A COMPARATIVE STUDY OF HYDRAULIC ENGINEERING IN ANCIENT SRI LANKA AND ANCIENT CHINA

by

D.L.O. Mendis

1.0 Introduction

This paper is a sequel to two earlier papers dealing with development problems in southern Sri Lanka (Mendis, 1988; Mendis, 1989b). It reports the culmination of efforts made during the past two decades and more, to arrive at a scientific understanding of ancient irrigation systems, and thereby establish and formulate a rational basis for design and construction of irrigation and multi-purpose development schemes in modern Sri Lanka.

The need for such a rational and scientific basis for design and construction of these schemes was highlighted by focussing on the location of the Uda Walawe and Lunugamvehera reservoirs. It was shown that these locations had been determined on an unscientific and irrational basis of within basin or single basin balance of water and land resources without consideration of possibilities for trans-basin diversion of water, on which the 1959 Water Resources Development Map of Ceylon had been prepared.

It was also shown that, that map was based on ‘a process of evolution which is thought to have occurred’ in the ancient irrigation systems in Sri Lanka, as postulated by R.L. Brohier, (Brohier 1956; Needham 1971, 369). It was argued that socio-political problems that have arisen at Uda Walawe and Lunugamvehera, (especially the latter), have their roots in the ‘destabilisation of ancient irrigation ecosystems’ in the Walawe and Kirindi Oya basins, essentially due to the wrong locations of these two major reservoirs constructed in modern times (Mendis, 1988; Mendis 1989b).

Professor Joseph Needham, F.R.S., who had used Brohier’s 4 stage theory in Volume 4, Part 3, of his great work, Science and Civilisation in China, has agreed that there are shortcomings in that theory, and has invited this author to undertake a comparative study of hydraulic engineering in ancient China and Sri Lanka to set the record straight.

2.0 Current situation at Walawe and Kirindi Oya

President Jayawardenena as Chief Guest at the Annual Sessions on October 21, 1988 described the 1988 paper as a ‘severe criticism of government policy’ and said that he would ask the Minister in charge of irrigation to appoint a Commission of Inquiry into Lunugamvehera.

In the event, in March 1989 President R. Premadasa appointed a Committee headed by the Director of Irrigation to report on representations made jointly by Mr. M.S.M. de Silva and the author on the proposed Southern Area Plan. On the recommendation of that Committee a Cabinet Sub-Committee on Infrastructure and Development chaired by the Secretary, Mr. Ivan Samarawickrema was convened and recommended that a study be commissioned by the Secretary, Ministry of Lands, Irrigation and Mahaweli Development. The Cabinet at its meeting on July 5, 1989, ratified this proposal, and in due course the Secretary, Ministry of Lands, Irrigation and Mahaweli Development requested the Chairman, Central Engineering Consultancy Bureau to organise an inter-disciplinary group of local experts to prepare preliminary proposals which would lead to the preparation of a Master Plan for development of the South-East dry zone. Eventually a Reconnaissance Report was prepared under Chairman, C.E.C.B. in September 1989 which was accepted without amendment by the President and Cabinet, in November 1989.

There were six major recommendations in that Report, of which the first two were:

1. Feasibility studies which will include an implementation program should be undertaken immediately, using local resources, and not by any foreign agency.

Mr. D.L.O. Mendis, BSc(Eng)Hons, MSc(Agric), CEng, FIE(SL) was President of this Institution in 1986/87.

He is General Editor of the recently launched History of Engineering series, his special interest being the history of irrigation. He was co-opted into the Committee on the History of Irrigation, Drainage and Flood Control at the 14th Congress of the International Commission on Irrigation and Drainage, Rio de Janeiro, Brasil, in May 1990. In June 1990 he began research on the project described in this paper at the Needham Research Institute, Cambridge, England, at the invitation of Professor Joseph Needham, F.R.S. who has described him as ‘one of the most important experts on ancient hydraulic technology’.
2. Simultaneously, the findings of this Reconnais-
sance Study should be made available to Mem-
ers of Parliament and Local officials in the
Southern region for their responsive criticism.

On January 26, 1990 the author had the privilege of
meeting H.E. President Premadasa, and appraising
him about the SEDZ development plan.

In March 1990 a loan of $365,000 was negotiated from
the Asian Development Bank for the feasibility
study of the SEDZ development. It is left to be seen
whether the first recommendation above will be
followed in the selection of consultants for this work.

Meanwhile, from Yala 1988 onwards, field studies have
been done at both Walawe and Kirindi Oya by
researchers from the International Irrigation Manage-
ment Institute (IIMI), some of which are listed under the
References in this paper. There is no indication in any
of these studies of any understanding of the concept of
irrigation ecosystems, on which the criticism of both
Uda Walawe and Lunugamvehera projects is based.

3.0 Science and Civilisation in China

The brief dust-jacket description of Volume I of
Needham’s monumental life-long work, Science and
Civilisation in China first published in 1954, states:

Dr. Joseph Needham’s account of the Chinese
achievement in Science and technology will stand
as one of the great works of our time. It has been
acclaimed by readers in both East and West and
also by readers with wider and more general
interests. The text, based on research of a highly
critical quality, is supported by many hundreds
of illustrations and is imbued with a warm appre-
ciation of China.

Dr. Needham’s presentation of China and Chi-
nese scientific achievements, in a detail that has
never previously been attempted, is a great
addition to the sum of our knowledge of Asia. By
tracing the merging of all medieval sciences it shows
how much the West is indebted to the dis-
coveries and inventions in China, and it demon-
strates the enlightenment that can be gained by one
civilisation through the study and true appraisal
of another.

The range of this work is vast. Dr. Needham,
besides spending many years himself in studying
the language, and living and travelling in China,
has needed, and received, help from specialists
in many branches of science and technology.
Above all, Chinese co-workers have been
essential ....

Volume I is an introductory volume, in which Dr.
Needham prepares his readers for the study of a
whole human culture. He begins by examining
the structure of the Chinese language; he
reviews the geography of China and the long
history of its people, and discusses the scientific
contacts which have occurred throughout the
centuries between Europe and East Asia.
(Needham 1988, Dust-jacket).

And, the dust-jacket introduction to Volume 4, Part 3,
Civil Engineering and Nautics, first published in 1971
states:

‘As Dr. Needham’s immense undertaking gath-
ers momentum it has been necessary to sub-
divide volumes into parts, each bound and
published separately .... Chinese civil engineer-
ing, both in scale and skill, was highly developed
in ancient and medieval times. This volume is the
pioneer study. Dr. Needham begins with an ac-
count of the building of roads and walls; then
follows a logical classification of bridges, from
the simplest of beam bridges to the more
elegant cantilever, arch and suspension
bridges; and finally in this section Dr. Needham
launches into a full-scale account of the great
public works of hydraulic engineering in which
the Chinese excelled’ (Needham, 1987, Dust-
jacket).

Volume I also carries an extensive list of the contents of
future volumes. Volume 4, Part 2, Section 27 (e) deals
with Hydraulic engineering I, and Volume 4, Part 3,
Section 28 (f) deals with Hydraulic engineering II, as
follows:

Hydraulic engineering : I. Water-raising machinery
1. The swape (shaduf : counter-balanced bailing
bucket)
2. The well-windlass
3. The scoop-wheel
4. The square-pallet chain-pump, and valve pumps
5. The Saqiyah (vertical pot-chain pump)
6. The noria (peripheral pot-wheel).

Hydraulic engineering : II. Control, construction and
maintenance of waterways
1. Problems and solutions
2. Silt and scour
3. The river and the forest
4. Engineering and its social aspects in the corpus of
legend
5. The formative phases of engineering art
6. Sketch of a general history of operations
7. The greater works :
The Chengkuo irrigation canal (Chhin).
ii) The Kuanhsien division head and cut (Chhin).
iii) The Kunming reservoir (Yuan) and the Shantan system (Ming).
v) The Grand Canal (Sui and Yuan).
vi) The Chhien-thang sea wall (Han. Wu Tai and Sung).
8. The literature of civil engineering and water conservancy.
9. Techniques of hydraulic engineering:
i) Planning, calculation and survey.
ii) Drainage and tunnelling.
iii) Dredging.
iv) Reinforcement and repair.
v) Sluice-gates, locks and double slipways.
10. Comparisons and conclusions.
(Needham, 1988, xxx, xxxi)

Needham’s presentation (after Brohier), of the ‘process of evolution which is thought to have occurred’, mentioned above, of the ancient irrigation systems in Sri Lanka, given in Volume 4, Part 3 under 10 Comparisons and conclusions is as follows:

‘The process of evolution which is thought to have occurred may be described as follows: (Fig. 926); first the farmers made numerous small tanks in the hills and foothills near their fields or terraces to catch the runoff water which they baled out at leisure. Then numbers of small dams (bunds, bemma) forming small reservoirs (tanks, wewa (Tam.) Kulam) were built, often in series on the upper reaches of tributaries of the greater rivers, thus retaining the annual or inundatory flow, and discharging it as desired by small canals (ela) along the valley sides. As time went on, larger dams were built, submerging or rendering unnecessary the smaller ones. The next step was revolutionary: a weir (anicut, (Tam.) tekkam) was built much higher up the main river (ganga, oya (Tam. aru) to form the headwork for a long lateral trunk derivation-channel (yodiela), which thus brought perennial water to join the annual monsoon supplies in the greater reservoir. This method, ambitious as well as scientific, had numerous advantages (a) it harnessed a greater volume of water than any local catchment area could yield; (b) it put monsoons as well as other rainfall to full use; (c) it secured a resource in drought periods as well as an even supply in normal years, and (d) it lessened the silt accumulation problem because the feeder canals could be cleared periodically much more easily than the thanks. Such yodi ela canals, dropping very slowly along the contours, often passed across one or more watersheds en route. They were generally
dyked only on one side (kandiya), sometimes spreading out into small lakes as they went, but in certain places a double embankment (depa-ela) was necessary. Smaller tributaries and gullies were crossed by means of spillway dams (gal-wana) with wing walls, sufficiently ample to take care of the greatest freshets, but also so arranged as to deliver a constant supply from the canal in dry periods; thus converting the fitful tributary into a perennial stream, and saving labour by the construction of purely artificial distribution canals. Elsewhere the yodi-elas ran (and run) for many miles over apparently flat country. For all these work can be traced today after many centuries, and many still function’ (Needham, 1987, 368-370). (Fig. 926, reproduced from Ibid, 369).

The errors and misconceptions that are embodied in this ‘process of evolution which is thought to have occurred’ have been discussed in other papers, where it has been shown that Brohier enunciated aview popular amongst irrigation engineers, that apparently originated in the mid-thirties (eg. Mendis, ,1990). However, it was not until 1984 etc.. subsequently, the concept of irrigation ecosystems was also developed, which is used in arguing against the present locations of Uda Walawe and Lunugamvehera reservoirs (Mendis, 1988, Mendis 1989a; Mendis, 1989b; Mendis 1990).

Professor Needham was kept informed of these developments during the past several years, through correspondece, and in the course of a very brief visit to Cambridge, in 1987. Professor Needham then invited the author to undertake research on a comparative study of hydraulic engineering in ancient China and Sri Lanka, saying inter alia: ‘I am sure that my treatment of the subject in Volume 4, Part 3 of Science and Civilisation in China, could be improved upon, and I am counting on you to do it’. (Personal communication May 1989).

This magnanimous statement from a Scholar of great wisdom and repute placed this author in the position of having to undertake a historical study of such scope as to daunt even a more resourceful and better equipped researcher. What finally prompted acceptance of the challenge, for it is indeed a challenge, was the hope that such a study would increase our knowledge and improve our understanding of irrigation ecosystems. If this is achieved it would surely be useful in tackling the present problems in Walawe and Lunugamvehera, and perhaps future problems in the Mahaweli. For, as the historian Kossambi has said:

‘Great history is written precisely when the historian’s vision of the past is illuminated by insights into the problems of the present ... The
function of history is to promote a profounder understanding of both past and present through the inter-relation between them' (Kossambi, 1965, 24).

4.0 Outline of Proposed Comparative Study

Water conservancy projects undertaken in ancient China, were based on the concept of 'shui li', or 'benefit of water'. A wealth of information is available about numerous water conservancy projects in ancient China, documented down the ages by scholars, and Needham and his co-workers have systematically sifted through these sources in the process of compiling science and Civilisation in China. One of the famous ancient Historians, Ssuma Chhien who lived twenty centuries ago, had said, in the course of a long discourse which Needham quotes in full to conclude Section 28 (f) Hydraulic engineering II:

‘And I say again, inconceivably great are the benefits and the destruction which water can produce’. (Needham, 1987, 378).

Needham says that there were four major aspects of shui li, ‘the benefits which water can produce’ namely, transport, flood control, irrigation and defense. (Needham, 1988, 214).

In Sri Lanka on the other hand, irrigation is the prime and most important benefit in the ancient systems, which therefore are always referred to as the ancient irrigation systems, and not for example, as water conservancy projects. Ssuma Chhien’s dictum quoted above, may appropriately be contrasted with the well-known dictum of Parakrama Bahu the Great:

‘In the realm that is subject to me there are, apart from many strips of country where the harvest flourishes mainly by rain water, but few fields which are dependent on rivers with permanent flow or on great reservoirs. Also by many mountains, by thick jungle, and by widespread swamps my kingdom is much straitened. Truly in such a country not even a little water that comes from the rain must flow into the ocean without being made useful to man’ (Culavamsa, 1954).

Clearly what is referred to here is irrigation; but in the ancient irrigation systems or water conservancy projects in ancient Sri Lanka, drainage is a necessary corollary to irrigation. Flood control is a derived or secondary benefit especially in the case of large storage reservoirs, and only a marginal benefit in the case of river diversion systems. Transport comes in as a benefit in the case of some of the larger diversion channels, like the Elahera canal and the Minipe yodiela, but the existence of roads along channel bunds perhaps made water transport secondary, in spite of the advantages of the latter for long haulages. As for defense, every waterway has a potential for defense during times of conflict, and the Mahaweli garga was used as a natural boundary on which fortifications were located in times of protracted conflict in ancient times. Similarly, moats were a common enough feature of many ancient citadels.

In ancient Sri Lanka then, the contrast with the shui li of ancient China was considerable. A comparative study should therefore take into consideration the following essential dis-similarities between water conservancy projects in ancient China and the ancient irrigation works in Sri Lanka:

i) Differences in emphasis on benefits, viz. transport, flood control, irrigation, and defense, vs. irrigation, drainage and flood control.

ii) Obvious differences in scale.

iii) Differences in agro-ecological conditions, especially in respect of climate (rainfall intensity and distribution and temperature), topography, soils, and crops.

iv) Differences in socio-economic and political conditions, including forms of social organisation and technology.

Using information culled from diverse sources in respect of the ancient water conservancy projects in China, Needham has said that ‘harnessing of a river can take place in one or more of the following ways’:

(Needham, 1987, 214):

a) Construction of a dam across a valley, forming a reservoir or tank.

b) Arrangement of retention basins ... to submerge agricultural or other land for a limited time, restoring fertility by silt deposition.

c) Canalisation of the main stream.

d) In other situations, as and when the bed or banks of a river was unsuitable for navigation, a lateral transport canal was cut, accompanying the main stream at the same or a somewhat higher level.

e) Derivation of a lateral irrigation canal high up the valley of a perennial river.

f) When a lateral canal has its terminus in a water course other than that from which it came it is termed a contour canal.

g) Connection between two river systems is finally afforded by the summit level canal.

Needham has used this analysis and terminology to describe in some detail the six Greater Works in ancient China, namely : (Needham, 1987, 285 ff):

i) The Chengkuo irrigation canal (Chhin dynasty).

ii) The Kuanhsien division head and cut (Chhin).

iii) The Kunming reservoir (Yuan) and the Shantun System (Ming).
The 'Magic Transport Canal' (Chhin and Tang).

The Grand Canal (Sui and Yuan)

The Chhien-thang sea wall (Han, Wu Tai and Sung).

These Greater Works are all also located in what has been termed 'Key Economic Areas' by Chi Chhao-Ting, a Chinese scholar to whose memory and that of Herbert Chatley, once time Professor of Civil Engineering at Thang-shan College, and Chief Engineer of the Huangpo Conservancy, Needham has dedicated his Volume 4, Part 3.

Chi Chhao-Ting whom Needham describes as 'Historian of China's waterways and works, and a friend beside the Chaling river, economic and financial leader in a resurgent land', has shown that water conservancy projects were essential features in the development of key economic areas, the control of which from time to time, enabled a ruler or a dynasty to have control over the whole country. (Chi Chhao-Ting, 1936). He and other scholars have studied the vast store of literature coming down from ancient times, to establish in greater detail the construction of water conservancy projects in ancient China.

It will be observed, however, that Needham's description of the ways in which a river was harnessed in China, (a) to (g) above, does not apply too well to the historical experience in Sri Lanka, on account of the differences listed previously. Study of the ancient irrigation systems in Sri Lanka on the other hand, led to development of the 7 stage theory (Mendis, 1984). As a preliminary step in the proposed comparative study therefore, it is intended to apply the 7 stage theory for the evolution and development of irrigation systems, to the history and pre-history of ancient China. It will be recalled that the 7 stages are: (Mendis, 1986b etc.).

i) Rainfed agriculture.

ii) Seasonal or temporary river diversion and flood or inundation irrigation of river banks.

iii) Permanent river diversion and development of channel systems.

iv) Development of weirs and spillways on diversion channels.

v) Invention of the sluice or sorowwa.

vi) Construction of storage reservoirs equipped with sluices.

vii) Damming a perennial river.

It is not to be expected that such a straightforward sequence in the evolution and development of irrigation or water conservancy systems in ancient China may be easily identified. Nevertheless, there is an inherent logic in this sequence of seven stages which suggests that it may be worthwhile to examine the evidence available from China, in the light of this theory.

Such a task is greatly facilitated by the references in Volume 4, Part 3, of Needham's Science and Civilization in China, to a wealth of source material in many languages, collected over the years and carefully collated and conserved at the Needham Research Institute in Cambridge. This priceless collection is available to visiting scholars, for study.

In contrast to the vast amount of material on China, there is perhaps a comparative dearth of information concerning the technical aspects of the ancient irrigation works in Sri Lanka. Brohier pioneered study and documentation of the available material, and his three volumes still remain the best starting point for serious research (Brohier, 1934). Perhaps as a result, Brohier's 4 stage theory of the 'process of evolution that is thought to have occurred' which was published much later (Brohier, 1956), has been accepted without question by all other researchers, including Needham himself who republished it in his great work, as quoted. However, Needham's statement that his 'treatment of the subject in Volume 4, Part 3 can be improved upon' re-opens the subject for new research on its most fundamental aspects. Therefore there is a need now, for a new collation of relevant information on the ancient irrigation systems of Sri Lanka. As a step in that direction an Outline for a Course of 20 Lessons on the Ancient Irrigation Ecosystems of Sri Lanka has been prepared, and is presented as an Appendix.

Special attention has to be given in a comparative study of hydraulic engineering to the invention of the sluice. A reconstruction of how the sluice (sorowwa) with its bisokotuwa or access tower, came to be invented in ancient times, is inbuilt into the 7 stage sequence for the evolution and development of irrigation systems. The sluice is also a vital element in the concept of the evolution and development of irrigation ecosystems.

In China, as could be expected there are numerous references to the sluice and sluice gates, to flash locks and pound locks on canals, and even to the use of sluices for silt ejection. An early reference quoted by Needham states:

'Chiia  Jan in - 6 submitted a written memorial containing three plans in preferential order. His second alternative was a network of irrigation canals. He said: "Now we can make a dyke of stone from Chhi khou eastwards and build many sluice gates (shui men)" 'Needham 1987.

Other references are to tan men which has been translated as water gate, or as 'head-gate or 'sudden-gate' (Ibid, 231). The sluice for silt control mentioned above. This may be compared with the madesorowwa or silt sluice found in ancient storage reservoirs or wevas in Sri Lanka.
Another feature of a comparative study of hydraulic engineering in ancient China and Sri Lanka will be in regard to terminology. In Sri Lanka, terminology commonly used to describe features of irrigation works that have to be mentioned are:

contour channel - a channel 'dropping very slowly' along the contours as described in Needham's section on the ancient irrigation systems in Sri Lanka
ridge channel - a channel on a ridge
irrigation channel - a channel supplying irrigation water or water for irrigation of fields
drainage channel - a channel leading off used irrigation water.

These are all self-evident in their meaning, and are commonly used and well understood in Sri Lanka. Other words worth mentioning include different terms to distinguish a perennial and non-perennial river viz.
ganga - perennial
oya or era, or in Tamil, aru - non-perennial

It should be possible to establish parallels between these terms and corresponding terms used in the Chinese literature, without loss of emphasis in the different contexts.

5.0 Conclusion

It is envisaged that some of the research for this comparative study of hydraulic engineering in ancient Sri Lanka and China, will be done in Sri Lanka, and some of it at the Needham Research Institute in Cambridge. One or more visits to China, at least to visit the five Greater Works mentioned, will also be necessary.

The International Commission on Irrigation and Drainage (ICID) has an ongoing project to compile the History of Irrigation in various countries. The author was co-opted into that Committee at the recent 14th Congress of ICID in Rio de Janeiro, Brasil in May 1990.

The History of Irrigation in Sri Lanka is to be compiled jointly by the Sri Lanka Committee of ICID, and the Institution of Engineers, Sri Lanka. It has been suggested that this history should be in three parts: the first from antiquity to the arrival of the Portuguese, the second the colonial period, and the third the period after Independence. The first part will be covered in the comparative study. The whole project may also be considered as a part of the History of Engineering series of this Institution.

Another project has been launched recently at the Institute of Fundamental Studies, Kandy School of Science, to compile a History of Science and Technology in South and South-East Asia. The author has been co-opted into the Sri Lanka Committee for this work, and will prepare a contribution which will incorporate much of the research envisaged for the comparative study.

6.0 Acknowledgements

I wish to express my deepest gratitude to Professor Joseph Needham, F.R.S. an extraordinary scholar who has devoted the better part of a long and full life to the study of Science and Civilisation in China, for having taken the trouble to respond to my observations on some aspects of his published work, with an open invitation to refer the source material at the Needham Research Institute in Cambridge, England. His invitation to me to undertake a comparative study of hydraulic engineering in ancient Sri Lanka and China, which I have accepted, may or may not result in the discovery of anything very significant, but I shall definitely give it my best effort, and most certainly enjoy every moment of it.

It is a pleasure to thank Professor Ho Peng-Yoke, Professor Needham's successor as Director, Dr. Michael Loewe, Deputy Director and Ms Liang Lien chu, Librarian, for all their help and kindness to me during my brief visit to the Needham Research Institute in June 1990. That visit was made possible by a generous grant from the British Council, Colombo for which I have to thank Mr. John Payne, Assistant Representative.

7.0 References

3. Central Engineering Consultancy Bureau; (September 1989), Southeast Dry Zone Development, Preliminary Project Proposals.


APPENDIX

Outline of Course of 20 lessons on the Ancient Irrigation Ecosystems of Sri Lanka

1. Introduction - 4 Introductory Lessons
   a. What is history? - A general discussion.
   b. Sri Lanka - general historical and geographical introduction.
   c. Sources -
      i. Historical period - Literary sources
         - Epigraphical sources
         - Archaeological sources
         - Foreign sources
         - Other sources
   ii. Proto-historic & pre-historic periods -
      - Archaeological sources
      - Myth and Folk-lore
      - Foreign sources
   d. Physical evidence -
      i. Topographical survey of Sri Lanka - physical evidence of the ancient irrigation works found on the field by land Surveys, from early British times, are shown described as 'working' or 'abandoned', on the one mile to an inch topographical survey sheets, now revised and reprinted to a metric scale of 1:50,000.
      ii. Similar evidence is to be seen on aerial survey sheets, but some of this evidence has to be interpreted. Examples are channels and tanks (small reservoirs) that have been silted up; and some ancient city fortresses that are now buried under the silt of ages:

2. Restoration of ancient irrigation works in recent times:

3 Lessons
   a. Piece-meal restoration- Dutch period, 1658 to 1797
      - Early British period (uptoabout 1900)
      - Late British period (IrrigationDepartment)
      - Post-independence, 1948
   b. Scientific Development of Village Irrigation Works - Kennedy (1933); Arumugam (1958).
   c. Restoration of Major works, and pioneer peasant colonization - Farmer 1957).

3. Three important aspects of the ancient irrigation ecosystems:

6 Lessons
   a. Evolution and development from prehistory to historic times.
   b. Sustainability and stability over very long periods of time.
   c. Decline without early restoration after the 12th century.
   a. Evolution and development -
      I. 4 stage theory : Brohier (1956); Needham etal (1971)
      i. Rain-fed tanks from which water was baled out.
      ii. Small village tanks.
iii. Large storage reservoirs, each submerging a number of small village tanks built earlier.
iv. Diversion channels from rivers to augment supply to large reservoirs from their own catchments.

II. 7 stage theory: Mendis (1984)
i. Rain-fed agriculture after the neolithic revolution.
ii. Seasonal or temporary river diversion, and floodor inundation irrigation.
iii. Development of permanent river diversion systems.
iv. Development of diversion channels equipped with weirs and spillways.
v. Invention of the sorowwa (sluice) equipped with a bisokotuwa (access tower corresponding to modern valve pit or valve tower) in about the 4th century B.C. (Parker, 1909).
vi. Construction of storage reservoirs equipped with sorowwa and bisokotuwa, for control and issue of irrigation water.
vii. Damming a perennial river.

b. Sustainability and stability over very long periods of time - explained in terms of the concept of irrigation ecosystems:
   i. (a) Haen govithan, or shifting cultivation.
      (b) Permanent tree-crios.
   ii. Seasonal cultivation under inundation or floodirrigation.
   iii. Seasonal cultivation under permanent river diversion and channel irrigation systems.
   iv. Seasonal cultivation under irrigation from small village tanks.

These four types i to iv are Micro ecosystems, of which types ii, iii and iv, are micro irrigation ecosystems.

v. Two season cultivation under irrigation from a large storage reservoir commanding one or more micro ecosystems of types ii, iii and iv, constituting a macro ecosystem.
vi. Two season cultivation under interconnected macro ecosystems forming a complex, through large channels which connect two or more large storage reservoirs, sometimes in different river basins.

c. Decline after the 12th century -

Discussion of a complex of causes. (Indrapala 1971)

4. Comparisons with some modern multi-purpose development projects in Sri Lanka

5 lessons
- Gal oya multi-purpose project modelled on TVA.
- Walawe project, supposedly modelled on Gal oya.
- Lunugamvehera project, based on the 1957 'Map of Water, Resources Development in Ceylon'.
- (Proposed) Southern Area Project.
- Mahaweli Multi-purpose development project.

5. Lessons of experience, and some philosophical considerations:

2 Lessons
- Lessons of experience for agriculture and settlement planning in tropical third world countries.
- Productive potential of ecologically stable and sustainable irrigation ecosystems.
- Modes of production, and relations of production, and an examination of successive changes in the use of water as the means of production.
- The static nature of the ancient hydraulic civilization, (Leach, 1959) and the role of Theravada Buddhism as an anti-thesis of the Protestant ethic.
**Brochier's Theory, quoted by Needham**

The process of evolution which is thought to have occurred may be described as follows:

First the farmers made numerous small tanks in the hills and foot-hills, near their fields or terraces to catch the run-off water they baled out at leisure. The numbers of small dams, bun bunds (bemma) were built, often in series, on the upper reaches of tributaries of the greater rivers, thus retaining the annual or inundatory flow and discharging it as desired by small canals (ela) along the valley sides, as time went on larger dams were built submerging or rendering unnecessary the smaller ones. The next step was revolutionary: a weir (anicut, Tamil = tekkam) was built much higher up the main river (ganga, oya, Tamil = aru) to form the headworks for a long lateral water to join the annual monsoon supplies in the great reservoir. This method ambitious as well as scientific, had numerous advantages:

a. It harnessed a greater volume of water than any local catchment area could yield.
b. It put both monsoons as other rainfall to full use
c. It secured a resource in drought periods as well as an even supply in normal years, and
d. It lessened the silt accumulation problem because the feeder canals could be cleared periodically much more easily than the tanks (Needham et al, 1971, 368)