SCIENCE EDUCATION SERIES

NO. 36

SCIENTIFIC PRINCIPLES SEEN IN ANCIENT ARTEFACTS AND MONUMENTAL STRUCTURES

by

T.K. Nimal P. de Silva
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FOREWORD TO THE SERIES

The dissemination of scientific information is one of the main functions of the Natural Resources, Energy & Science Authority. The Journal of the National Science Council published by this Authority provides a medium for the publication of scientific research papers, and "Vidurava", the quarterly science bulletin contains scientific articles of a general nature which is of interest to the public.

There is still a wide gap in the availability of reading material on scientific subjects of local interest. One result of this is that science students confine their reading only to their school notes and to the few available text books which are mostly published abroad. In an attempt to improve this situation, the Steering Committee on Science Education of the Natural Resources, Energy and Science Authority decided to publish a series of booklets on scientific topics of local interest as supplementary reading material for students and the general public. The authors who have been selected by the Committee to prepare these booklets are experts in their respective fields. The manuscripts that are submitted by the authors are examined by referees before being accepted for publication. The views expressed in these publications are those of the authors and are not necessarily those of the Natural Resources, Energy & Science Authority.

I must thank the Steering Committee on Science Education of the Natural Resources, Energy and Science Authority of Sri Lanka, for the work they have done to make this project a success.

Prof. Priyani E. Soysa
Director-General

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SCIENTIFIC PRINCIPLES REFLECTED IN OUR ANCIENT RUINS - PRODUCTION OF ART AND ARCHITECTURE

Prof. T.K. Nimal P. de Silva
Department of Architecture, University of Moratuwa and Chairman of the Sri Lanka National Design Centre

INTRODUCTION

The growth of civilization in different parts of the world has demarcated the mile stones in the historical development of mankind. Civilization have grown in different parts of the world demarcating the mile stones in the historical development of mankind. These developments have taken place independently, interdependently or in parallel and have evolved cultures with distinct identity. Cultures were identified as the product of harmonious development of human beliefs with the nature and the environment, fulfilling the activities of men. In the past, these processes have not threatened and destroyed the environment of the living beings, and have always reached a harmonious balance while utilizing the natural resources. The tradition evolved in these civilizations can be considered as the accumulated wisdom of the past.

Science is the logical understanding of happenings and the human race has continuously used this understanding and knowledge for the betterment of the activities performed by man. The situational demands faced by man has conditioned him to evolve new knowledge through science. Developments evolved during the historical periods were simple in nature, basic in approach, but served the purpose. Today, the developments achieved with science has gone beyond man's control and reflected back on the environment he is living in by threatening his own survival. At this moment it is appropriate to study the cultural and archaeological remains of the past in order to understand the accumulated wisdom, the scientific principles adopted for guidance and inspiration for future development and the survival of man.

The Sinhalese civilization that flourished in this island has realized supreme cultural standards during the last 25 centuries of the past. During this long period of time Sri Lanka has reached high standards in their achievements in areas like irrigation and agriculture, art and architecture and many other areas of technology related to the achievements of the nation. The beauty of this technology used was that those were developed on a time tested theory, simple in approach and utilizing local materials and the skills. There were many "Shilpa texts" written and used in the past. Unfortunately most of them were lost for ever. But by studying the remaining "Shilpa texts", the archaeological remains of the past and continuing traditions found today in utilizing the modern scientific knowledge, it is possible to understand the chronological development of the traditional technology and to use the best in the most appropriate way for the benefit of man.

SETTLEMENT PLANNING

As understood from the available archaeological evidence, the pre-historic man in Sri Lanka probably dates from the late Pleistocene period. i.e. from about 75,500 years ago, stone and bone implements food residues, such as mollusc shells and animal bones and human skeletal remains have given some idea of the distribution, physical characteristics and way of life of pre-historic Sri Lankan man. It is found that pre-historic man in Sri Lanka occupied a number of different habitats, from the maritime belt and the low land plains of the wet and dry zones to the high plateaus and rain forests of the central and south western mountain regions. This shows he had the capability of adopting himself to living in the many different environmental conditions that could be encountered in the island.

The main indicators, at present, of the distribution of pre-historic and early historic settlements are 'megalithic' and other related burial sites as well as sites containing associated black and red pottery indicating the presence of settled and relatively advanced iron-age agriculturalists in the period preceding and in some examples overlapping the beginnings of Sri Lankan history.

The distribution of the settlement patterns, method of living, some of the technology adopted and the interrelationships developed among the settler groups etc. could be understood by carrying out a scientific study on the following items related to their settlement patterns:

(a) The irrigational tanks and the wide spread irrigation system;

(b) The development of rock-shelter monasteries and the appearance and proliferation of early Brahmin inscriptions;

(c) The monastery complexes, monumental architecture and other material expressions of the spread and patronage of Buddhism;

(d) The growth of urban and port centres.

Those areas where the climate, soil and topography were suitable for farming were occupied by the early settlers. Looking at the distribution pattern of the larger tanks and the small village tanks that were located in the dry zone area gives an identification of their understanding in handling of seasonal rain water, the distribution of stream and river network, topography and the water retaining quality of the dry zone soil. In the layout and construction of irrigation tanks they have adopted two systems. One is by organizing small tanks in to a cascading sequence within micro catchments allowing greater efficiency in watery usage and management. Drainage from the paddy fields in the upper part of the cascade flowed in to a down stream tank for reuse in the paddy fields below. The system is to have large tanks built with a longer storage capacity and distribute water into other smaller tanks through channels. They had organized community effort and coordination for the maintenance of the hydraulic system and for water management. In the construction processes earth consolidated dams were used with the understanding of the level variations in the topography, precipitation in the catchment area and the water retaining nature of the soil in the dry zone.

With the introduction of Buddhism in the 3rd century BC a new trend had developed in the country to adopt rock caves and to offer those to the Buddhist clergy, the Sanga for habitation. It was a tradition to carve the name of the donor on the top of the cave ceiling. With the help of these epigraphical records, chronological variations of the Sinhala alphabet and the distribution pattern of this caves have given a clear understanding of the habitation pattern and the development trend of the settlements during that era. With the help of these caves one can understand the quality of iron tools developed at that time to carve granite and to engrave letters on the rock. The drip ledge or the 'Katarama' carved on along the top edge of the rock ceiling to stop rain water running in to the chamber of the cave is an unique design development in Sri Lanka. It was found that all chipped material of the rock was well packed underneath clay finished floor to avoid dampness in the habitable chamber. The rock ceiling and walls were plastered white and finished with decorative paintings.

The ancient monastery complexes established in Sri Lanka are unique in scale, layout and planning. The urban monasteries were densely occupied and located just outside the citadel in capital cities.

In some monasteries there were more than three thousand to five thousand monks residing, learning and practising Buddhism. When one looks at the numbers it is hardly possible to believe but the architectural remains of buildings, ponds, hospitals, refectories etc. gave authentic proof. It is surprising to understand how they maintained and managed food, health and other day to day activities of the monks in these large monasteries. The king and the large urban and suburban population would have sustained these religious establishments. There were another type of monasteries for meditating monks called forest monasteries. They are also large but located away from the cities in association with rocks and mountains. The distribution of settlement pattern could be identified with the scale and the distribution of the scattered remains of the ancient monastery complexes throughout the country.

The wide spread archaeological remains of the urban centres and the port centres, gives an indication of the urban settlement patterns, their distribution and the relationship with the well established tanks, irrigation systems and perennial rivers. Anuradhapura the major historic city of Sri Lanka is unique in the world. It has served as the capital of Sri Lanka for a continuous period of more than one thousand three hundred years. The excavations of the citadel in Anuradhapura revealed that the original occupational level is more than ten metres below the present ground level. Different cultural layers have indicated the deposits taken place due to continuous occupation of the city. Potsherds found at the lowest levels have shown the advancements achieved in the production of clay pottery at that time and the cultural links that existed with India during that period.

ARCHITECTURE

The architectural remains of Sri Lanka dating back to a period of more than two thousand three hundred years can be classified under three headings: religious architecture, secular architecture and the architecture of the common man. The first two categories were monumental and the third type was temporary in nature due to the utilization of temporary materials like timber, mud and thatch. Before the introduction of Buddhism the popular construction material would have been mud but within one century, the use of fired clay bricks in Sri Lankan architecture has produced monumental stupas like Mirisewatiya and Ruwanweliseya built by King Dutugamunu (161-137 BC). Rulers in the island used architecture to express their power and built large religious buildings and managed to create stupas like Jetawana where it remains as the tallest brick structure in the world even today.

More than ninety percent of the architectural remains in Sri Lanka are religious buildings, specially built in and around urban areas like Anuradhapura and Polonnaruwa and also found scattered in the dry zone. In addition to the large number of multistorey residential buildings, Chapter Houses and Image Houses that were considered important sacred buildings were always built in monumental scale. All statues that are found in the open today had a suitable building to house it. In addition to those being works of creative art it also expresses the creative technology in relation to height, span, stability and materials.

Among the monumental religious buildings, 'Uposathaghara' or the congregation building was always large in scale and height.

As given in the Mahawansa, the Brazen Palace built by King Dutugamunu in the 2nd Centuary BC was nine storied and covered with bronze tiles. In the 12th Century, King Parakramabahu I rebuilt the same and the remaining 1600 stone columns near Sri Maha Bodhi are the ruins of the magnificent building. Uposathaghara at Jetawana and Abhayagiriya were also of this mammoth scale. The Badda Seema Pasada built in the 12th Century at Alahana Pirivena, Polonnaruwa was a 12 story building. The architectural remains of these buildings gives an indication of the technological achievements and the scale of construction during these historical periods.

Location and layouts

Selection of suitable sites for these religious, secular and domestic buildings was always done to suit the urban and rural settlement pattern in consideration with the geography and the environment. For an example, the selected sites for meditation monasteries were always isolated rocky, hilly forests. The buildings were designed in harmony with the natural setting and created a peaceful atmosphere required for meditation and relaxation. The location of different types of buildings to perform different functions have been planned beautifully to facilitate its utility and in a most logical manner. As a general principal the sacred buildings such as stupa, image house, congregation hall and the Bo-tree shrine were located on the highest elevation of the site. If the site does not permit this naturally, they were located on artificial platforms.

Lovamahapaya (Brazan Palace)
Remaining 1600 stone columns of the ground floor.

As generally found in all classical architecture, the layouts of buildings and building complexes were principally axial in arrangement and in the development process they have become multi-axial and have embraced the natural elements like rocks, boulders, water and the topography resulting in an organic development harmonizing beautifully with the natural environment. It is very special in Sri Lankan architecture that layout planning, landscaping and architecture has developed and designed together evolving building complexes and cities.

Landscape

In architectural planning, landscape was considered as part and parcel of the building by creating a built environment. Topography was used to its maximum. Terraces have been created using even small level differences and drained down the rain water from one level to another through designed gargoyles and invariably collected into a pond.

Kaludiya and Sigiriya are some of the finest examples of terrace landscaping. In the process of creating a built landscape the natural elements existed at the site such as rocks, boulders, streams etc. and have been well blended with the buildings by respecting and intergrading the natural form into the built structure. All man made step cuttings along sloping rock surfaces once formed the footings for brick walls. The brick flight of steps ant the platform carrying the Mirror Wall at Sigiriya is still standing on the steep rock surface since the 5th Century.

In Sri Lankan architecture water has been used to embrace the landscape and the special quality of the created built environment. Water was used as a protective barrier, a surface to get a reflection of the clouds and buildings, to cool the environment for pleasure, utility to grow aquatic plants, to enjoy the beauty of movements in fountains. When the Cultural Triangle Project cleaned the conduits in Sigiriya, the 5th Century water fountains got reactivated and gave glimpses of the past glory. The total hydraulic system used in Sigiriya is still being studied and yet to be understood.

Materials used

Concepts, selection and limitations - In selecting materials for a specific use one should have an understanding of obtaining the material, its performance and the behaviour patterns. In selecting materials for different activities in the past some were used in natural form after conversion for example stone, timber, some materials by extracting it from the natural state for example metals, some by fire conversion for example brick and lime and some mixing many ingredients like clay, plasters, alloy etc. Ancient people would have understood the character and behaviour of materials by trial and error methods and by proper logical observations. In using natural and man made materials they have developed suitable tools, methodology of conversion, manufacture and fabrication.

Timber - A commonly used material for construction of buildings, chariots, furniture, sculpture etc. The behaviour patterns, performance and durability of different varieties of timber were well understood in the past and used in the most appropriate manner. In ancient structures timber was never used in minimum sizes but in large sections in order to obtain structural stability with its weight and to remain for a longer period in case of a fire. When the trees were cut for timber, mature trees were selected and cut for the new moon. They have understood the fact that the sugar content in timber is less in the new moon than the full moon and therefore destructive wood borers are not attracted. Axe, adze and the chisel were the common tools used in timber work.

Mud - In using clay they have understood the behaviour patterns of different clay varieties and selectively used for different purposes. Clay was the bonding mortar used in construction of all big stupas like Jetawana, Abhayagiriya, Ruwanweliseya etc. In this construction, a thin slurry of clay was used only to keep the bricks pasted in position and the stupa was totally covered with a thick lime plaster protecting the clay body from natural elements. Clay was the key material used to build houses, it was simple in construction, easily available, good insulation properties and with the decay it went back to the nature. When clay was used as the main ingredient for plaster and for sculpture it was carefully mixed with many other materials such as sand, sulphur, lime, gums, glues, resins, fiber etc. Mirror wall of Sigiriya is a fine example of good quality clay plaster that has survived in open exposing it to all weather conditions since the 5th century AC.

Bricks - With the introduction of Buddhism to Sri Lanka, the technology of burning bricks also would have come from India. But within a period of about hundred years Sri Lankans have mastered the brick technology and constructed large stupas like Mirisavetiya and Ruwanweliseya during 2nd century BC and managed to construct the tallest brick building in the 3rd Century AC. In analyzing the ancient bricks, it was found that the mixture of clay and sand, it's compaction and the firing quality was good. Its crushing strength is more than the present day machine made wire cut bricks.

Stone - In building historic monuments, stone was a common construction material selected due to its strength and durability. Steel tools have been used for cutting, shaping and refining stone made building components and sculpture. Many thousand of stone columns found in ancient cities like Anuradhapura and Polonnaruwa stand testimony, to the skill of using stone in architecture. Brazen Palace built in Anuradhapura by Parakramabahu I in 12th Century has 1600 stone columns that supported a multi story timber building still standing insitu. Wide stone bridges built across Malwatu Oya during Anuradhapura period can be seen even today. No doubt the ancient people have mastered the technology of using stone for their construction mostly in dressed form.

Lime - In building construction, lime was used as the hardener for mortars and plasters. Shell, Corals and dolomite lime stone have been used for burning lime. During earlier periods lime was used mainly for plaster work but during Polonnaruwa period lime mortar became the main structural bonding material. They have used three methods of hardening slaked lime i.e. by exposing into atmosphere carbon dioxide forming carbonate of calcium, by mixing with burnt brick powder and hardening as a silicate of carbon and by mixing with milk to form calcium cassinate. Lime was also used as the paint receiving outer layer in doing wall paintings and also used as the white pigment in painting.

Metals - The use of metals in making utensils, weapons, tools etc. was known to Sri Lanka for a long period. The use of metal in architecture was recorded from second century BC where King Dutugamunu has used metal tiles in roof cladding in the nine story 'Lovamahapaya'. Excavations have revealed bronze tile, large number of iron nails both big and small and remnants of iron mongery used in buildings and furniture. Precious metals were used extensively in making jewellery and sculpture. Jewellery excavated in Abhayagiriya, Jetawana, Sigiriya etc. were of excellent artistic and technical quality. The gem studded gold earing found at Sigiriya is a fine example to understand the artistic skill of the craftsmen who created it in the 5th Century AC.

The art and architecture produced by Sinhalese civilization during the past two thousand or more years can be considered as a joint achievement of science, technology and art. They had the knowledge, necessity, courage and the capacity to design and build large buildings, cities, reservoirs, bridges and stone sculpture. In doing structures they perfected the foundation and used framed structure, load bearing and earth compacted structures and also constructed arches, vaults and domes. In most of the major construction work, the systems used were unique and indigenous.

In visualizing the creation of large statues like Maligavila Buddha and Dambegoda Maithriya Bodhisathwa, it is not only the unique artistic talent that is exhibited but also the technological and scientific knowledge that has gone in producing these free standing 15 m and 10 m crystalline lime stone statues. These large blocks of stone have been transported from a distance and in the case of Dambegoda statue it has been lifted up on to a hill. The available brick foundations and column foundations were evidence to indicate there were large tall buildings to house these statues. Crystalline lime stone being the material used in Maligawila Buddha Statue. The sculptor has understood about the heavy load coming on the shoulder of the free standing cantilevered right arm and given additional support by hanging the arm on to the shoulder by using thick steel straps that would have got covered with the plaster and paint. By knowing the technical difficulties undergone and time taken by the present day engineers to lift the fallen statue, it is possible to visualize the technical skills that was their during the original construction carried out in the 7th Century.

Good samples of Sinhalese paintings from the 5th Century AC have survived upto date. In doing mural paintings both clay and lime based plaster was used as the painting ground. Sri Lankan artists have painted on dry plaster with a binding medium to paste the pigments. In extracting required colours from the nature both mineral and vegetable materials were used. Specially the mineral colours red, yellow, blue and green extracted from earth material have lasted for a much longer period than vegetable pigments.

The archaeological remains are of great importance to the nation to understand the performance and achievements of the past. Specially in countries like Sri Lanka, the correct understanding of the 2500 years of national heritage of high standard will provide confidence, pride and encouragement to face the present and to create for the future.

SCIENTIFIC PRINCIPLES EMBODIED IN THE EVOLUTION AND DEVELOPMENT OF ANCIENT WATER AND SOIL CONSERVATION ECOSYSTEMS (IRRIGATION SYSTEMS) IN SRI LANKA

D.L.O. Mendis

Introduction

The purpose of this article is to draw attention to some scientific principles embodied in the evolution and development of the ancient irrigation systems in Sri Lanka, which are now recognized as water and soil conservation ecosystems, and to contrast them with some modern projects that lack such an underlying scientific basis.

These scientific principles have not been properly understood by a majority of high-level decision makers. Some of the reasons for this lack of understanding and the consequences of this situation are also described. Detailed discussion of some better known characteristics of ancient irrigation works such as slopes of earth embankments, quality of earthworks, relapana protection on the water face of bunds, foundation conditions, and levels of channels, though important in themselves, has not been attempted in this article.

However, mention is made of recent archaeological discoveries on ancient iron and steel manufacture in wind-powered furnaces, a previously unknown technology dated to the pre-Christian era, because iron and steel tools and implements were used for construction of the ancient works. High quality steel had also been used for manufacture of surgical instruments that compare favourably with modern surgical instruments, that had been in use in ancient hospitals.

Background

Until construction of Senanayake Samudra in the Gal Oya valley in 1949-51, all major and minor irrigation projects in Sri Lanka were based on restoration of ancient major or minor irrigation works, by far the large majority of them in the dry zone. Broadly, the ancient irrigation works consisted of two types, river diversion systems, and gravity-fed storage reservoirs.

River diversion systems could be minor or major in scale, and seasonal, temporary or permanent systems. Storage reservoirs could be small, medium or large scale.

Of the permanent ancient river diversion systems, the best known are the famous 54 1/2 mile long trans-basin channel, Jaya Ganga, leading from Kala Wewa to the Anuradhapura city tanks, and Elahera-Minneriya-Kantalai Yoda Ela, coincidentally almost the same length when constructed between the 1st and 5th centuries. Some better known examples of large ancient reservoirs are Kala Wewa, Nachchaduwa, Kantalai, Minneriya, Giants tank and Parakrama Samudra all in ancient Rajarata. Out of an estimated 30,000 small tanks built in ancient times, about 17,000 are shown numbered on the one mile to an inch topographical survey sheets, nearly 8000 described as restored and functioning the rest as abandoned.

R.L. Brohier (1934) documented the ancient irrigation works known at the time, and C.W. Nicholas (1959, 1960) described the history of these ancient works. They showed that a complex and intricate system of reservoirs and channels had been developed in virtually all the river basins in the dry zone. Nicholas has also shown that both dry zone and wet zone were occupied in the pre-Christian era, but there had been an afflux from the wet zone to the dry zone in the 1st century. Thereafter the wet zone had remained unoccupied till after the 10th centuary, when it began to be occupied again. Meanwhile systematic development of irrigation systems in the dry zone continued over the intervening centuries (Figure 1).

Anuradhapura city tanks

Anuradhapura, the earliest capital city, was first supplied by city tanks, Basawakkulama and Tissa Wewa, that were larger than the village tanks (Figure 2). Basawakkulama is the oldest of these, identified as having been built in the 4th century BC, while Tissa Wewa had been built in the 1st century BC. Both these reservoirs have small catchments of 3 1/2 and 2 square miles respectively, and would have been built with "river closure" in the dry season without need for river diversion. It is conceivable that either or both these reservoirs had been built initially without sluices, equipped with adequate spill capacity to deal with excess rain season flow. Water could have been drawn from the tanks by

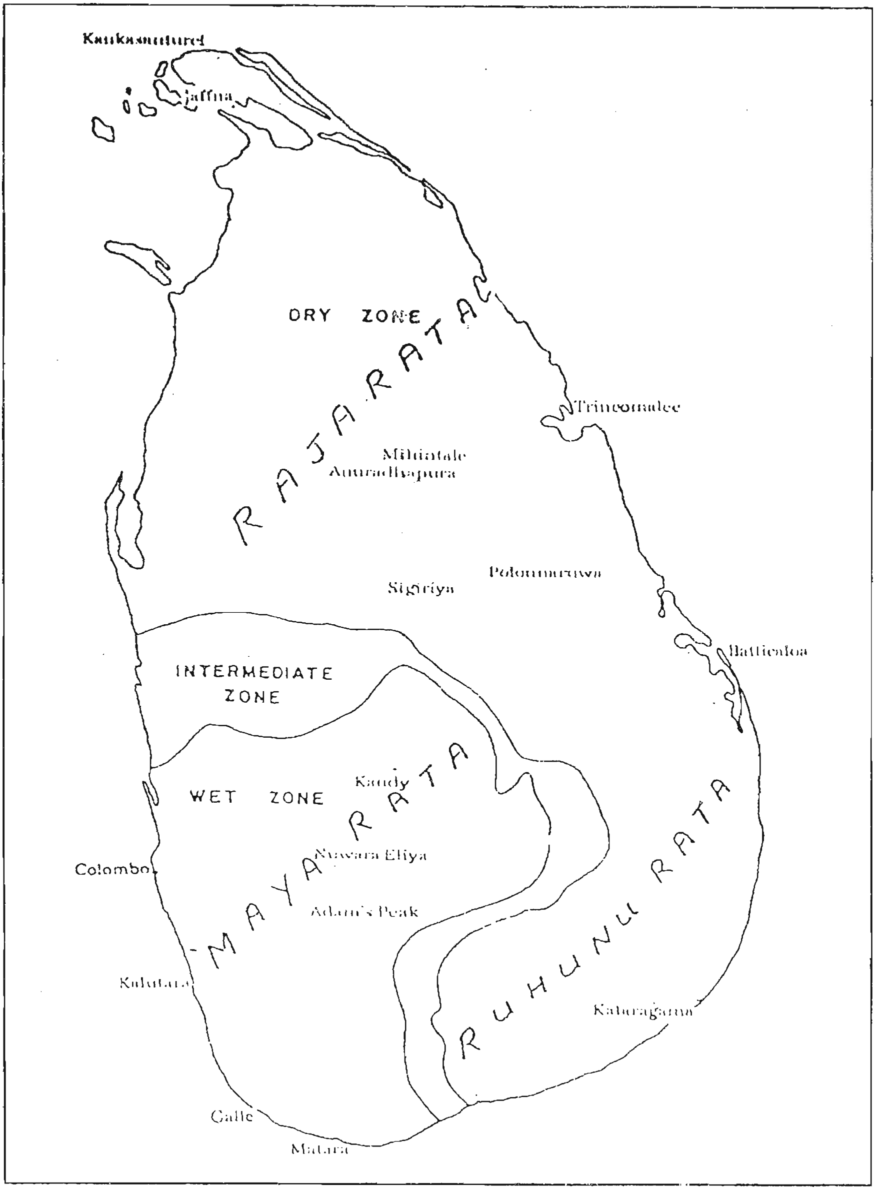

Figure 1: Sri Lanka showing rainfall zones and ancient kingdoms.

means of suitably located weirs, and by cutting the embankment at points where natural rock would not have endangered the earthfill.

However, during the early period before the invention of the sluice, irrigation for crop production would have been by means of river diversion. An ancient river diversion system had existed consisting of a "stone dam " (anicut) across the Malwatu Oya upstream of Anuradhapura, and a right bank channel (Figure 2). This system would have diverted water mainly during the northeast monsoon rain season for irrigation of lands supplying rice to the growing capital city.

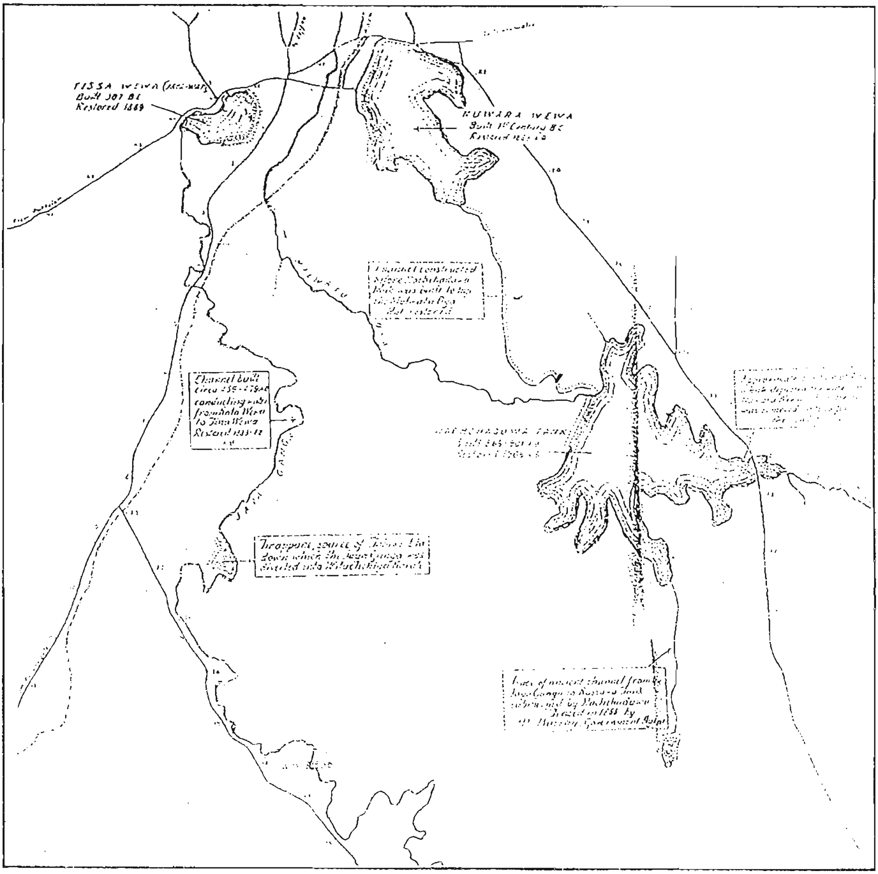

Figure 2: Diagram showing Nachchaduwa Wewa, Nuwara Wewa, Tissa Wewa and the ancient canal system.

Nuwara Wewa, at the tail end of this diversion channel with a catchment area of 32 1/2 square miles is a medium-scale reservoir, equipped with a sluice (Sorowwa) with a "Bisokotuwa". It could have been built with river closure in the dry season and temporary river diversion through the sluice. The word Bisokotuwa means indraft enclosure which could be transliterated to mean "access tower", since it provides access for the sluice gate controlling the outflow of water through the sluice culvert. It has been described as a "cistern", which term, on account of the unfortunate use of the word in domestic water supply systems, tends to take away from the grandeur of the original invention, which Henry Parker described in the following words:

> "Since about the middle of the last century, open wells, called 'Valve-pits' when they stand clear of the embankment, and valve-towers when they are on it, have been built on numerous reservoirs in Europe. Their duty is to hold the valve, and the lifting gear for working them, by means of which the outward flow of water is regulated or totally stopped. Such also was the function of the bisokotuwa of the Sinhalese engineers; they were the first inventors of the valve-pit, more than 2100 years ago".

Construction of a large reservoir depends on invention of the sluice (Sorrowwa) which, according to Henry Parker, took place around the 3rd century BC in Sri Lanka. The date assigned to construction of Nuwara Wewa, 1st century suggests that it coincided with the movement of population from the wet zone to the dry zone mentioned above, but is three centuries after Parker's date for invention of the sluice, the Sorowwa with its "Bisokotuwa". Since Nuwara Wewa supplying the capital city, may have been one of the first large reservoirs, archaeological clarification of these dates has to be done.

Ancient water and soil conservation ecosystems (irrigation systems) in Rajarata

As the capital city grew, the need for assured water supplying for irrigation and domestic consumption resulted in construction of Nachchaduwa Wewa (Figure 2). Here we see a classic example of water resources development, with construction of a large reservoir at the head end of an old diversion channel, submerging the diversion structure. River closure would have been done with temporary diversion through a newly constructed right bank sluice, and a new right bank channel which is still in use while the early channel lies abandoned. The usual date given for construction of Nachchaduwa is the 8th century, but it is more than likely that it was constructed earlier. In fact some historians suggest that the 5th century is the more likely date. When the Dambulla-Anuradhapura road was being built by the British in the last century, the original ancient diversion anicut across the Malwattu Oya was found in the bed of the Nachchaduwa Wewa which was breached at the time.

The next important feature in the ancient Rajarata is the augmentation of the city tanks from the adjacent Kala Oya basin. Construction of the twin tanks Kala Wewa-Balulu Wewa by Dhatusena in the 5th century represents an epic achievement in the history of Sri Lanka. It is generally tacitly assumed that the Kala Wewa Yoda Ela, known as the Jayaganga, was also built in the same period, thus pre-supporting the type of water resources development planning practised today. However, the stage by stage development described above, suggests that the Jayaganga was built well before the Kala Wewa, as a diversion irrigation system which was later consolidated by construction of the great reservoirs at the head end, exactly like construction of Nachchaduwa described above. River closure may have been facilitated by first constructing one tank in the dry and temporary diversion into this tank thereafter, the "twin-tank" method.

In a historic lecture to the Royal Asiatic Society, Ceylon Branch, in 1935, titled the Inter-relation of Groups of Ancient Large Reservoirs and Channels, R.L. Brohier described how all the large reservoirs in the ancient Rajarata were inter-connected by means of man-made channels, some of them trans-basin channels.

This was later further documented by C.W. Nicholas and S. Paranavitana in their Concise History of Ceylon in 1960 (Figure 3). Brohier also clearly explained the dependence of the small village tanks on the large system, when he described the right bank main channel of the Kala Wewa, the Jaya Ganga as follows:

> "The Jaya Ganga, indeed an ingenious memorial of ancient irrigation which was undoubtedly designed to serve as a combined irrigation and water supply channel, was not entirely dependent on its feeder reservoir, Kala Wewa, for the water it carried. The length of the bund between Kala Wewa and Anuradhapura

intercepted all the drainage from the high ground to the east which otherwise could have run to waste. Thus the Jayaganga adapted itself to a wide field of irrigation by feeding the little tanks in each subsidiary valley which lay below its bund. Not infrequently it fed a chain of village tanks down these valleys the tank lower down receiving the overflow from the tank higher up on each chain". (Brohier, 1937).

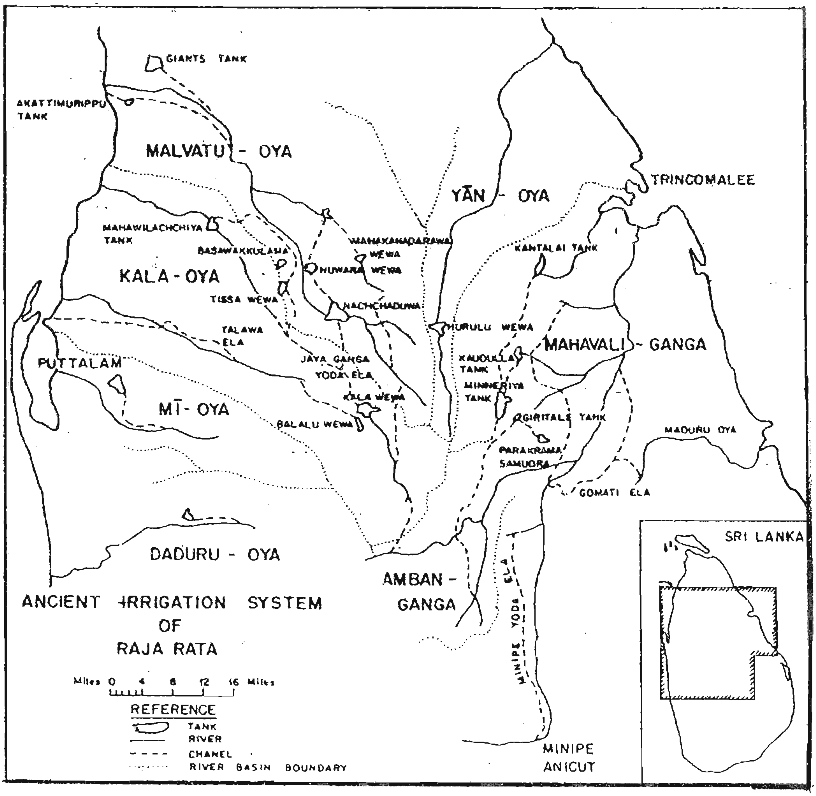

Figure 3: **Ancient irigation system of Rajarata.**
(Source: Concise History of Ceylon, 1960)

It will be shown that this correct statement of how the ancient irrigation systems in Rajarata functioned, was ignored in later years by Brohier himself, who lent his name to a wrong interpretation for the evolution and development of ancient irrigation systems that was due to hydraulic engineers in the Irrigation department.

Ancient water and soil conservation ecosystems (irrigation systems) in Ruhunurata

It contrast to the intricate system of inter-dependent large reservoirs, channels and small tanks, in ancient Rajarata, there was a different system in the southern part of ancient Ruhunurata. There are several important river diversion systems taking off from anicuts across Walawe Ganga, Kirindi Oya, Menik Ganga and Kumbukkan Oya. There are some larger reservoirs too, in these basins, but they are not inter-connected by channels, as in Rajarata. Moving from west to east, topographical survey sheets also show a vast number of small tanks in the lower basins of Walawe Ganga, Malala Oya, Kirindi Oya, Menik Ganga and Kumbukkan Oya.

Two large reservoirs in the Mau Ara basin on the left bank of Walawe Ganga, Hambegamuva Wewa and Urusitta Wewa (also known as Magama Wewa or Pandikulama), have been restored, the former by the British and the latter during construction of Uda Walawe headworks. The earth embankments contain magnificent sluices of the ancient type described by Parker. A carved stone depicting a many-hooded cobra had been placed, symbolically to guard each sluice structure. At Hambegamuva Wewa, the cobra has five hoods, and at Urusitta Wewa it has seven hoods. Paranamana has said that the number of hoods in the guardstone is an indication of the extent of land under command, or of the storage capacity of the reservoir. The remains of a third (unrestored) large reservoir, Galamuna Weva, is located midway between Hambegamuva and Magama. A seven hooded cobra is expected to be discovered at Galamuna Weva.

Small tanks are equipped with other types of sluices of which the Keta Sorowwa or village tank (VT) type sluice is well known. The large number of small tanks in cascade formation in the Walawe basin shown on the Timbolketiya topographical survey sheet, especially in the Weli Oya and Mau Ara basins on the left bank of the Walawe Ganga, has always been an enigma to scholars (Figure 4). Either the surveyor or a draughtsman in the Survey office had described these ancient earth bunds as abandoned "small tanks". However, by definition an irrigation tank must be equipped with a sluice for control and issue of water for irrigation, and virtually all these bunds were not so equipped. In fact they were earth bunds called “vetiyas”, well known to traditional agriculturalists in the dry zone, and now seen as a water and soil conservation structure that is described below.

In the nineteen twenties attempts had been made by the Irrigation department to manufacture village tank type sluices in Hambantota sub-division. The intention had been to restore and equip with sluices, some of the large number of ancient "small tanks" in the Walawe basin, shown on the topographical sheet. Some of them, especially in the Weli Oya and main Walawe Ganga basins, had been restored thus as small tanks equipped with sluices, but we now know that by far the large majority of these were not conventional tanks but "vetiyas". Again, in the late nineteen sixties and early nineteen seventies, the Freedom from Hunger Campaign prepared an idealized model of "tank villages" based on this cascade formation, assuming the existence of sluices in these bunds.

More recently, a study has been done on the possibility of restoring these structures on an extensive scale, as conventional small tanks equipped with sluices. K. Gunasekera has shown that if restored in this manner, depending on location they could give cropping intensities of between 0.9 and 1.5, in a year of average rainfall, assuming a return flow of 20%. Also they could sustain a population of 4.6 to 7.3 persons per hectare of land irrigated.

However, without sluices these "small tanks" (vetiyas) serve more than one purpose. After first irrigating well-drained soils at a higher elevation, surface and sub-surface return flow can irrigate the impermeable soils in the bottamlands, as wil be described below. The assumption of a 20% return flow is conservative in this context, and a return flow of up to 60% under careful management and re-use is possible.

In southern India, small tanks equipped with sluices are called eris or yeris, and their function is recognized as water and soil conservation structures. For example, Mukundan (1992) says: "Tank is actually a misnomer for the artificial reservoir known as eri in Tamil. There are four functions of these small tanks:

1. As appropriate irrigation devices in the cultivation of paddy;
2. As a system which acted as a flood control device, thus preventing soil erosion and wastage of runoff waters during periods of heavy rainfall;

3. As storage devices which acted as insurance against low rainfall periods and also recharged ground water in the surrounding area;
4. As a device which was crucial to the overall eco-system."

This statement applies equally to the diversion dams or vetiyas of the Mau Ara basin. The alternative of restoring them as small tanks as advocated by K. Goonasekera, with the implied introduction of sluices as attempted by the Irrigation department some years ago, is feasible, but not necessary. The same rice yield could be achieved by restoring the ancient system without the additional cost of the new sluices, with the additional benefit that Other Field Crops (OFC) could be cultivated with the same water. It is now apparent that this was indeed the purpose of the small earth bunds, which represent an unique man-made ecosystem which will be described below.

Engineering surveys

In a Preface to Brohier's comprehensive ancient Irrigation Works in Ceylon, then the Surveyor-General, G.K. Thornhill, had said:

> "It must be noted however that Mr. Brohier deals only with the historical and general aspect of the question and not with the engineering problems. These must be investigated by making further engineering surveys to supplement the topographical surveys" (Brohier, 1937).

When detailed engineering surveys were in fact done in the Walawe basin in the nineteen sixties, it was revealed that the ends of all these small earth bunds were curved in the downstream direction. However, this vital fact remained unnoticed for nearly three decades until a very recent study (IFS, 1994) after which it was given publicity in various published papers. The vital significance of this is discussed below.

Ancient systems in Ruhunurata explained

The remains of large numbers of small earth bunds shown on the engineering survey sheets, are also found on the field. Some of these bunds built across small streams (Ara) which had been assumed to be the bunds of small village tanks, had their ends curved in the downstream direction, and were in echelon at corresponding elevations on all the minorstreams that feed into the main stream, the Mau Ara, or mother river (Figure 4). Coupled with the fact that these bunds did not have any sluices, and that these otherwise dry streams carry runoff only during three or four months of the northeast monsoon season, their function was immediately recognized and explained as follows.

These were diversion structures built to raise the monsoon runoff above the low humic gley paddy soils in the valley bottoms, and divert it into the well-drained soils in the valley sides, mainly shallow reddish-brown earth soils with underlying bedrock. Some of the diverted water would soon drain back as return flow along the underlying bedrock, to the paddy soils in the valey bottoms.

Once the functioning of the small earth bunds is understood, other parts of the puzzle fall into place very neatly. The absence in southern Ruhuna of inter-connected large reservoirs and channels, as in Rajarata, could be explained.

The following recent comments explain some of the scientific rationale underlying this ancient irrigation system in Ruhunurata:

> "The fairly intricate irrigation system that was in existence in ancient times was designed in such a way as to derive optimum utilization from surface run-off. This was accomplished by damming tributaries at different places. Our team of researchers found that there exists a very hard pan comprising impermeable layers of soil in many of the old tank beds, thus preventing infiltration....."

> "Alluvial soils occur mainly along river beds and delta areas, and on the terraces of perennial streams. However, out field observations showed that depressions caused on ancient rocks have often been filled with alluvial deposits. A good example of this is found along the lower catchment of the Walawe river, and also along the Kirindi Oya" (Ratnayake, 1992).

It is easy to see that this unique river diversion system based on deflection earth bunds without sluices, permits cultivation of what are called Other Field Crops (OFC), in the valley sides, as well as the conventional paddy crop in the valley bottoms. Under the Hambantota

Integrated Rural Development Program (IRDP), rainfed OFC have been cultivated in non-rice soils during the north-east monsoon season, with great success. Undoubtedly, restoration of ancient diversion systems of deflection bunds and diversion channels will result in successful simultaneous cultivation of OFC and rice crops in valley bottoms as well, using both surface and sub-surface return flow water. The question that now remains to be discussed is how the ancient systems came to be so badly misunderstood in recent times?

Modern development - Irrigation Department

An irrigation branch existed in the Public Works Department until the Irrigation Department was set up in 1900. Therefore the Irrigation Department was responsible for major irrigation works and minor irrigation works were under the purview of Government Agents. In 1923, due to heavy rainfall a chain of small tanks in Medawachchiya area breached, and the resultant flood washed away part of the railway line with much damage to property and loss of life. The Irrigation Department then undertook a study of the ancient small tanks and ten years later, J.S. Kennedy, then Deputy and later Director of Irrigation, presented a landmark paper at the Engineering Association of Ceylon titled "Evolution of Scientific Development of Village Irrigation Works in Ceylon". Kennedy made a statement in this paper which was to have momentous impact on future development of irrigation works in the island. He said: "The small village tanks, like the village cattle, are too numerous for efficiency".

Irrigation engineers came to the wrong conclusion that this statement meant that the small village tank was a stage in the evolution and development of irrigation works in Sri Lanka, and should therefore be replaced by large reservoirs. Kennedy's paper was used as a Handbook in the Irrigation Department for the next 25 years, until S. Arumugam published his paper on Village Irrigation Works, which replaced Kennedy's paper as a Handbook on Minor Irrigation Works. But it was too late then to change the wrong thinking that had become established in the minds of hydraulic engineers in the department.

The Water Resources Development Plan of Ceylon, 1959

The view that the small tank was inefficient and had to be replaced by large reservoirs gained credence, especially in the Irrigation Department. This is well illustrated by an extract from a Reconnaisance Report for the proposed Heda Oya reservoir, prepared in the Designs and Research Branch of the department in 1950:

> "The development of Heda Oya is recommended as it compares very favourably, from technical and financial viewpoints, with other major schemes already undertaken by government. There does not exist any doubt as to the need to achieve self-sufficiency in food. This is an achievement that cannot be realized by spending large sums of money on tiny village tanks which do not have the staying power in a drought, nor can a better standard of living be taken to a people depending on them. Vagaries of the monsoons and resulting destitution can be fought only by spending public funds on large schemes and not by creating little evaporating pans and relief works. The age of the village pond has passed away and the time has come to embark on large projects like the scheme under review". (D.W.R. Kahawita, 1950)

This purely hydraulic engineering perspective expresses contempt for small village tanks as "little evaporating pans". Their social, biotic and ecological significance in the dry zone, and their functional inter-dependence with inter-related channels and large reservoirs, in the Rajarata are totally ignored.

Based on this type of thinking, the Designs and Research Branch of the Irrigation Department prepared a map described as the Water Resources Development Plan of Ceylon, which was published by the Surveyor-General in 1959. The thinking behind the plan shows how little engineers knew or cared about the ancient irrigation systems. The basis for preparation of the map was a single-basin or within-basin balance of water and land resources for most of the large river basins in the country. The location and proposed capacity of both the Uda Walawe reservoir, built in 1965-68, and the Lunuganvehera reservoir, built in 1978-86, were determined on this basis and shown on the Water Resources Development Plan of Ceylon, 1959. The location of these reservoirs has been responsible for environmental degradation in the southern area, which has also contributed to civil commotion and unrest.

Brohier's 4 stage hypothesis

R.L. Brohier, a non-engineer, was President of the Engineering Association of Ceylon (whose membership was open to engineers, and members of allied professions) in its 50th Jubilee year, 1956. In this Presidential Address titled "Some Structural Features of the Ancient Irrigation Works in Ceylon", Brohier presented a hypothesis for the evolution and development of the ancient irrigation systems in the following four stages:

1. Rainfed tanks from which water was bailed out;
2. Small village tanks;
3. Large storage reservoirs submerging small tanks which they replaced;
4. Augmentation of a large reservoir from a river by construction of a diversion weir and an inlet channel.

Brohier's hypothesis was a statement of the prevailing dogma in the Irrigation Department at the time, as seen in the extract from the Heda Oya Reconnaisance Report quoted above, to which Brohier unfortunately lent his illustrious name.

Not long after this hypothesis was announced in October 1956, serve cyclonic storms devastated the irrigation systems in the island in late 1957. Many of the ancient large reservoirs that had been restored were breached again, and their beds were exposed to view. Small tanks were not evident in any of them, but this early evidence of the fallacy of the four stage hypothesis went unnoticed and unremarked at the time. In fact the four stage hypothesis is untenable because it assumes that storage reservoirs, which represent water management in time, pre-date river diversion systems which represent water management in space. This of course is incorrect.

A glance at the Timbolketiya topographical survey sheet shows that the four stage hypothesis appears to have been largely influenced by the ancient irrigation works in the Walawe ganga basin (Figure 4). The ancient Magama Wewa (also called Urusitta Wewa) appears to submerge a large number of small tanks, and is augmented by a diversion channel taking off from the Walawe Ganga at Tenketiya. However this is the only example of its type anywhere in the country.

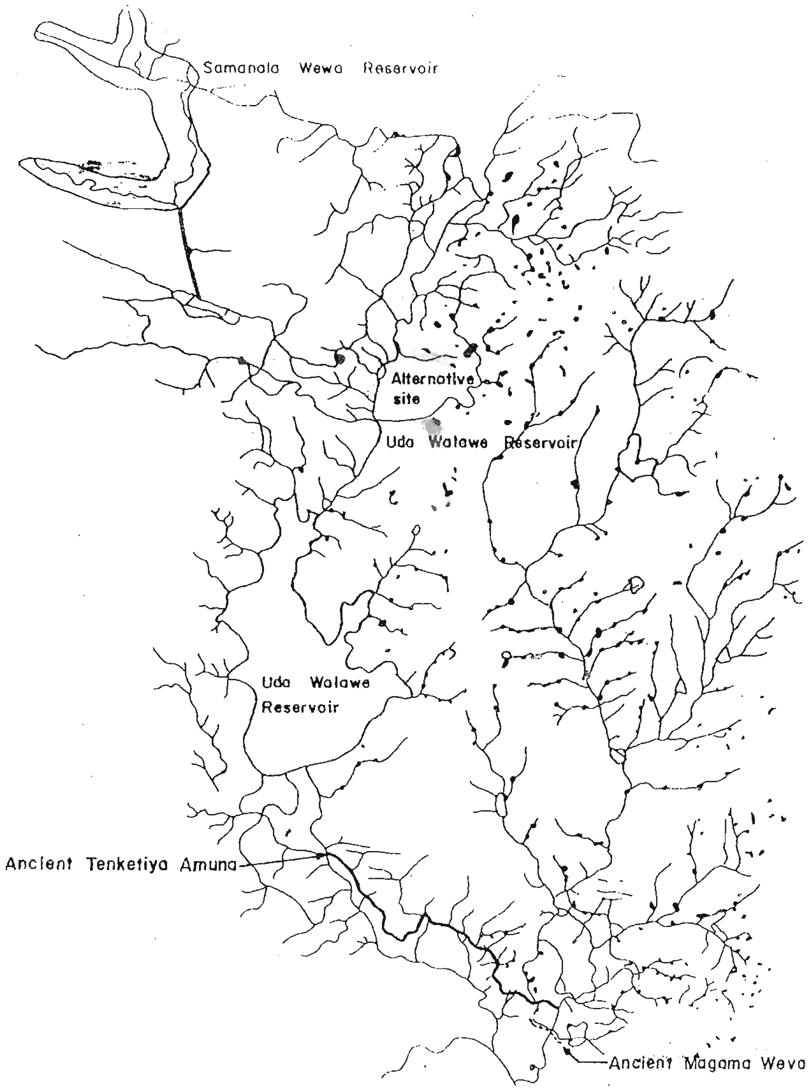

Figure 4: Walawe basin development - ancient dispersed small-scale system vs modern centralised large-scale system.

This hypothesis was re-published by Joseph Needham in 1971, in Vol. 4, part 3, of his monumental classic Science and Civilization in China (Figure 5). Needham has now recognized that this is an erroneous hypothesis and invited me to undertake its revision, saying inter alia: "My treatment of the subject can be improved upon and I am counting on you to do it".

[In passing it may be mentioned that although I have undertaken this work, I have made it clear that the prioriy is not revision of a few pages of Needham's great work, but studying and achieving a correct understanding of the ancient irrigation systems in Sri Lanka, and ameliorating the problems caused by a wrong understanding of these systems, especially in the southern area of Sri Lanka].

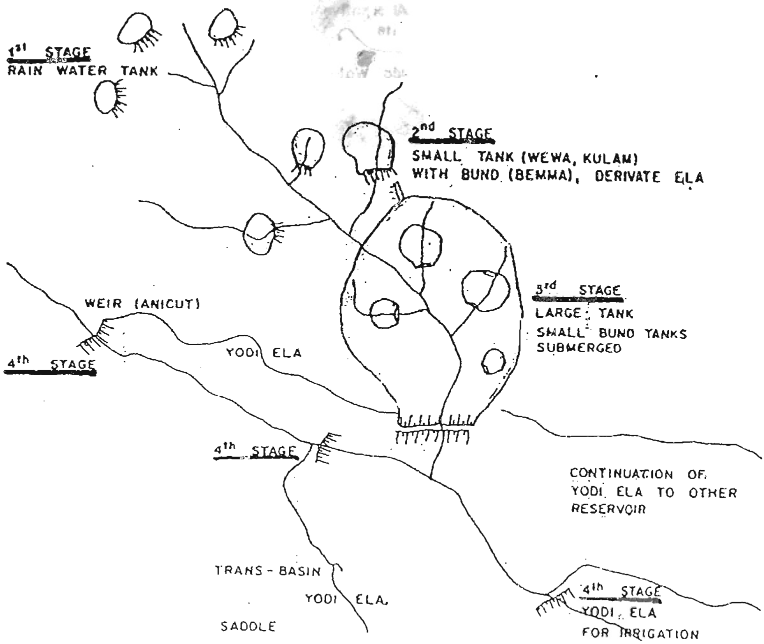

Figure 5: Evolution and development of ancient irrigation systems according to Brohier's hypotesis (From: Needham, 1971).

Theory, Paradigm and Crisis in understanding the history of irrigation

The sequence of stages through which the incorrect understanding of the ancient irrigation systems in Sri Lanka has passed, may be described with an analogy from Thomas S. Kuhn's Structure of Scientific Revolutions.

In this seminal study, widely described and recognized as "a landmark in intellectual history", Kuhn identified five stages in the progress of science:
(a). a pre-paradigm stage of competing theories; (b). the arrival of a paradigm in the form of an accepted theory; (c). paradigm- based normal science; (d). a crisis; and (e). a revolution, which is the arrival or acceptance of a new paradigm.

The pre-paradigm stage in our understanding of the history of ancient irrigation systems in Sri Lanka started with Kennedy's paper in 1933. The paradigm was the statement of Brohier's four stage hypothesis in 1956 (followed by publication of the Water Resources Development Plan in 1957-1959). The third stage, "paradigm-based normal science" was paradigm-based engineering which took the form of construction of large reservoirs identified from this plan, namely Uda Walawe in 1966-68, and Lunuganvehera in 1978-86. The stage of crisis that followed is still with us in the downstream development areas of Uda Walawe and Lunuganvehera, and may also be seen in some of the Mahaweli areas in the future.

The final stage of revolution should be the arrival of a new paradigm. Such a paradigm-candidate was the seven stage hypothesis for the evolution and development of the ancient irrigation systems of Sri Lanka, now described as water and soil conservation ecosystems, published in 1984, as follows:

1. Rain-fed agriculture;
2. Seasonal or temporary river diversion and inundation irrigation;
3. Permanent river diversion and channel irrigation;
4. Construction of weirs and spillways on diversion channels;
5. Invention of the sorowwa (sluice) with its access tower (Bisokotuwa);
6. Construction of reservoirs equipped with sluices;
7. Damming a perennial river.

Arising from this seven stage hypothesis, it has been possible to identify the following six different types of man-made ecosystems, of which all but the first are irrigation ecosystems, or soil and water conservation ecosystems:

1. Rain fed agriculture ecosystems;
2. Inundation irrigation ecosystems dependent on seasonal or temporary river diversion;
3. Channel irrigation ecosystems dependent on permanent river diversion;
4. Micro irrigation ecosystems dependent on small village tanks;
5. Macro irrigation ecosystems dependent on large storage reservoirs commanding one or more micro irrigation ecosystems of types 2,3 or 4;
6. A complex of macro irrigation ecosystems consisting of a number of interconnected macro irrigation ecosystems as in the ancient Rajarata.

Walawe Ganga basin

Two large reservoirs Samanala Wewa in the upper Walawe Ganga basin, and Uda Walawe in the lower basin, were shown on the Water Resources Development Plan, 1959. Construction of both reservoirs together, or Samanala Wewa first, and then Uda Walawe, was recommended by Consultants (ECI, 1960). However, Uda Walawe was selected for construction in the mid nineteen sixties, before Samanala Wewa. Even while headworks were being constructed, the very location of Uda Walawe reservoir itself was being questioned. It was argued that according to principles of water resources development planning enunciated by Kuiper, an alternative upstream site was preferred (Figure 4).

These principles were:

1. Define the purpose of the engineering project. Formulate its useful end which makes the creation of the project a desirable objective;
2. Plan the project in accordance with its established purpose. Investigate alternative proposals, and select the project that will most effectively fulfil this purpose;
3. Design the project in the most efficient manner and in accordance with appropriate criteria of safety;
4. Construct the project according to its design, while applying suitable standards of workmanship;

5. Operate the project, thus bringing the useful end of the engineering plan into concrete existence.

Today, it has become apparent that the location of Uda Walawe reservoir presents a formidable obstruction to rational water resources development in the southern area, but at the presentation of the 1967 paper the subject was not discussed at all because the Irrigation Department took the Water Resources Plan of Ceylon, 1959, as sacrosanct. It was apparent that, as Galbraith has succinctly pointed out: "The high public official is expected, and is indeed sometimes required to expound the conventional wisdom". Alternative proposals simply could not have been investigated. Immediately after, when investigations were started for Lunuganvehera reservoir, in 1970, an alternative site at Huratgamuva, identified by engineers in the Ministry of Planning was once again not even considered. Still later, an alternative for constructing Samanala hydropower project as a run-of-the-river project initially, was also not even considered.

The modern Uda Walawe project is plagued with so-called water management problems mainly because of the layout of its extensive channel distribution system in well-drained soils in valley shoulders, with a once only use of irrigation water. In the ancient layouts water was always re-used many times before it ran to drainage, a vastly more efficient water use system. The ancients had also made a virtue out of a necessity with great ingenuity, and used the well drained soils themselves as a reservoir fed by streams during the monsoon season, as was seen above. The monsoon runoff was not allowed to run down river directly, but was raised and diverted by means of small earth bunds or vetiyas to saturate the surrounding earth. Channels had been built, not on the extensive trans-basin scale seen in the Rajarata, but in conjunction with the deflection bunds, as seen in the Engineering survey sheets, while natural streams and rivers, Ara, Oya and Ganga, had been used wherever possible.

Samanala Wewa or Upper Walawe reservoir, as it was called earlier, is located at one of the best sites for a large reservoir to be seen on the topographical survey sheets, on account of the topography and the rainfall from both monsoons at this site (Figure 4). However, it has turned out to be a problem project after construction by foreign contractors of the rock-fill dam designed by foreign consultants, on account of foundation leakages. For this reason it has received adverse publicity in foreign technical journals.

Samanala "linear" furnaces and ancient iron and steel production

During construction of Samanala dam, archaeological sites, which according to local tradition were places where iron and steel had been manufactured in ancient times, using iron ore that is freely available in the vicinity, were investigated by a British archaeologist under the direction of the Archaeological department.

These investigations revealed that high quality steel had been manufactured using an unique and previously unknown type of wind-powered "linear" furnaces. This type of furnace is quite different to the foot-bellows operated type documented by Ananda Coomaraswamy (1909) which had still been in use to produce steel in Balangoda area at the turn of the last century.

A proto-type of the ancient furnace had been built by the archaeologist assisted by local people, and very high quality steel, wrought iron and cast iron had been produced. The oldest such furnace was carbon-dated to the 3rd/2nd century B.C., but most of them were dated to the 7th and 9th centuries. Gill Juleff estimated that a minimum of 9000 tons of steel would have been produced in these furnaces during this period. She also said that the famous damascus steel used for sword-making during the time of the Crusades, had come from Samanala furnaces in "Serendib", as documented by Arab scholars. Fa Hsien has reported the existence of an iron chain on the pilgrim path to Adam's Peak in the 5th century which may have been made in Samanala type furnaces.

It is quite evident from the slag deposits found in various parts of the country today, that the steel required for tools and implements used in agriculture and in industry in ancient times were locally made at numerous dispersed sites. A great deal of further study has to be done in this interesting field, for example to estimate the requirements of steel tools and implements that would have been used in construction of the ancient earth embankments and stone revetments and structures, including sluices; and also to estimate the seasonal requirements of the "Udella" and other agricultural implements. Similarly although the local manufacture of specialized surgical instruments has already been documented, more inter-disciplinary research remains to be done in this area. This has also been stressed by another modern archaeologist who is researching ancient archaeological sites to document our cultural heritage in the southern area. M. Priekett Fernando has expressed fears that due to lack of awareness some of these archaeological sites are being vandalized in the course of modern development.

Kirindi Oya basin

The problems in the Lunuganvehera project in lower Kirindi Oya basin are similar to those at Walawe, but more severe. This reservoir too was selected from the Water Resources Development, Plan of Ceylon, 1959 by hydraulic engineers in the Irrigation Department, who ignored a far better site about 15 miles upstream at Huratgamuva. Numerous problems are faced on this project all of which can be traced to the wrong location of the reservoir. Suppression of ancient water and soil conservation ecosystems based on river diversion and storage in medium-scale tanks near the ancient city Magama followed. Those ancient systems that had evolved down the ages were replaced by hydraulic engineering designs.

Hydraulic engineering vs. water and soil conservation ecosystems

At this stage it is useful to elaborate on hydraulic engineering and irrigation ecosystems, or water and soil conservation ecosystems. Hydraulics is a study of properties of water in motion and at rest, a subject of great importance to engineers. Water is treated as being inanimate, but active, on account of its energy expressed in terms of velocity energy, pressure energy, and potential energy, the sum of which is constant. In the biotic approach on the other hand, water is seen to be animate but passive. It is the vehicle for conveyance of nutrients in nature's biogeochemical cycles, of which the hydrological cycle is itself one. Western science has defined aquatic, terrestrial, and atmospheric ecosystems. This is an artificial constraint on the study of an irrigation system which may be defined as any intervention by man in nature's hydrological cycle. From a biotic perspective moreover, an irrigation system is a man-made ecosystem, which encompasses all three domains of the biosphere, the hydrosphere, lithosphere and atmosphere. Further analysis shows that irrigation ecosystems are in fact water and soil conservation ecosystems, which term should be used to describe them, more so on account of their sustainability over a period of about seventeen centuries.

By analogy with Amory Lovins concepts of soft energy and hard energy paths, the hydraulic engineering approach may be described as a hard technology and the ecosystems approach as a soft technology approach to water resources development planning in Sri Lanka. A summary of the contrasting features of the hydraulic engineering approach and the ecosystems approach is given in Table 1.

Table 1: Hydraulic engineering vs. water and soil conservation eco systems.

		Hydraulic engineering perspective (hard technology)	Ecosystems perspective (soft technology)
1.	Water	inanimate, active	animate, passive
2.	Small tank	"inefficient", stage in evolution and development to be replaced by large reservoir.	micro irrigation ecosystem part of total macro irrigation complex of man-made ecosystems.
3.	Large reservoir	"efficient" system in combination with channel distributory system.	part of macro water and soil conservation ecosystem -with micro ecosystems in its command area.
4.	Diversion channel	built to augment large reservoirs,last stage in irrigated agriculture.	earliest stage in irrigated agriculture and evolution of irrigation ecosystems.
5.	Vetiya	"abandoned small tank"	deflection structure - micro water and soil conservation ecosystem
6.	Downstream development area	must be cleared of all vegetation to lay out channel distribution irrigation systems	must be designed as a series of micro water and soil conservation ecosystems.
7.	Forest areas	limited to catchment areas	not only in catchments interspersed with paddy lands in irrigable areas.

Decline of the ancient water and soil conservation ecosystems (irrigation systems) in Sri Lanka

Three important aspects of the ancient irrigation systems in Sri Lanka are their

- evolution and development in stages down the ages;
- sustainability over a long period of more than 17 centuries;
- final decline after about the 12th century.

The decline of the ancient irrigation systems after the reign of Parakrama Bahu (1153-86), appears to have been rapid and without hope of remedy unlike previous declines. The ultimate cause of this was the collapse of the structure of society due to a combination of factors including invasions, inter-necine strife, foreign elements in the State, occupation of the irrigated heartland by invaders, the advent of malaria, and elimination of "Kulinas", the class of persons responsible for operation and maintenance of the irrigation systems. Murphey (1957) discussed all these causes and also mentions a few others, like soil exhaustion, salinity, and changes in rainfall patterns.

It seems that hydraulic engineering may have been another contributory cause as will now be explained.

Parakrama Bahu the Great is eulogized for restoring a large number of irrigation projects during his reign. His record of work indeed remains unsurpassed to this day. The Culavamsa mentions three new very large reservoirs which he had built, referred to as "Seas of Parakrama". Of these, Parakrama Samudra has been identified but Parakrama Sagara and Parakrama Talaka remain unidentified to this day. There is some evidence that these two "seas" may have been built across the perennial Amban Ganga at Elahera and Angamedilla, respectively. If this is correct it means that the perennial river was dammed for the first time when the great king accelerated irrigation development during his reign.

This may have been the first introduction of a hydraulic engineering approach to irrigation which became another contributory cause (even perhaps the proverbial last straw), for decline of the ancient systems.

Until the Parakrama Bahu era large reservoirs in the Rajarata and Ruhunurata had been built either in so-called "dry valleys", away from rivers, like Nuwara Wewa, Minneriya Wewa, and Tissa Wewa, for example, or across Oyas and Aras, like Kala Wewa and Nachchaduwa, and not across Gangas. These large reservoirs therefore did not cause problems of environmental degradation of the type experienced on modern large reservoir projects which has led to a world-wide campaign against "large dams". It will profit environmentalists to study the large reservoirs in the ancient water and soil conservation ecosystems of Sri Lanka.

It can never be too late to carefully study and learn the lessons of history, which must necessarily be a multi-disciplinary exercise, for "To learn about the past in the light of the present is to learn about the present in the light of the past". A conceptual plan for such a study is given in Figure 6.

Multi-disciplinary Study of Ancient Irrigation Systems in Sri Lanka

	Archaeologist and Historian	
	Study of History of irrigation systems in Sri Lanka	
Bio-scientist		Social scientist
Study of man and and environment in the evolution and development of eco-systmes at different stages in the evolution and development of irrigation systems	Study of successive changes in the means of production i.e. study of successive changes in the means of production for irrigated agriculture i.e. successive changes in the use of water for crop production today	Study of modes of production and relations of production at different stages in the evolution and development of irrigation systems
Intensification of agriculture for crop production	"Lessons of experience" for rational water resources development planning, by the hydraulics engineer	Problem of irrigation water management settlement planning problems

Figure 6

While modern irrigation systems in Sri Lanka lack sustainability, and need costly "rehabilitation" from time to time, there is evidence of rice fields that have been cultivated for centuries without interruption, including our own fields for example under Minneriya Wewa. E.P. Odum has made an important observation on this:

> "It is perhaps significant that rice paddies have been cultivated for over 1000 years in the Philippines, a record of success that few agricultural systems in use today can claim. According to Sears these rice paddies are interspersed with patches of forests that are preserved by "religious taboos"...... We should first find out if the inter-mixture of forest and paddies has something to do with admirable balances before we rush in and recommend that the forests be bulldozed in order to plant more rice". (E.P. Odum, 1969).

Trees provide *"admirable balances"* for nutrient cycling, but in modern Sri Lanka a large project starts with extensive *"jungle clearing."* At Gal Oya in the late nineteen-forties, chain felling was introduced by US contractors to wantonly destroy the tropical forest. This was accepted blindly by local engineers as the "modern" method of jungle clearing. As a result some years later, "when it cost the Land Development department *"an average of no more than Rs. 200 to clear and stump an acre of land"*, by labour intensive methods, *"a private contractor secured a contract to clear and prepare 5000 acres for the Board by mechanical methods at just over Rs. 5000 pera acre"*.

Included in the environmental destruction at Gal Oya was part of the Aralu, Bulu, Nelli "Kele", which all agree is a man-made medicinal "jungle" or ecosystem. The fruits of centuries of conservation, part of our priceless heritage, were thus destroyed in a matter of days in the name of "development".

Modern development: the Mahaweli development program

The modern Mahaweli development program was of course planned, as was to be expected, on purely hydraulic engineering principles. A number of large reservoirs were selected from the Water Resources Development Plan, 1959, for construction. The downstream development areas were designed on hydraulic engineering principles, and the ancient systems were largely discounted. All small tanks were to be levelled off, and only the largest ancient reservoirs and channels were to be incorporated in the new designs. The first implementation of the downstream development program was System H area under command of Kala Wewa, augmented by diversion of the Mahaweli Ganga at Polgolla.

In the mid-seventies, when bulldozers were sent to Kala Wewa to level off the existing small tanks that were heart of the village settlements from ancient times, there were massive spontaneous protests by local villagers. Then the Chairman of the Mahaweli Development Board himself lived in the area for some time to find out for himself why the villagers were protesting, when the Board had promised them an assured system of irrigation water under the new blocking out plans (BOP). He was convinced that the ancient small tanks served a purpose and instructed that as many as possible of these small village tanks should be incorporated in the new BOP. He thus re-discovered from the villagers the function of the Jaya Ganga that leads from Kala Wewa to the Anuradhapura city tanks, which had been described by Brohier as quoted above.

In fact the same thing had happened a few years earlier. When this was attempted in Walawe in the early nineteen seventies, the local villagers protested against it. This has been commented on by observers writing from a great distance away in space and time, as follows:

> "In fact the official land distribution never occurred. Once the land had been levelled and prepared, purana villagers, infuriated by the coming of outsiders,forcefully and disorderly occupied the land." (M. Dreoey, N. Shanmugaratam,1984)

It is of course easy to assume that the purana villagers were “infuriated by the coming of outsiders”, but similar protests a couple of years later in Mahaweli System H area and the response of the Chairman to those protests give the lie to this facile supposition.

Under the Mahaweli development program another large channel was planned for construction leading from Kala Wewa above the ancient Jaya Ganga for which a new sluice had to be constructed in the bund of the Kala Wewa. When excavation work was started at the site of the proposed sluice, an ancient sluice was unearthed there. This was dismantled and reconstructed on the bund of the tank where it is to be seen at present, while a completely new sluice was constructed at the site.

Discovery of the ancient Maduru Oya dam and sluice

One of the new reservoirs proposed under the Mahaweli program was the Maduru Oya reservoir which was originally planned to have an earth dam. However, after initial foundation work had been done on the earth dam by the River Valleys Development Board (RVDB), the work was handed over to foreign consultants who designed a rock-fill dam for this site. Meanwhile the RVDB, successors to the Gal Oya Development Board (GODB) known lacally as the Good Old Dam Builders, had discovered a breached ancient earth dam at the very site at which the new dam was located. The breached dam had escaped the eye of topographical surveyors who had no doubt mistaken it for a natural hill formation. This is quite understandable when it was in its abandoned state, covered with massive jungle trees. Later, a magnificent ancient sluice was unearthed in this embankment, which has an unique Bisokotuwa. The ancient dam was quite correctly recognized as an archaeological monument that had to be preserved, and the modern dam was relocated at a new site slightly upstream of the ancient dam.

The Dry Zone Forest Garden

The Dambulla arboretum developed by F.H. Popham is an example of how a dry zone forest can be nurtured with rainfall alone. With the ancient seasonal diversion irrigation system of the Mau Ara basin (and elsewhere) not only seasonal crops (as convincingly demonstrated in the rainfed cultivation in the Hambantota IRDP) but perennial tree crops could be grown as well. These include Kohamba (margosa), Woodapple, Mango, Murunga, and timber species like Satin, Ebony and Palu, as well as Veera commonly used for production of charcoal by traditional blacksmiths. This suggests that a man-made ecosystem may have existed in the dry zone in ancient times, which benefitted from an ingenious water and soil conservation ecosystem. This could be described today as a Dry Zone Forest Garden, analogous to the Kandyan Forest Garden, part of the ancient man-made water and soil conservation ecosystem.

Recent research in the US has shown that some trees with deep root systems have the ability to draw up ground water in the night and leak it to the top soil, where it benefits other crops in the immediate vicinity. This and the importance of trees for the cultivation of rice over continuous long periods running into centuries, mentioned above, suggest that conservation of forests rather than extensive jungle clearing is necessary in irrigation schemes.

When a road is dug up for installation of water, sewerage, electricity or telecommunications conduits, the first item in the estimate usually is for excavation of trenches, and the last item is for reinstatement of roadway. Similarly, the first item in an irrigation project estimate usually is for "Jungle Clearing" (with heavy equipment at that), but there is no question of any restoration of forest cover. However, if and when the scientific principles embodied in the evolution and development of the ancient water and soil conservation ecosystems in stages, in harmony with nature, is understood and accepted, the last item would be "Reinstatement of the Dry Zone Forest Garden".

The Southern Area Plan

In the mid nineteen sixties, an engineer, M.S.M de Silva, prepared a conceptual plan described as the Southern Area Plan. It was based on the principle that excess water from the southwest wet zone would be transferred to the southeast dry zone by means of two transbasin diversion channels - a typical hydraulic engineering proposal. The origin of the concept in fact was a study done by foreign consultants for development of large reservoirs in the Kalu Ganga, Gin Ganga and Nilwala Ganga basins (ECI 1960). It was found at the time that the Uda Walawe reservoir was in the wrong location to fit into this plan, and that the upper site identified in 1968, mentioned above, fitted into the plan (Figure 4).

Even though transbasin diversion had been built in the ancient Rajarata at least fifteen centuries ago, this conceptual plan was ridiculed by many who claimed that it was too grandiose a concept. It appeared as if such criticism was intended to justify the location of the existing Uda Walawe reservoir. The effect of such criticism was to deny the need for a blueprint for rational development of water and land resources in the southern area, well into the 21st century. The concept of the Southern

Area Plan was ignored and Lunugamvehera reservoir which did not fit into this plan was constructed, in the face of reasoned criticism, and without considering the alternative upstream site at Hurtgamuva even for a pre-feasibility study.

Wild life reservations and national parks in the southern area

As a result, wildlife reservations have been demarcated above both Uda Walave and Lunuganvehera reservoirs, and these two reservations have been joined together and also joined to the Yala national park, and ribbon development settlements exist all along this road. Below the national park are the lands cultivated under the Sevanagala Sugar Corporation, separated from the park by a live electric fence, to keep elephants away from the sugar.

It has been argued that the location and layout of these two major irrigation projects in the south has created the infrastructure for perpetual conflict between man and beast and between man and man for the foreseeable future. The only feasible alternative ever proposed to avert this grim forecast of perpetual conflict in the south, is a modified form of the original Southern Area Plan based on hydraulic engineering principles. The modified plan is based on principles of water and soil conservation ecosystems, making maximum use of ancient irrigation systems or water and soil conservation ecosystems in the southern area. Very briefly, the proposed Upper Trans-basin channel of the Southern Area Plan has to be built from near the Ukgal Kaltota anicut in the Walawe ganga to the site of the Huratgamuva reservoir below the confluence of the Kuda Oya and Kririndi Oya.

The first few miles of this channel coincides with the trace of an ancient channel mentioned by Brohier, which will fall into Hambegamuva tank. This trace has been surveyed by the Director of Irrigation on the instructions of the Minister of Irrigation, recently. When this upper channel is built, the present Uda Walawe-Lunugamvehera national park with its 260 elephants should be re-located above this channel. Thereafter the ancient water and soil conservation ecosystems now lying in this national park may be restored in stages, and stable and sustainable man-made ecosystems re-created.

Meanwhile there is no apparent permanent solution to the continuing environmental degradatation in the southern area, other than relocation of both Uda Walawe and Lunugamvehera reservoirs. There seems to be a tendency to adopt an ostrich-like attitude in the face of such a situation as that faced in the southern area. The lack of any reference in the Sri Lanka National Report to the 1992 UNCED, to environmental degradation in the southern area of Sri Lanka, is a good example.

The absence of a chapter on the ancient irrigation works in the much vaunted National Atlas of Sri Lanka, is a similar lacuna, an indication of the ignorance and indifference of modern scientists to this subject. Their "conventional wisdom" apparently eschews any study that may lead to a new understanding of the ancient irrigation systems, as water and soil conservation ecosystems.

THE ANCIENT SOIL AND WATER CONSERVATION ECO-SYSTEMS OF SRI LANKA

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> "........... the missionaries of the Indic civilization in Ceylon, once achieved the TOUR DE FORCE of compelling the monsoon smitten highlands ..... to give water and life and wealth to the plains, which Nature had condemned to lie parched and desolate .... "
>
> *Toynbee in A study of History (1934)*
> *Voll II P.4*

The history of man can be viewed as a series of challenges by nature and man's responses to the challenge. The intricate systems of meeting the challenge of nature in our dry zone, otherwise condemned to be parched and desolate, can be seen to this day in the tank - landscape, particularly in Rajarata and Ruhuna. During the last century, governments attempted to renovate some of the individual components of this system albeit without understanding the rationale of the design and their true function. These systems have been in existence for 2000 or more years and the "golden age" of Agriculture was reached between the 4th and 12th century. It is only in the last 30 years or so, that we are beginning to really understand the system and to realize that this veritable wonder of the world was not a mere irrigation system that supplied water for growing paddy, but was really a man-made ecosystem that involved the complete lifestyle and culture of a whole village community. Our ancient civilizations were sustained by our tank - villages, and archaeological studies are still "unearthing" more and more evidence of how the system worked and the profound "science" on which it was based. Over the last several decades we have made many mistakes, and a few colossal blunders in the rehabilitation of parts of the system by regarding them as a pure hydraulic engineering effort.

The Wewa

The basic component of this ecosystem was the Wewa or tank, formed by the damming of a valley to hold up the excess rainfall during the rainy season. These dams or bunds were earth embankments and created a storage reservoir for water. Tanks were of various sizes, some like small village ponds and some large and covering a few hundred acres of water surface. Both small and big tanks had their special function as we shall see later. Two structures were essential to such a reservoir. One was a spillway to remove excess water during heavy rains so that the water would not overflow the bund and damage it, and the other was the sluice to control the supply of water stored in the tank, to the paddy fields that were irrigated. The mechanism for controlling the issue of water in the sluice (Sorowwa) was housed in a value pit or valve tower (Bisokotuwa). These structures can be seen even today, some still working and most in ruin. Henry Parker, and Englishman who spent 30 years in the country during the last century wrote as follows eighty five years ago:

> "Since the middle of the last century, open wells called "value pits" when they stand clear of the embankment, and "valve towers" when they are on it, have been built on numerous reservoirs in Europe. Their duty is to hold the valves and the lifting gear for working them, by means of which the outward flow of the water is regulated or totally stopped. Such also was the function of the Bisokotuwa of the Sinhalese engineers. They were the first inventors of the valve pit, more than 2100 years ago." (Parker 1909).

The small tank

Recent mapping of our country shows tens of thousands of small tanks - some marked as 'abandoned'. A close examination will show two major features of their location.

Firstly, the embankments or bunds never span a perennial rivulet or stream, but span a seasonal water course that flows only during the heavy monsoon rain. Secondly, these small tanks together form a cascade - that is, the excess water after irrigation of the paddy fields, and the natural drainage flows into another tank and so on, so that water is reused several times over. The system is a water conservation system.

Land use

The small tank and its catchment area was a complete system. We could call it a micro ecosystem. The presence of the tank's body of water had a significant effect on the water table in the rest of the catchment. We can now recognize five land classes in such a catchment.

(1) The paddy fields below the tank and irrigated by it. This was a very important component, since rice is our staple food. In the ancient tank village, the paddy area or Yaya was divided into 3 sectors- an upper, middle and lower Yaya. All cultivators had access to all three sectors. Thus, during a bad season when water was insufficient to cultivate the whole Yaya, only the upper one or two were cultivated. This *bethma* system was necessary to counter the natural vagaries of the monsoon from year to year. It was a situation where water was the scarce resource (today land is a scarcer resource than water and the pattern of land allocation of successive governments makes the bethma system difficult to establish).

(2) The areas adjacent to the tank had reasonably high water tables. Wells could be dug in this land class, and so the homesteads were established here with perennial crops like coconut and fruit trees and also home gardens.

(3) The backwaters of the tank which were communal grazing grounds for the village cattle - an integral part of farm and village life.

(4) The crests of the hills or watershed which was left in forest to control erosion, provide protection from wind, fuel for cooking, timber for building and medicinal and other herbs, fruits and other forest produce.

(5) The forest on the gentler slopes which provided other food crops through chena cultivation.

Each tank therefore was the lifeblood of the village, and each village had a high degree of self sufficiency.

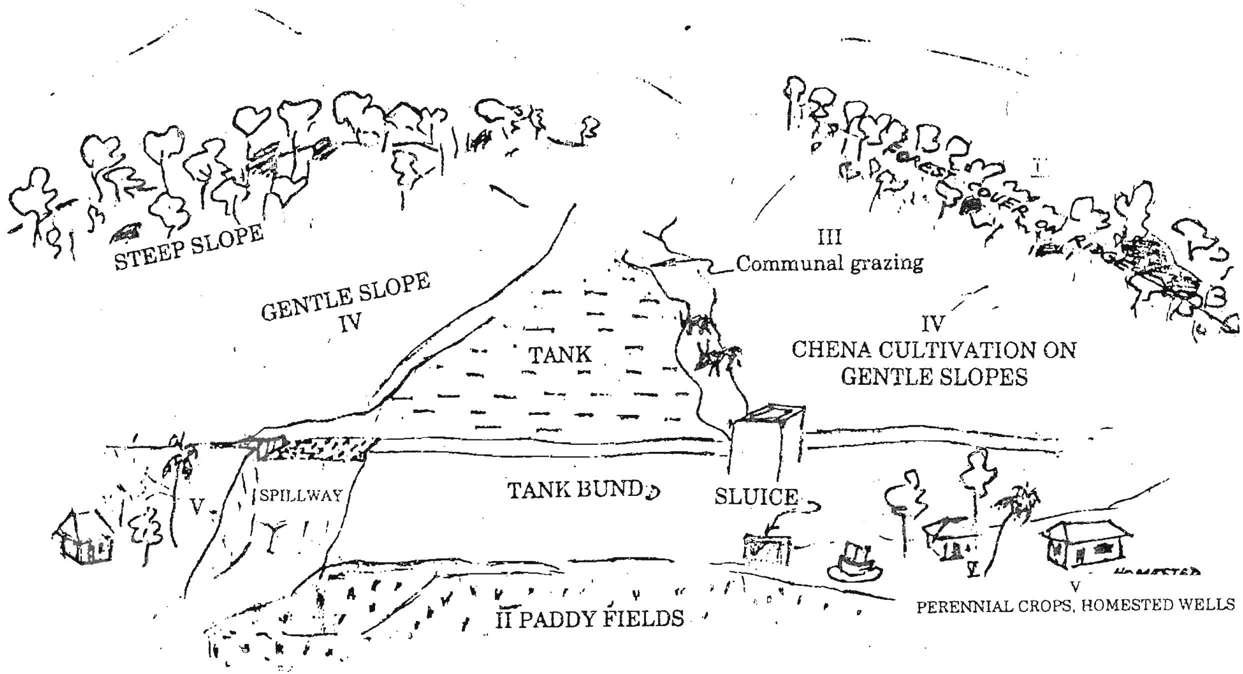

Diagram of Tank Landscape
(Slopes are exaggrerated)

Although each tank village was virtually self - sufficient, there was apparently much going to and from village to village. The excess production of one village could be exchanged for produce from another, and the village fair or Pola, is a long-standing development of the primary rural market, evolved over centuries and being modified from time to time to meet the demands of a changing environment.

Trees are an essential element in tropical agriculture. They tap deep layers of the land for nutrients and help in recycling nutrients to the surface through leaves and litter. They also intercept heavy rain, and heavy winds. Trees have always been regarded as necessary of protection and various taboos and religious beliefs have developed in many countries to protect and nurture trees. This is probably true of ancient Sri Lanka as well, as is evident from some of the beliefs, rituals and taboos of our own aboriginals, the veddahs.

The macro system

What may be termed the macro system was based on the large tanks such as Kala Wewa, Parakrama Samudra, Minneriya, Padaviya. These large tank bunds were also built across small rivulets, tributaries and aras and never across gangas or rivers. Their main purpose was to augment small tanks in their command area. They also irrigated a Yaya of paddy directly. Land use was similar to the small tanks but there was one important feature.

Large tanks were often connected one to another by transbasin canals. Thus several macro systems were merged into a major pattern. Archaeological evidence points towards the transbasin canals being first built and the tank being fed, built afterwards. These transbasin canals or Yoda Elas augmented tanks along the way as well. A well known example in Sri Lanka is the Yoda Ela that runs from Kala Wewa to feed the tanks in Anuradhapura. This itself is a tremendous engineering feat, marvelled at by modern engineers. These transbasin canals were constructed by building a bund on the lower side. They ran on a contour and therefore collected the runoff from the upper slopes during rain. In addition, they carried water from the main large tank.

One of the problems of modern irrigation engineers concerns the loss of water through seepage in the canals. In the Yoda Ela, this seepage created moist conditions in the lower area and here, our ancients established man-made forest gardens to provide medicinal plants, timber and fruit trees. Some of these man-made forest gardens can still be seen and are hundreds of years old. Our Arulu, Bullu and Nelli forests are good examples. Unfortunately, some of these have been destroyed for ever in the name of development, like what happened when the Gal Oya scheme was built, when the first operation was jungle clearing - a task performed by two giant bulldozers levelling the forest with a giant chain connecting them.

The south eastern dry zone

The south eastern dry zone, particularly the Hambantota district, which we know as Ruhuna, offered a challenge to the ancients different from the north central dry zone or Rajarata. Here, the rainy season was shorter although the intensity of rainfall was probably higher. The dry season too was more pronounced. The system of soil and water conservation seen here is similar to the Rajarata, but there is a significant addition. There are ruins of thousands of small tanks bunds without any trace of a sluice . It was only in recent years that it was realized that these bunds had their ends curved downstream, and their true function was not that of a storage reservoir but of a water diversion device. These bunds spaned small areas and streams that were dry during most of the year, and carried water only during the monsoon rains.

The way these devices worked was probably to divert the water to the lower slopes of the valley. The soils on these slopes are different to those of the valley bottom. They are well drained and could be cultivated with food crops other than paddy, for which the valley bottom soils were suited. Much of the diverted water was thus stored in the soils of the lower slopes (These soils are termed Reddish Brown Earths or RBE'S). This enabled other food crops to be cultivated on these slopes. The excess water drained into the valley bottoms where it was held by the so-called Low Humic Gley soils or LHG's on which the paddy crop could be obtained. Archaeological evidence to suggest a Thriving Agrarian Civilization in Ruhuna is still being found and a more detailed explanation of the soil and water ecosystem of ancient Ruhuna will, one day, be revealed.

The more we learn about what our ancients achieved in meeting the challenge of establishing a civilization in a parched and desolate area, the more we feel how much might have been achieved if we had this knowledge a century ago. Successive governments have tried to re-create and modernise what was seen of ancient ruins, and the failures and blunders committed have been due to a lack of understanding of what was operate in ancient times. Above all, the approach was restricted to the consideration of only the hydraulic engineering aspects, neglecting the agricultural, social, economic and cultural aspects of our ancient systems, aspects that formed an integral part of the basis of the dry zone civilization.

HEALTH PRINCIPLES REFLECTED IN ANCIENT RUINS

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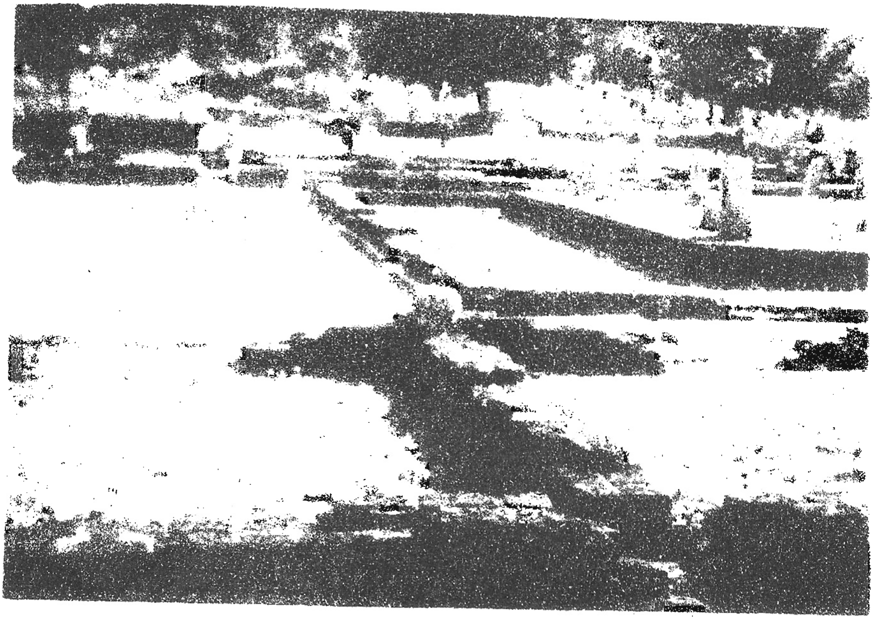
The existence of sound medical principles in ancient times is reflected in ruins that have survived. This is not surprising for a civilization to which belonged the earliest concept of a hospital where a number of patients could be collectively housed in a special centre with attendant advantages to the sick. Assyria, Babylon and early Egypt had systems of medicine which were older than Ayurveda, but neither these countries nor China had hospitals in those remote times.

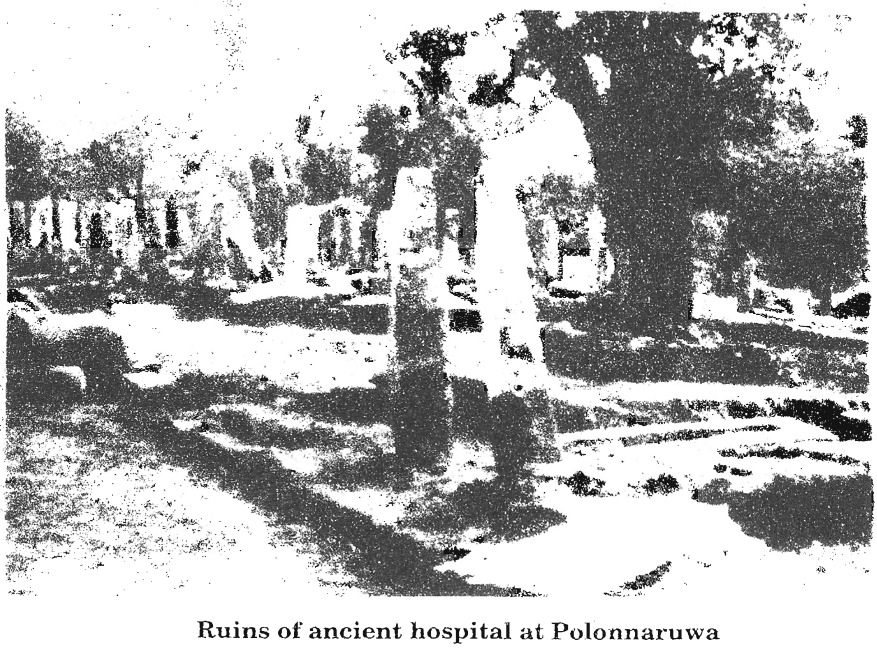
Ancient hospitals

Ruins of hospitals have been excavated in relation to the ancient monasteries of Mihintale, Alahana in Polonnaruwa and Medirigiriya. The ruins at Minintale, which date back to the ninth century, are perhaps the oldest of any hospital in the world. These leading monasteries were institutions of university status, and it is tempting to think that these infirmaries functioned as teaching hospitals, a concept that is in consonance with modern medical education.

These ruins demonstrate a characteristic plan for a hospital, namely a central courtyard with cells around it for sick monks and an adjoining outer courtyard surrounded by rooms used for common amenities such as taking of meals, bathing and preparation and storage of medicines. Some artefacts which would have had medical uses have come to light. Surgical instruments such as scissors and knives were found at Alahana. A quern used for grinding medicine was unearthed at Minintale. This item of equipment consists of two similar circular stones between which the herbs were crushed when the upper one was rotated over the lower half. Two blue glazed jars of Persian origin found at Mihintale, and pieces of ceramic at Alahana suggest that imported containers were used for purposes of storage of medicines. However, the hallmark of an ancient hospital was the stone medicine trough.



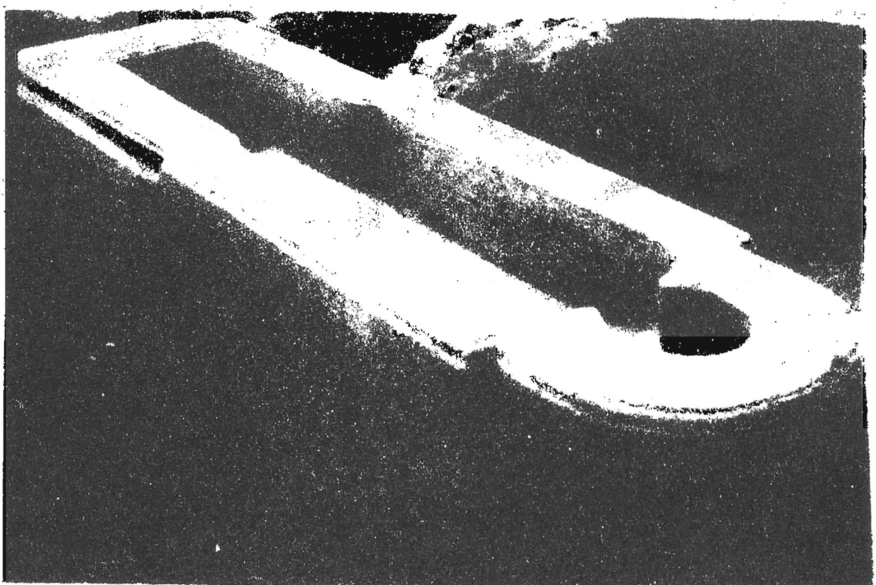
Ruins of ancient hospital at Mihintale



Ruins of ancient hospital at Polonnaruwa

Medicine trough

Altogether six medicine troughs have so far been discovered in Sri Lanka, and these were at Anuradhapura (two), Mihintale, Alahana, Medirigiriya and Dighavapi. These structures at first intrigued archaeologists till their purpose was realised. These were used in ancient times for immersion therapy where patients were placed in them and immersed with medicinal fluids for ailments such as fever, skin disease and rheumatism. These stone troughs, referred to in Sinhala as Beheth Oruva, have been carved out of a single rectangular stone slab which had been scooped out to conform to the configuration of a human body. When a patient positions himself in the trough, almost the entire volume of its concavity would be taken up by his body, and therefore very little of the medicinal fluid would be required to immerse him. In this way, the human configuration of the trough ensures economy in the volume of the precious medicinal fluid needed for treatment. The medicine trough therefore employs sound principles of hydraulics.



Medicine trough (Beheth oruwa)

Sanitation

There is convincing archaeological evidence that an efficient system of sanitation existed, at least in principal monasteries and palaces in ancient Sri Lanka. Some of the archaeological remains point to the adoption of sound scientific principles in the construction of sanitary facilities, a fact which is not surprising in a people who evolved a sophisticated irrigation system. There is a little doubt that the emphasis placed by both Buddhism and Ayurveda contributed to the observance of sanitary habits.

The remains of several toilet complexes in ancient Buddhist monasteries have come to light, and some of them which have been conserved give an idea of the engineering capability of the designers. Each complex consisted essentially of a urinal stone and a soakage pit. Many of these urinal stones had elaborate decorative motifs carved in relief on them. Some of these, such as the urinal stone near Ruwanweliseya in Anuradhapura, depict a shrine in which the open doorway has been utilised as the orifice of the urinal stone. These stones have intrigued archaeologists, who in trying to explain the reason behind the elaborate dressing of such utility structures, have invoked religious reasons in support of their theories.

A beautifully carved urinal stone, with a drain leading to a terra-cotta soakage pit behind it, was discovered at Galabadde in the Eastern Province. Recent excavations at Alahana Pirivena in Polonnaruwa too brought to light a toilet complex in which one room was used for bathing and the other as a toilet. Two soakage pits, built of bricks, were found behind each of these two rooms. Bricks lining the interior of the pit were laid with wide spaces filled with plaster, an arrangement that would have facilitated soakage of water.

Remains of toilets have generally been discovered in ancient mousatic sites, but the one at Panduwasnuwara was attached to a corner of the palace. A stone conduit drained the water from the toilet floor to a circular brick built pit lined with rings of terra-cotta. A stone slab once sealed this seven foot deep pit, but treasure hunters had smashed it under a mistaken notion that it hid valuables.

In some instances, drainage water, instead of running into a pit, was led into an earthenware pot or a series of pots, placed one above the other, behind the urinal stone. In the latter arrangement, the pot below was larger than the one above, and there was a hole at the bottom of each pot.

It may be seen that toilets were attached to the living quarters of monasteries and palaces. Their very situtatin demanded that they should have been free of smells. The arrangement of drainage, as could be pieced together from existing remains, would have ensured this requirement.

Water

The populous areas happened to be in the dry zone of today, and it is a tribute to the ancient system of irrigation tanks and channels that the little water that flowed through it was harnessed to yield maximum service to the people. Water for drinking and personal hygiene would have come from this system as well as from wells. Several old wells have been discovered in the ruined cities. These wells were lined with brick, rubble or dressed granite, thus ensuring as clean a supply of water as possible. The remains of ancient baths at Anuradhapura, Polonnaruwa and other ancient sites, which are noteworthy for their artistic appearance, demonstrate an engineering arrangement by which clean water was led into them from neighbouring tanks and channels by means of underground pipes of stone or terra-cotta.

While some of the large Buddhist monasteries were built in cities such as Anuradhapura and Polonnaruwa, hundreds of smaller ones were scattered in remote sites which have since been claimed by the jungle. One of the constant features of these monastic sites was the presence of a naturally occurring water-hole, which in the first place probably would have determined its original choice as a site for a monastery. The most enduring water-holes are found in the outcrops of gneiss rock, the caves of which provided monks with a puritan abode. Often, the rock slabsloping gently towards the hole, provided a catchment area for rain water, and its depth ensured a water supply through months of drought.

In areas where rivers, tanks and channels were not available, wells provided the main source of water. Remains of wells have been discovered in ancient sites other than the ruined cities. At Kudaramalai, which was an ancient habitation now falling within the Wilpattu National Park, the remains of a well were discovered near the coastline. It was lined with cylinders placed one above the other in a stratified fashion. These perfectly circular cylinders made of baked clay were approximately 3 feet in diameter, 18 inches in height and 1 3/4 inches in thickness. It has been suggested that this clay lining helped to keep the water cool. The period of the site has been assigned to the eleventh century AD.

Drainage

Ancient builders were aware of the principles of drainage of water. Many of the ancient Dagabas had provision for drainage of rain water. The ground immediately surrounding an ancient dagaba was usually at an elevated level and it served as a stage for worshippers to make their religious observances. In order to provide an egress for rain water that fell on the Dagaba and its precincts which were surrounded by a parapet wall, stone drains a few feet long were fitted through holes made in the wall. These ancient gutters which have survived are a common sight at these historic monuments.

At the ruins of the Mihintale hospital, a cubicle has been identified as a bathroom that served sick monks by means of an outlet drain. Similar drains too have been demonstrated at Alahana in Polonnaruwa.

One of the most interesting items of engineering skill in drainage is to be seen in the hundreds of jungle girt rock caves which many centuries ago provided homes for Buddhist ascetics. On the brow of each cave was chiselled a drip ledge which interrupted the flow of rain water and directed it to dribble downwards vertically, instead of allowing it to flow along the under surface of the roof into the living quarters of monks. Some of these drip ledges are found at great heights, and the fact that artisans had to toil at such dizzy elevations indicates the importance attached to this concept by ancient builders. The drip ledge has now become the hallmark for identifying ancient caves that provided habitation to monks.

Burials and Cremations

There is archaeological evidence that burieal and cremation of the dead were practised even in pre-historic times. In 1956, a Stone Age burial site containing several skeletons was discovered at Bellan Bandi Palassa. In the Iron Age burial site at Pomparippu, earthenware urns contained bones, sometimes of several individuals in the same vessel. In the case of children, the stains on teeth indicated that cremation had taken place before burial. These sites constituted virtual cemeteries.

An interesting example of a burial was discovered during excavations near the bund of Tissawewa at Tissamaharama. A large, wide-mouthed chatty or earthenware vessel that was unearthed contained a number of calcined bones. It is believed that these remains belonged to the fourteenth century AD.