334. Anaikoddai
335. Navaly
336. Navaly

APPENDIX - II

Data of Some Selected Wells

Water in the Well (in feet)

AGA's Division Village	Well No.	1965-1966		1966-1967		1967-1968	
		1-8-65	1-1-66	1-8-66	1-1-67	1-8-67	1-1-68
Koil Vayal	5	1.42	11.98	4.42	6.67	2.67	12.67
Ittavil	8	-	-	5.00	7.94	3.06	10.11
Puloppallai	9	1.00	-	3.04	4.83	0.65	9.67
Maruthankerni	16	1.01	3.43	1.01	2.64	1.60	3.35
Eluthumaduvil	17	2.41	0.37	2.37	6.20	1.87	9.66
Varany Thavalai	30	2.08	7.29	2.38	6.60	2.15	7.33
Kodigamam	34	0.92	6.75	0.88	4.12	1.17	6.67
Iyattalai Sarasalai	38	3.25	6.37	3.04	5.54	3.23	6.25
Kaithady	40	-	5.50	3.75	4.50	4.75	5.42
Koilakandy	42	2.87	5.95	2.87	5.33	2.99	5.66
Maravan Pulam	45	2.25	7.42	2.17	6.67	1.96	7.25
Kachchai North	53	3.50	11.92	4.56	10.17	6.67	13.09
Nagarkovil	61	1.32	4.84	1.17	3.75	1.04	4.58
Kudathannai Karayoor	70	0.42	3.09	0.51	1.63	0.58	3.16
Thumpalai	80	5.67	8.33	5.25	7.25	5.31	8.00
Alvai North	100	0.08	3.33	0.08	1.58	0.08	1.83
Udupiddy	146	3.29	4.46	3.21	4.71	3.15	4.46
Kerudavil	155	2.74	5.33	2.66	4.66	2.58	4.91
Pathaimany	163	-	3.71	0.96	3.04	1.13	3.25
Puttur East	174	-	6.92	3.75	7.42	5.42	7.04
Neervely	181	-	6.75	3.83	6.03	3.95	6.33
Urumpirai	187	-	2.13	2.60	3.13	1.43	3.47
Vasavilan	205	2.00	4.58	1.78	3.96	1.92	4.08
Vasavilan	208	3.09	5.17	2.80	5.29	2.81	3.66
Myliddy East	214	1.08	1.83	7.84	3.75	1.54	3.92
Chunnakam	234	4.89	8.14	4.81	7.64	5.33	5.58
Tellippalai East	247	0.84	2.17	1.38	4.38	2.38	4.63
Pandaitharippi	307	3.40	7.57	3.09	6.42	3.84	7.61
Chulipuram	314	3.08	7.54	2.92	6.67	2.92	8.00
Araly North West	327	1.00	5.92	1.00	5.42	1.33	6.00
Manipay	328	5.63	11.67	5.42	4.50	5.00	13.08
Karainagar North	337	1.58	8.16	2.16	8.08	3.91	7.83
Karainagar East	340	0.17	1.63	3.17	9.67	6.12	10.30
Kayts	343	1.11	7.55	1.26	6.72	2.01	8.30
Saravanai	349	3.40	10.07	3.57	9.45	1.55	11.67
Analativu	361	0.54	2.79	0.49	2.75	0.67	2.83
Pungudutivu West	367	5.38	10.50	5.92	9.17	4.17	9.67
Thirunelvely	377	-	8.33	4.75	5.65	4.92	8.08
Delft	408	-	-	-	6.85	0.39	6.48
Delft	410	-	-	1.93	5.09	1.12	2.68

APPENDIX - III

Data of Some Selected Wells

Elevation of Water Surface in Well – M.S.L. Datum

AGA's Division Village	Well No.	1965-1966		1966-1967		1967-1968	
		1-8-65	1-1-66	1-8-66	1-1-67	1-8-67	1-1-68
Koil Vayal	5	1.27	11.83	4.27	6.52	2.52	12.52
Ittavil	8	-	-	3.49	6.43	1.55	8.60
Puloppallai	9	-1.20	-	0.34	2.63	-1.55	7.47
Maruthankerni	16	0.92	3.34	0.02	2.33	1.51	3.26
Eluthumaduvil	17	0.08	7.04	0.04	3.87	-0.46	7.33
Varany Thavalai	30	-1.38	3.83	-1.08	3.14	-1.31	3.87
Kodigamam	34	-0.93	4.90	-0.97	2.27	-0.68	4.82
Iyattalai Sarasalai	38	0.32	3.44	0.11	2.61	0.28	3.32
Kaithady	40	-	2.83	1.08	1.83	2.08	2.75
Koilakandy	42	-0.26	2.82	-0.26	2.20	-0.14	2.53
Maravan Pulam	45	-1.95	3.22	-2.03	2.47	-2.24	3.05
Kachchai North	53	-2.03	6.39	0.97	4.64	1.14	7.56
Nagarkovil	61	4.06	7.58	3.91	6.49	3.78	7.62
Kudathannai Karayoor	70	-0.20	2.47	0.11	1.01	0.04	2.54
Thumpalai	80	2.17	4.83	1.75	3.75	1.81	4.50
Alvai North	100	0.00	3.25	0.00	1.50	0.00	1.75
Udupiddy	146	0.94	2.11	0.86	1.36	0.77	2.11
Kerudavil	155	0.27	2.86	0.19	2.19	0.11	2.44
Pathaimany	163	-	2.80	0.05	2.13	0.22	2.34
Puttur East	174	-	3.40	0.23	3.90	1.90	3.52
Neervely	181	-	3.16	0.24	2.44	0.33	2.74
Urumpirai	187	-	1.86	0.53	2.86	1.16	3.20
Vasavilan	205	-0.60	1.98	-0.82	1.36	-0.68	1.48
Vasavilan	208	-0.22	1.86	-0.51	1.98	-0.47	0.35
Myliddy East	214	-3.64	2.89	3.12	-0.97	-3.18	-0.80
Chunnakam	234	0.16	3.41	0.08	2.91	0.60	0.85
Tellippalai East	247	0.70	2.03	0.14	2.86	0.86	3.11
Pandaitharippi	307	0.13	4.30	-0.18	3.15	0.57	4.34
Chulipuram	314	0.22	4.68	0.06	3.81	0.06	5.14
Araly North West	327	-1.14	3.78	-1.14	3.28	-0.81	3.86
Manipay	328	0.42	5.62	-0.63	4.45	-1.05	7.03
Karainagar North	337	-2.68	3.90	-2.10	3.82	-0.35	3.57
Karainagar East	340	-5.90	-4.44	-2.90	3.60	0.05	4.31
Kayts	343	-2.02	4.43	-1.86	3.60	-1.11	5.18
Saravanai	349	-1.24	5.43	-1.07	4.85	-3.09	6.43
Analativu	361	1.21	3.46	1.16	3.42	1.34	3.50
Pungudutivu West	367	0.64	5.76	1.18	4.43	-0.57	4.93
Thirunelvely	377	-	3.90	0.32	1.22	0.49	3.65
Delft	408	-	-	-	5.01	-1.45	4.64
Delft	410	-	-	0.65	3.81	-0.16	1.40

APPENDIX - IV

Data of Some Selected Wells

Data of Salinity From Sample of Water Found at Bottom of Well (Chloride ions in parts per million)

AGA's Division Village	Well No.	1966-1967		1967-1968	
		1-8-66	1-1-67	1-8-67	1-1-68
Koil Vayal	5	90	75	170	160
Ittavil	8	40	55	35	25
Puloppallai	9	110	105	115	340
Maruthankerni	16	45	25	25	30
Eluthumaduvil	17	200	210	90	110
Varany Thavalai	30	7750	225	750	330
Kodigamam	34	125	90	180	20
Iyattalai Sarasalai	38	975	890	930	1010
Kaithady	40	250	175	350	90
Koilakandy	42	3175	1905	1880	1590
Maravan Pulam	45	1625	172.5	1540	1300
Kachchai North	53	62.5	37.5	20	40
Nagarkovil	61	403	60	50	15
Kudathannai Karayoor	70	65	110	20	20
Thumpalai	80	2362.5	2225	2590	900
Alvai North	100	1878	2075	2150	3060
Udupiddy	146	410	750	1130	580
Kerudavil	155	180	150	210	70
Pathaimany	163	1850	1520	Not Clear	1560
Puttur East	174	850	625	870	650
Neervely	181	470	250	490	420
Urumpirai	187	110	137.5	195	270
Vasavilan	205	75	125	75	200
Vasavilan	208	-	175	190	275
Myliddy East	214	120	87.5	120	60
Chunnakam	234	75	112.5	70	130
Tellippalai East	247	5.3	200	190	275
Pandaitharippi	307	-	200	200	310
Chulipuram	314	275	50	290	30
Araly North West	327	1650	7000	5850	Not Clear
Manipay	328	425	375	450	430
Karainagar North	337	-	280	450	220
Karainagar East	340	-	510	Not Clear	510
Kayts	343	6037	2825	Not Clear	1800
Saravanai	349	1175	700	1075	675
Analativu	361	1850	125	Not Clear	125
Pungudutivu West	367	2210	700	2200	600
Thirunelvely	377	300	975	300	1150
Delft	408	-	8140	15200	3850
Delft	410	477.1	145	430	170

APPENDIX - V

Number of Ponds and Surface Storage According to AGA's Division in the Jaffna Peninsula (excluding Islands)

AGA's Division	No. of Ponds	Capacity in Ac.ft.
Jaffna and Nallur	41	313.46
Valigamam South West	25	194.29
Valigamam South	10	110.00
Valigamam North	95	457.18
Valigamam East	27	17.90
Valigamam West	46	346.16
Vadamaradchy South West	216	2537.92
Vadamaradchy North East	04	1.47
Thenmaradchy	528	1872.08
Pachilappalli	61	491.93
Total	1053	6342.39

APPENDIX - VI

Monthly and Annual Rainfall in Inches, During 1970-79 at Representative Precipitation, Stations on the Jaffna Peninsula Maintained by the Water Resources Board

Stations	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1970													
Ampan	1.2	1.13	-	3.37	4.99	2.47	-	2.52	0.83	7.24	19.99	4.25	47.99
Mirusuvil	1.08	1.04	-	-	5.80	-	-	-	2.50	7.97	19.32	5.38	43.09
1971													
Jaffna	4.42	1.01	0.24	0.13	1.74	1.71	1.30	0.57	1.72	4.92	4.15	22.64	44.55
Ampan	5.07	0.55	-	1.03	0.99	Not Clear	-	1.00	2.53	3.88	2.23	27.00	45.32
Mirusuvil	7.07	0.89	-	0.23	0.64	Not Clear	-	0.98	2.61	6.59	4.20	28.67	52.57
1972													
Jaffna	0.98	-	-	93	5.93	1.92	1.56	0.04	1.36	15.36	10.94	6.45	45.27
Ampan	1.30	-	-	-	6.16	0.17	0.83	-	Not Clear	12.53	3.71	12.05	38.62
Mirusuvil	-	-	-	-	7.57	-	-	-	1.33	9.07	9.58	11.64	39.19
1973													
Jaffna	0.15	0.83	0.73	0.60	2.89	0.25	0.66	3.56	Not Clear	Not Clear	7.24	15.05	41.83
Ampan	-	1.55	-	-	1.60	-	-	2.35	0.69	5.32	10.42	14.53	Not Clear
Mirusuvil	0.05	-	-	-	0.53	-	-	-	0.69	6.18	10.83	18.95	37.23

Contd.......

APPENDIX - VI Contd....

Stations	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1974													
Jaffna	1.36	0.93	0.06	1.07	-	-	-	-	-	-	-	9.11	12.53
Ampan	1.02	0.94	-	-	3.30	1.75	1.60	-	3.40	3.60	2.85	6.98	25.44
Mirusuvil	0.64	0.98	-	0.06	1.63	1.10	0.11	-	1.94	1.03	2.23	4.83	14.55
1975													
Jaffna	3.50	0.55	1.02	1.42	1.33	0.03	2.40	0.97	3.16	14.21	10.74	16.88	56.21
Ampan	2.25	-	-	-	1.25	1.50	1.55	2.65	-	8.33	12.00	14.50	44.03
Mirusuvil	3.25	0.06	0.86	0.47	NR	NR	NR	NR	NR	NR	NR	Not Clear	Not Clear
1976													
Jaffna	0.78	-	0.35	4.07	-	0.05	0.43	-	0.05	9.86	11.66	11.94	39.19
Ampan	0.75	-	1.30	1.60	-	1.75	-	1.85	-	9.75	12.72	12.10	41.82
Mirusuvil	-	-	-	0.01	-	0.03	-	-	-	10.12	10.35	12.59	33.10
1977													
Jaffna	0.27	2.17	0.69	2.01	5.86	0.63	1.72	3.40	0.45	24.19	15.47	3.04	59.9
Ampan	-	0.65	-	0.75	3.75	1.53	-	2.09	-	18.71	17.59	5.03	50.10
Mirusuvil	0.31	0.77	-	0.22	3.15	2.07	1.06	1.19	2.06	18.00	19.18	3.01	51.02
1978													
Jaffna	-	0.18	0.07	0.80	1.73	-	0.03	0.05	0.89	7.27	15.60	19.13	45.75
Ampan	-	-	1.0	0.25	0.85	-	0.80	-	3.45	9.28	13.02	15.72	48.37
Mirusuvil	-	-	-	0.39	1.26	-	0.17	-	1.33	9.33	12.12	21.17	45.77
Thirunelvely	-	-	-	-	-	-	0.59	0.03	0.82	7.21	20.06	18.26	46.97

IF – Irrigation Facilities

APPENDIX - VII

DOMESTIC AND AGRICULTURAL EXTRACTION DATA OF N.N.ZONE - INTENSIVE AREA STAGE-I

PREPARED BY : T.GUNASEGARA, T.A. & R.THAMBIRATNAM

Group Area in ACS	Total Saline Wells	Total Fresh Wells	Total Wells	AV. Recuperate Time	Acreage Cultivated	Agricultural extraction for 17 weeks 2 IF per week	Agricultural extraction for 20 weeks 1½ IF per week	Total number of Persons	Domestic extraction for 52 weeks	Total Agricultural extraction for 37 weeks	Domestic & Agricultural extraction one year
2704	271	896	1167	4	555.0	1467.4	1294.8	4025	77.0	2762.20	2859.20
608	61	117	178	2	39.0	102.8	90.7	748	13.2	193.50	206.70
882	46	230	276	3	21.1	55.6	49.1	1056	19.8	104.70	124.50
1938	186	879	1065	12	534.1	1410.1	1244.5	4998	102.0	2654.6	2756.60
1136	368	322	690	3	311.0	820.7	724.4	3083	59.0	1545.1	1606.00
5264	46	1020	1066	4	741.0	1956.2	1726.5	3347	64.0	3682.7	3746.70
856	36	175	211	6	115.3	304.3	268.5	1187	22.7	572.8	595.50
928	21	990	1011	3	476.2	1257.1	1109.5	620	114.5	2366.6	2481.10
996	82	745	827	4	636.4	1680.2	1482.9	412	79.4	3163.1	3242.50
1600	96	586	682	3	81.2	214.3	189.2	1513	44.2	403.5	447.70
3408	53	623	676	4	342.3	903.5	797.4	2593	50.0	1700.9	1750.90
2280	4	1269	1273	3	895.0	2362.8	2065.4	418	80.84	4448.2	4529.04
Not Clear	1458	554	1992	6	625.5	1650.0	1456.3	300	57.98	3106.3	3164.28
1200	575	803	1378	1	406.4	1071.8	946.8	5051	97.49	2017.8	2115.29
1800	192	1035	1227	3	280.0	739.2	652.4	6090	117.54	1391.6	1509.14
876	Not Clear	427	444	3	355.4	937.2	827.2	4805	92.69	1764.4	1857.09
1072	100	271	371	4	190.8	504.2	445.0	1207	23.30	949.2	972.50
203	20	88	100	3	Not Clear	37.78	33.34	392	7.50	71.12	78.62
2944	451	876	1327	4	75.0	198.0	174.75	1906	36.79	372.75	409.54
1024	270	735	1006	3	107.2	282.5	249.3	2034	39.26	531.8	571.05
320	2257	355	612	6	366.0	966.2	852.8	2367	45.63	1819.0	1864.63
768	83	251	354	3	553.0	1407.1	1241.9	3011	58.11	2649.0	2707.11
3920	1348	192	1540	4	972.0	2566.1	2264.8	1422	27.44	4830.9	4858.34
608	57	150	207	3	103.0	271.9	240.0	1652	31.88	511.9	543.78
1020	235	373	506	3	Not Clear	496.3	438.0	3940	76.04	934.3	1010.34
38144	**6143**	**13862**	**20006**		**8964.2**	**23663.28**	**20884.69**	**73770**	**1439.19**	**44547.97**	**45987.12**

IF – Irrigation Facilities

EDITOR'S APPENDIX

Editor's Appendix I

Spelling and Pronunciation of Place Names

Alaveddy: *அளவெட்டி*: Aḷaveṭṭi

Alvai: *அல்வாய்*: Alvāy

Ampan: *அம்பன்*: Ampaṉ

Anaikoddai: *ஆனைக்கோட்டை*: Āṉaikkōṭṭai

Analaitivu: *அனலைதீவு*: Aṉalaitīvu

Araly: *அராலி*: Arāli

Ariyalai: *அரியாலை*: Ariyālai

Atchuvely: *அச்சுவேலி*: Accuvēli

Chankanai: *சங்கானை*: Caṅkāṉai

Chavakacheri: *சாவகச்சேரி*: Cāvakaccēri

Cheddikadu: *செட்டிகாடு*: Ceṭṭikāṭu

Chemmani: *செம்மணி*: Cemmaṇi

Chempiyanpattu: *செம்பியன்பற்று*: Cempiyaṉpaṟṟu

Chillalai: *சில்லாலை*: Cillālai

Chiviyatheru: *சிவியதெரு*: Civiyateru

Chulipuram: *சுழிபுரம்*: Cuḻipuram

Chundikulam/ Chundikkulam: *சுண்டிக்குளம்*: Cuṇṭikkuḷam

Chunnakam: *சுன்னாகம்/ சுண்ணாகம்*: Cuṉṉākam/ Cuṇṇākam

Delft: *நெடுந்தீவு*: Neṭuntīvu

Earlalai: *ஏழாலை*: Ēḻālai

Eluthumadduvil: *எழுதுமட்டுவாள்*: Eḻutumaṭṭuvāḷ

Eluvaitivu: *எழுவைதீவு*: Eḻuvaitīvu

Idaikurichi: *இடைக்குறிச்சி*: Iṭaikkuṟicci

Inuvil: *இணுவில்*: Iṇuvil

Irupalai: *இருபாலை*: Irupālai

Ittavil: *இத்தாவில்*: Ittāvil

Iyattalai: *இயற்றாலை*: Iyaṟṟālai

Kachchai: *கச்சாய்*: Kaccāy

Kadduvan: *கட்டுவன்*: Kaṭṭuvaṉ

Kaithady: *கைதடி*: Kaitaṭi

Kalkovilam: *கற்கோவளம்*: Kaṟkōvaḷam

Kallady: *கல்லடி*: Kallaṭi

Kankesanthurai: *காங்கேசன்துறை*: Kāṅkēcaṉtuṟai

Kaputhu: *கப்புதூ*: Kapputū

Karainagar: *காரைநகர்*: Kārainakar

Karaitivu/ Karainagar: *காரைதீவு/ காரைநகர்*: Kāraitīvu/ Kārainakar

Karaiyur/ Karaiyoor: *கரையூர்*: Karaiyūr

Karanawai: *கரணவாய்*: Karaṇavāy

Karaveddy: *கரவெட்டி*: Karaveṭṭi

Kayts: *ஊராத்துறை/ ஊர்காவல்துறை*: Ūrātturai/ Ūrkāvaltuṟai

Keerimalai: *கீரிமலை*: Kīrimalai

Kerativu: *கேரதீவு*: Kēratīvu

Kerudavil: *கெருடாவில்*: Keruṭāvil

Kilaley: *கிளாலி*: Kiḷāli

Kodikamam: *கொடிகாமம்*; Koṭikāmam

Koil Vayal: *கோயில்வயல்*: Kōyilvayal

Koilakandy: *கோயிலாக்கண்டி*: Kōyilākkaṇṭi

Kondavil: *கோண்டாவில்*: Kōṇṭāvil

Kopay: *கோப்பாய்*: Kōppāy

Kudathanai Karaiyoor: *குடத்தனை கரையூர்*: Kuṭattaṉai Karaiyūr

Kuppilan: *குப்பிழான்*: Kuppiḻāṉ

Madduvil: *மட்டுவில்*: Maṭṭuvil

Mallakam: *மல்லாகம்*: Mallākam

Mandaitivu: *மண்டைதீவு*: Maṇṭaitīvu

Manipay: *மானிப்பாய்*: Māṉippāy

Mannar: *மன்னார்*: Maṉṉār

Manthuvil: *மந்துவில்*: Mantuvil

Maravan Pulam: *மறவன்புலம்/ மறவன்புலவு*: Maṟavanpulam/ Maṟavaṉpulavu

Maruthankerni: *மருதங்கேணி*: Marutaṅkēṇi

Mathagal: *மாதகல்*: Mātakal

Maviddapuram: *மாவிட்டபுரம்*: Māviṭṭapuram

Meesalai: *மீசாலை*: Mīcālai

Mirusuvil: *மிருசுவில்*: Mirucuvil

Moolai: *மூளாய்*: Mūḷāy

Muhamalai: முகமாலை: Mukamālai

Muhavil: முகாவில்: Mukāvil

Mulliyan: முள்ளியான்: Muḷḷiyāṉ

Myliddi: மயிலிட்டி: Mayiliṭṭi

Nagar Kovil: நாகர்கோயில்: Nākarkōyil

Nallathanni Thoduvai: நல்லதண்ணித்தொடுவாய்: Nallataṇṇittoṭuvāy

Nallur: நல்லூர்: Nallūr

Navakiri: நவக்கிரி: Navakkiri

Navaly: நவாலி; Navāli

Navat Kadu: நாவற்காடு: Nāvaṟkāṭu

Navatkuli: நாவற்குழி: Nāvaṟkuḻi

Nayinativu: நயினாதீவு: Nayiṉātīvu

Neervely: நீர்வேலி: Nīrvēli

Nelliady: நெல்லியடி: Nelliyaṭi

Nilavarai: நிலாவரை: Nilāvarai

Nunavil: நுணாவில்: Nuṇāvil

Pachilapalli: பச்சிலைப்பள்ளி/ Paccilaippaḷḷi

Palaly: பலாலி: Palāli

Pallai: பழை: Paḻai

Pandattarippu/ Pandaitharippu: பண்டத்தரிப்பு: Paṇṭattarippu

Pannalai: பன்னாலை: Paṉṉālai

Pathaimany: பத்தைமேனி: Pattaimēṉi

Periya Pachilapalli: பெரிய பச்சிலைப்பள்ளி: Periya Paccilaippaḷḷi

Periya Mandapam: பெரிய மண்டபம்: Periya Maṇṭapam

Periyavilan: பெரிய விளான்: Periya Viḷāṉ

Polikandy: பொலிகண்டி: Polikaṇṭi

Puloly: புலோலி: Pulōli

Pulopallai: புலோப்பழை: Pulōppaḻai

Punkudutivu: புங்குடுதீவு: Puṅkuṭutīvu

Punnalakadduvan: புன்னாலைக்கட்டுவன்: Puṉṉālaikkaṭṭuvaṉ

Puttur: புத்தூர்: Puttūr

Raja Veethi: இராசவீதி: Irācavīti

Sandilipay: சண்டிலிப்பாய்: Caṇṭilippāy

Sarasalai: சரசாலை: Caracālai

Saravanai: *சரவணை*: Caravaṇai

Sinna Mandapam: *சின்ன மண்டபம்*: Ciṉṉa Maṇṭapam

Sirupiddy: *சிறுப்பிட்டி*: Ciṟuppiṭṭi

Soranpattu: *சோரன்பற்று*: Cōraṉpaṟṟu

Suthumalai: *சுதுமலை*: Cutumalai

Tellippalai: *தெல்லிப்பழை*: Tellippaḻai

Thanankilappu: *தனங்கிளப்பு*: Taṉaṅkiḷappu

Thavalai: *தாவளை*: Tāvaḷai

Thenmaradchi/ Thenmaradchy: *தென்மராட்சி*: Teṉmarāṭci

Thirunelvely: *திருநெல்வேலி*: Tirunelvēli

Tholpuram/ Tolpuram: *தொல்புரம்*: Tolpuram

Thondaiman Aru/ Thondaimanar: *தொண்டைமான் ஆறு/ தொண்டைமானாறு*: Toṇṭaimāṉ Āṟu/ Toṇṭaimāṉāṟu

Thumpalai: *தும்பளை*: Tumpaḷai

Thunnalai: *துன்னாலை*: Tuṉṉālai

Udupiddy: *உடுப்பிட்டி*: Uṭuppiṭṭi

Uduvil: *உடுவில்*: Uṭuvil

Uppu Aru: *உப்பு ஆறு/ உப்பாறு*: Uppāṟu

Urelu: *ஊரெழு*: Ūreḻu

Urikkadu: *ஊரிக்காடு*: Ūrikkāṭu

Urumpirai: *உரும்பிராய்*: Urumpirāy

Usan: *உசன்*: Ucaṉ

Vadamaradchi/ Vadamaradchy: *வடமராட்சி*: Vaṭamarāṭci

Vaddukkoddai: *வட்டுக்கோட்டை*: Vaṭṭukkōṭṭai

Valigamam/ Valikamam: *வலிகாமம்*: Valikāmam

Valukkai Aru: *வழுக்கை ஆறு*: Vaḻukkai Āṟu

Valvettithurai: *வல்வெட்டித்துறை*: Valveṭṭitturai

Vannathavillu: *வனாத்தவில்லு/ வண்ணாத்திவில்லு*: Vanāttavillu/ Vaṇṇāttivillu

Varany: *வரணி*: Varaṇi

Vasavilan: *வசாவிளான்*: Vacāviḷāṉ

Veemankamam: *வீமன்காமம்*: Vīmaṉkāmam

Velanai: *வேலணை*: Vēlaṇai

Vilan: *விளான்*: Viḷāṉ

Editor's Appendix II

CERTIFICATE

This is to certify that this Thesis "Water Resources Development in the Jaffna Peninsula - Sri Lanka" was prepared by Mr. R. Mathanakaran under my guidance to be submitted to the University of Mysore for the award of the Degree of Doctor of Philosophy.

P.D. Mahadev,
Supervisor,
Department of Post-Graduate Studies and Research in Geography,
University of Mysore, Mysore 570 006.
1982

DECLARATION

I hereby declare that this Thesis "Water Resources Development in the Jaffna Peninsula - Sri Lanka" was prepared by me under the supervision of Prof. P. D. Mahadev, Professor and Head of the Department of Post-Graduate Studies, and Research in Geography, University of Mysore, and had not been previously submitted for any Degree or Diploma to any other University.

R. Mathanakaran,
Department of Post-Graduate Studies and Research in Geography,
University of Mysore,
Mysore 570 006.
1982

Thesis Submitted to the
Department of Post-Graduate Studies and Research in Geography
for the award of the Degree of DOCTOR OF PHILOSOPHY
UNIVERSITY OF MYSORE
MYSORE
1982

Editor's Appendix III

UNIVERSITY OF MYSORE

(Re-accredited by NAAC with 'A' Grade)
(NIRF-2022: Ranked 33rd in University Category and 54th in Overall Category)

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No.Ex. Ph.D/RM/1978-79

Dated: 17-03-2023

To:

Ajanthie Mathanakaran
58A, Pegasus Trail,
Scarborough, Ontario MIG 3N7
Canada.

Sir,

Sub: Permission to Publication of Ph.D. Thesis -Reg.
Ref: Your letter dated: 19-01-2023.

******

With reference to the above subject, you are permitted to publish your Ph.D thesis in a book format entitled ***"Water Resources Development in the Jaffna Peninsula – Sri Lanka"*** without any financial Commitment on the part of the University.

Yours faithfully
20/3/23
Registrar (Evaluation)
Registrar (Evaluation)
University of Mysore
MYSORE

Copy to:

1. The Chairman, DOS in Geography, Manasagangotri, Mysore-06.
2. The Chairman, BOS in Geography, Manasagangotri, Mysore-06.
3. Office Copy.

Thanks are due to Professors Krishnamurthi, Mahadev and Chandrabhanu Pattanayak who helped in contacting the University of Mysore to get this permission.

Editor's Appendix IV

Profile of Dr. Rajathurai Mathanakaran

27.07.1941 – 16.04.2022

Education:

1951 - 1959 Urumpirai Hindu College

1959 - 1961 Jaffna Hindu College

1961 - 1965 University of Ceylon, Peradeniya

1976 - 1982 University of Mysore, India

Qualifications:

July 1965 B.A. (Special Degree) University of Ceylon, Peradeniya

July 1978 M.A. Department of Post Graduate Studies and Research in Geography, University of Mysore, India

August 1978 D.D.P. (Postgraduate Diploma in Development Planning and Management) Institute of Development Studies, University of Mysore, India

1984 Ph.D. Department of Post Graduate Studies and Research in Geography, University of Mysore, India.
Thesis Title: Water Resources Development in the Jaffna Peninsula, Sri Lanka [Thesis submitted in 1982]

Academic Distinctions:

1978 M.A. - First Rank with First Class, Awarded Two Gold Medals

1978 D.D.P. - First Rank with First Class

1974 - 1976 Commonwealth Scholar in India

Academic Speciality:

Hydrology, Groundwater Hydrology, Development Planning and Management

Career:

1965 - 1966 Temporary Tutor – Department of Geography, University of Ceylon, Peradeniya

1966 - 1967 Temporary Assistant Lecturer, Department of Geography, Jaffna College, Ceylon

1967 - 1974 Assistant Lecturer, Department of Geography, Jaffna College, Sri Lanka

1974 - 1988 Assistant Lecturer, Lecturer, Senior Lecturer; Department of Geography, University of Sri Lanka, Jaffna Campus, later from 1.1.1979, University of Jaffna, Sri Lanka

Seminar, Field Study and Workshop:

1966 - 1979 Participant in several seminars organized by Jaffna College jointly with the Education Department, Northern Region for popularization of Geography in the schools of Jaffna Peninsula

1966 - 1974 Organized several field studies of Geographical interest while at Jaffna College

1965 Filed work carried out on 'Tobacco Cultivation in the Jaffna Peninsula' as partial fulfilment for the Bachelor's Degree Examination

1971 Took part in a preliminary 'Raw Materials survey of the Jaffna Peninsula' carried out by Jaffna College on the request of the Industrial Development Board of Sri Lanka

1977 Participant in a Karnataka State Universities Seminar on 'Population and Youth Education' organized by the Dean, Student Welfare, University of Mysore, India

1978 Carried out field work on 'Socio - Economic Survey of Belavadi Village, Mysore, India' as partial fulfillment for Postgraduate Diploma in Development Planning and Management, University of Mysore

1978 Carried out field work in the Jaffna Peninsula to prepare a dissertation on 'Water Resources of the Jaffna Peninsula' as partial fulfillment for M.A. Examination, University of Mysore

1978 Participant in an All India workshop on 'Locational Analysis for Social Services' jointly organized by the University of Mysore and ICSSR, India at University of Mysore

1979 Team Leader for 'Socio – Economic Survey of Chavakacheri Electorate, Jaffna District' jointly conducted by the Ministry of Planning and Department of Geography, University of Jaffna

1982 Participant in a Seminar and workshop on 'Coastal Zone Inventory' using remote sensing techniques. Co-sponsored by the Ministry of Lands and Land Development and the Food and Agricultural Organization of the United Nations.

Publications:

1971 'Some major Raw Materials Survey of Jaffna District' – Reports jointly on 'Fruits and Vegetables' and 'Tobacco – IDB publication'

1974 'Food Production and River Valleys Development in Sri Lanka'

'Cinthnai' University of Sri Lanka, Jaffna Campus

1978 Salt Water Exclusion Scheme – Jaffna Peninsula 'Ootru' journal September – October

1980 Presented a paper on 'Water Resources of the Jaffna Peninsula' at a seminar on Integral Rural Area Development of the Thenmaradchi Division – jointly organized by the Sri Lanka Foundation Institute and Department of Geography, University of Jaffna

1981 Presented a paper on 'Strategies and Constraints for rural development' jointly organized by the Sri Lanka Foundation Institute and Department of Geography, University of Jaffna at Thondaiman Aru

1982 Presented a paper on 'Water as a Scarce Resource' at a seminar organized jointly by Sri Lanka Foundation Institute and Department of Geography, University of Jaffna at Sri Lanka Foundation Institute, Colombo

1983 'Common Characteristics and Diversified Structures in the Developing Countries', Cintanai Journal of the Faculty of Arts, University of Jaffna

1984 'The Effects of De-rocking of Limestone in the Jaffna Peninsula', Cintanai Journal of Faculty of Arts, University of Jaffna

Parents: **Mother:** Manonmany
Father: Rajathurai

Birth Place: Railway Road, Kokuvil, Jaffna, Sri Lanka

Family: **Wife:** Baleswary Mathanakaran (Daughter of Abiramy & Canagaratnam)
351, Navalar Road, Nallur, Jaffna, Sri Lanka

Children: Thayaparan Mathanakaran, Ajanthie Mathanakaran

FIGURE 24 - The Vice-Chancellor, President, Deans, Pioneer Staff, 1st Batch of the Science Faculty Students of the University of Sri Lanka, Jaffna Campus, 1975

Dr. R. Mathanakaran – Seated 5th from the Right

Dr. Rajathurai Mathanakaran (1941–2022), born in Kokkuvil, Jaffna, had his early education at Jaffna Hindu College from where he proceeded to the then University of Ceylon at Peradeniya to get his B.A. (Hons) degree and to the University of Mysore to get Master's and PhD degrees, all in the field of Geography. He taught Geography at Peradeniya and at the undergraduate section of the Jaffna College, before becoming one of the founder teachers at the University of Jaffna when it was established in 1974. He was among the pioneers who organized the Department of Geography at the University of Jaffna, where he became a Senior Lecturer in Geography. He left Jaffna in 1988 to live in Canada. Coming from a horticultural village background, groundwater in Jaffna was a concern to him throughout his career. His PhD thesis on this topic submitted to the University of Mysore in 1982 is now brought out here in print, considering its importance to current development needs.

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