WATER RESOURCES DEVELOPMENT
SANITATION IMPROVEMENT

Northern and Eastern Provinces of Sri Lanka

Mott MacDonald

UNIVERSITY OF SURREY

Mott MacDonald is pleased to publish this brochure which demonstrates how our collaborative research programme with the University of Surrey, in the disciplines of water and environment, has brought substantial benefits to practising engineers, scientists and research institutes worldwide. Since its commencement, over a decade ago, the collaboration has contributed immensely to enhancing our understanding of water and environmental engineering. The programme has provided us with a platform for the transfer of knowledge to all the involved parties which we have reinforced by releasing our specialists to teach post-graduate and research students at the university, encouraging these students to also gain practical experience at our office in Cambridge.

In order to disseminate the findings of our collaborative research the University of Surrey, supported by Mott MacDonald, has organised this international conference on water resources development and sanitation improvement at Universiyt of Cambridge. When considering water resources, the sanitation and water quality issues are equally important and complementary for achieving sustainability. This conference addresses these issues together with the impacts of climate change and initiates ideas on renewable energy that is affordable for developing countries. We will continue to support research and disseminate the results to meet the challenges facing the development of water resources worldwide.

Jim Perry
Managing Director
Water and Environment

"WE SEEK TO DELIVER INNOVATIVE, INCLUSIVE, SAFE AND SUSTAINABLE SOLUTIONS WITH NET POSITIVE SOCIAL, ENVIRONMENTAL AND ECONOMIC IMPACT"

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Divisional Director, Mott MacDonald

UNIVERSITY OF SURREY AND MOTT MACDONALD LTD

University of Surrey and multidisciplinary consultant Mott MacDonald in the United Kingdom are internationally well known for their involvement in the water sector. A joint venture by UNIS and Mott MacDonald on collaborative research relating to water resources development and sanitation improvements has contributed to address the future issues in these disciplines. This collaborative research was led by Professor B J Lloyd from the Centre for Environmental Health Engineering (CEHE), University of Surrey and Professor K Guganesharajah from Mott MacDonald Ltd. Professor Lloyd has an extensive knowledge of sanitation issues and methods of wastewater treatment and is an international expert in these disciplines. Professor Guganesharajah is a civil engineer and a leader in the field of hydrology and computational hydraulics. He has developed the HYDRO suite of hydraulic and water quality models which have been applied to over 150 studies in more than 35 countries. His early experience includes design of hydraulic structures and major irrigation systems. The two experts jointly supervised over 25 MSc projects and 5 PhD studies and have published over 15 papers in international journals and proceedings of international conferences.

UNIVERSITY OF SURREY

The Centre for Environmental Health Engineering (CEHE) is a research centre with international expertise in projects covering the entire water cycle. The projects encompass water resources surveillance, modelling and management, water treatment, supply and regulation, wastewater treatment, disposal and safe reuse, pollution control and waste management. These themes are also covered within CEHE's highly successful taught programme (MSc, PG Diploma) in Water and Environmental Engineering, which attracts students from all over the world, as well as professionals from the UK water industry and environment sectors. Research projects are completed by the MSc students as an integral element of the programme, often on a collaborative basis with industry.

CEHE is a designated World Health Organization (WHO) Collaborating Centre for the Protection of Water Quality and Human Health (with UniS' Robens Centre for Public and Environmental Health). The Centre provides support to overseas governments through international agencies (WHO), the Pan-American Health Organization (PAHO) and its regional sanitary engineering research centre CEPIS-PAHO in Peru, and relief organizations (eg. OXFAM). Research, consultancy and training projects have been completed by the staff of CEHE in at least 45 countries. Strong research and development contacts are maintained with UK and European water utilities (notably Thames Water, Southern Water and Stadtwerke Karlsruhe (Germany)) and some of the doctoral programmes of research supervised by the Centre are in collaboration with them.

MOTT MACDONALD

Mott MacDonald is a global management, engineering and development consultancy. Our £900 million business spans 140 countries with over 14 700 staff working in all sectors: transport; energy; buildings; water and environment; health and education; industry and communications. Our breadth in skills, sectors, services and global reach makes us one of the world's top players in delivering management, engineering and development solutions for public and private sector customers. We use our worldwide resources and experience to plan, design, procure and deliver projects on any scale; provide management consultancy built on technical know-how; and help shape and implement development policies and programmes.

Mott MacDonald Ltd was formed in 1989 by the merger of two consultancies: Mott Hay & Anderson (founded 1902) and Sir M. MacDonald & Partners (founded 1922). Ewbank Preece (founded 1898) joined Mott MacDonald in 1994. Our company has been involved in some of the world's most prestigious projects. Water is one of our core sectors. Our expertise extends globally and encompasses all aspects of the water cycle. Whether the project concerns water resources, water supply or wastewater, we provide sustainable solutions. Our knowledge of the environmental impacts of water developments enables us to ensure projects are undertaken in a way that will improve quality of life for beneficiaries without damaging the environment.

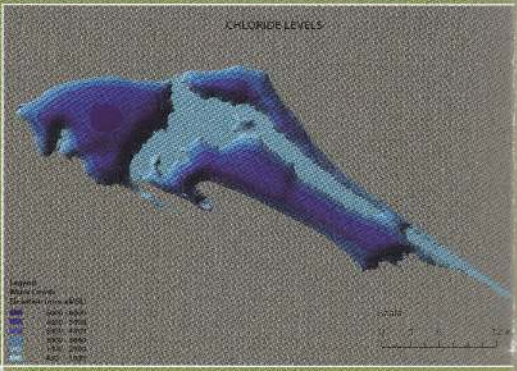
Our Environment Division delivers a full range of environmental services across the globe. Its services cover the multidisciplinary areas of environmental planning, environmental management, and environmental risk management. It has its own staff in the main technical specialist areas, such as water, soil, GIS, ecology, landscape, sustainability, and waste, and works closely with specialists from other parts of the company.

Mott MacDonald

SIMULATION

GROUNDWATER AND LAGOON MODELLING, JAFFNA PENINSULA

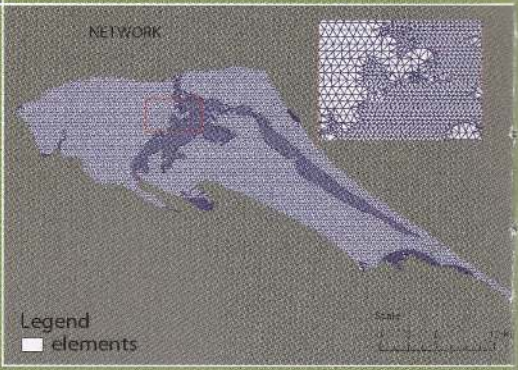
Intrusion of saline water, soil salinisation and high nutrient levels have affected large tracts of agricultural lands and adjacent water bodies in many countries in the world. The impacts on the water bodies include eutrophication and contamination resulting in extensive damage to the species in them. As addressing and mitigating these problems is pertinent to the Jaffna Peninsula a five year PhD research programme was undertaken at the University of Surrey which was completed in June 2009. The study focuses on sustainable management strategies to mitigate the problems through the application of a newly developed ground and surface water model. The area of the peninsula is 1,068 km^2 and includes two internal lagoons, namely the Vadamarachchi Lagoon and the Upparu Lagoon. The areas of these lagoons are 87 km^2 and 35 km^2 respectively.



JAFFNA PENINSULA
(Vasileios Tyriakidis - 2008)

NATURAL ENVIRONMENT IN LAGOONS

NETWORK
(Vasileios Tyriakidis - 2008)



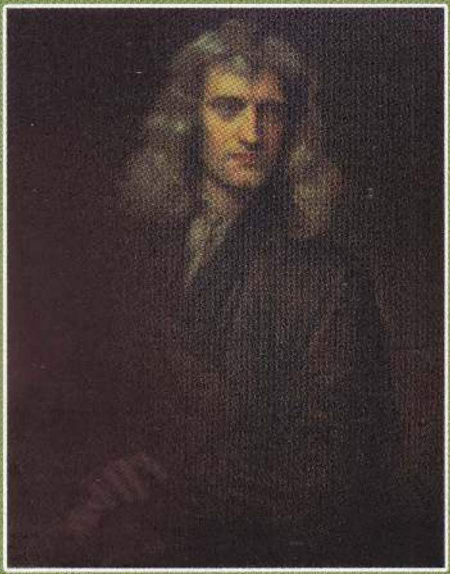
There are over 100 000 abstraction wells which are solely used for domestic needs and irrigation. A substantial quantity of surface and ground water in the peninsula is lost to sea. Over-abstraction of water for irrigation has contributed to intrusion of saline water to the aquifers. The contamination problems are further exacerbated owing to the application of agrochemicals for agriculture and lack of treatment facilities for wastewater. In order to understand the mechanisms of saline intrusion arising from deep tube wells a comprehensive three-dimensional hydraulic and water quality model has been developed to help manage the water resources in the region.

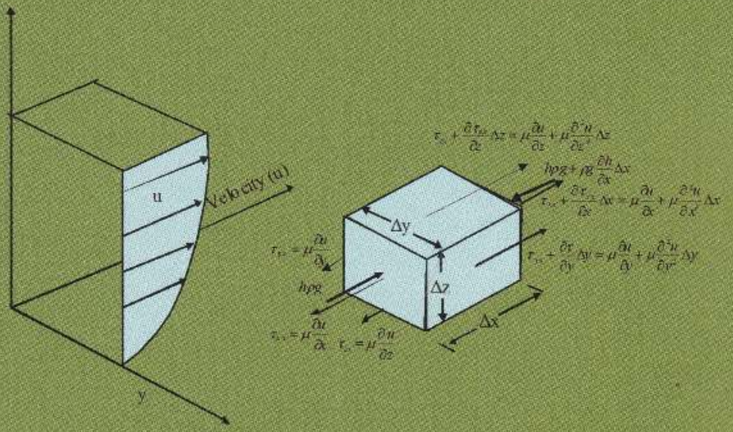
HYDRO-3D has been used to assess the current and future conditions in the aquifer and lagoons. The model was used to achieve effective control techniques which will mitigate contamination problems while maximising the exploitation of water resources and protecting the lagoons.

INNOVATION

DEEP TUBE WELLS

The deep tube wells in the Jaffna Peninsula and the Mannar district in the north-west region of Sri Lanka accelerated the salt water intrusion into the limestone aquifers. In order to understand the mechanisms of saline intrusion arising from deep tube wells, comprehensive research analysing the theory of groundwater movement has been undertaken.





SIR ISAAC NEWTON

(By kind permission of the Trustees of the Portsmouh Estates)

EXPLORING THE RELATIONSHIP BETWEEN DARCY'S LAW FOR GROUNDWATER FLOW AND NEWTON'S LAWS OF MOTION AND VISCOUS FLOW

$$v_r = K_h \frac{\partial s_r}{\partial r} = \frac{Q}{2\pi m}\left[-\frac{1}{r} - \sum_{n=1}^{\infty}\frac{2}{(z_2 - z_1)}\left[\sqrt{\frac{K_v}{K_h}}\right] K_1\left(r\frac{n\pi}{m}\sqrt{\frac{K_v}{K_h}}\right)\right]\times$$

(1) (2)

$$\left[\sin\left(\frac{n\pi z_2}{m}\right) - \sin\left(\frac{n\pi z_1}{m}\right)\right]\cos\left(\frac{n\pi z}{m}\right) + \int_0^{\infty} J_1(r\lambda)\, e^{-\frac{K_v}{S}\lambda^2 t}\, d\lambda -$$

(3)

$$\sum_{n=1}^{\infty}\frac{2m}{n\pi(z_2 - z_1)}\left[\sin\left(\frac{n\pi z_2}{m}\right) - \sin\left(\frac{n\pi z_1}{m}\right)\right]\cos\left(\frac{n\pi z}{m}\right)\times$$

(4)

$$\int_0^{\infty}\left[\frac{\lambda J_1(r\lambda)}{\left(\lambda^2 + \frac{K_v}{K_h}\left[\frac{n\pi}{m}\right]^2\right)}\right] e^{-\frac{K_h}{S}\left[\lambda^2 + \frac{K_v}{K_h}\left[\frac{n\pi}{m}\right]^2\right]t} d\lambda \qquad 0 \le r \le n$$

COMBINED SOLUTION DERIVED FROM BESSEL FUNCTION, FOURIER SERIES AND LAPLACE EQUATION (GUGANESHARAJAH ET AL., 2006)

This enables the definition of mitigation measures and testing of management scenarios through the application of the three-dimensional model HYDRO-3D.

MODELLING LAGOONS FOR ECOLOGICAL STUDIES

Elephant Pass lagoon is a large salt lagoon with some fringing mangroves and sea grass beds. The lagoon is situated in the south of the Jaffna Peninsula. It originally formed part of the Jaffna Lagoon; however, construction of the Elephant Pass causeway on the western part of the lagoon has isolated it from the Jaffna Lagoon. This disturbance and the ensuing water quality changes have caused adverse impact on the marine habitats of the lagoon. Furthermore, since the lagoon has been cut off, large areas have dried out during the dry season with the result that contaminants are inadequately diluted.

MODEL NETWORK OF ELEPHANT PASS LAGOON

The overall objective of this project is the environmental protection of this lagoon through implementation of effective management techniques that safeguard the surface water resources of the catchment area. In this project, the HYDRO-3D model was employed to simulate the hydraulic characteristics and water quality of the lagoon and also to evaluate the extent of water pollution and the subsequent impact on marine resources of the lagoon.

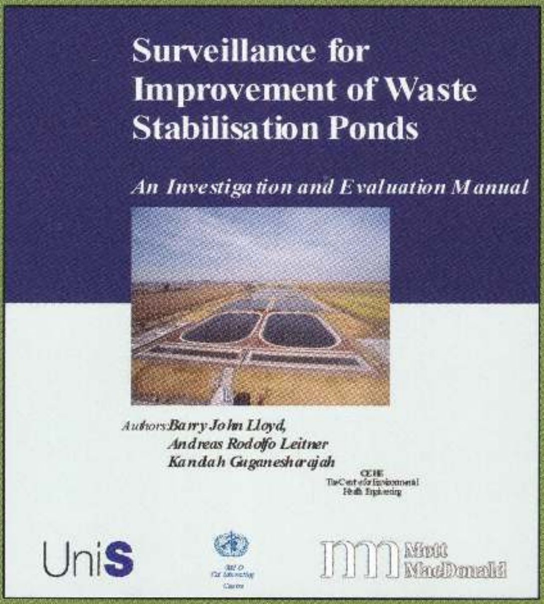
This model has future application for the identification of measures to protect the resources and the marine environment.

SANITATION

MOTT MACDONALD AND UNIS

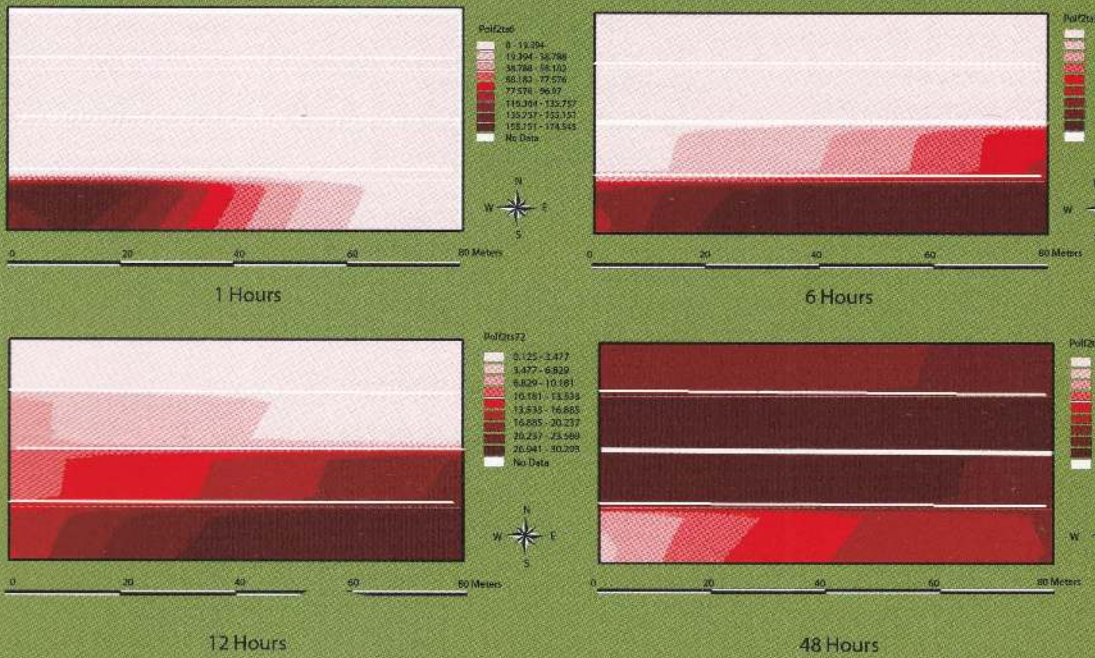
Currently our studies focus on exploiting the solar energy using lenses and a detailed evaluation of renewable energy in Sri Lanka.

WASTE STABILISATION PONDS



Waste stabilisation ponds (WSPs) are a cost effective means of providing treatment of sewage and have the potential for reducing the health risks associated with massive environmental pollution by excreta-related pathogens and parasites. Recent estimates of the world-wide prevalence of intestinal parasites suggest that 1.5 billion (25%) of the human population are infected (Helmer, 1999).

A joint research project between UNIS and Mott MacDonald with contributions by four PhD and four MSc students has resulted in the production of a manual on WSPs which is largely aimed at developing countries. This manual addresses the evaluation of WSP systems and the causes of their under-performance. The strategy and methods presented here originated from studies of performance problems of systems in a number of countries with widely varying climatic and socio-economic conditions.



EVALUATION OF PERFORMANCE OF MULTIPLE CHANNEL WSP USING THE HYDRO-3D MODEL

A systematic approach to the identification of the causes of under-performance is applied as a prelude to upgrading plants to meet effluent guidelines and regulatory standards. It is earnestly hoped that the lessons learned and methods described may be applied globally to avoid the widespread misapplication of a potentially valuable technology in regions of the world where, at present, it is scarcely used, and lead to its redemption in those areas where its reputation is tarnished by poor perfomance.

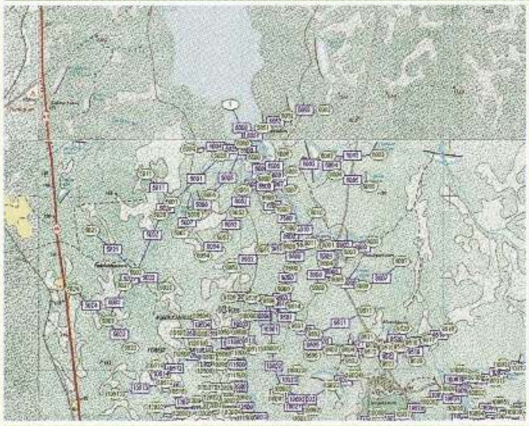
BASIN MANAGEMENT

MANAGEMENT OF IRANAMDU RIVER BASIN

HYDRO-1D is a one-dimensional transient hydraulic and water quality model which has process based robust routines to manage the water resources of a river basin. Since its development in 1982, the model has been applied to more than 150 studies in over 30 countries. The model is extensively used for teaching postgraduate students and in research studies, at both the University of Surrey and University of Edinburgh in the United Kingdom. The model interactively uses the ArcView GIS system through its own powerful graphical user interface. The landuse details of catchments and geological features are used to model the runoff from the river catchments.

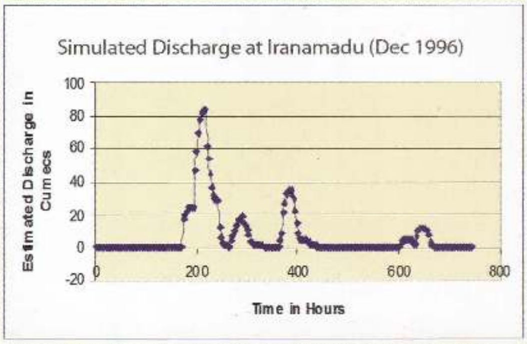
The Kanagarayan River Basin model was developed to manage the water resources of the region above the Iranamadu Reservoir which impounds the runoff from a catchment area of 588 km^2. The capacity of this reservoir is 131 million m^3 and the stored water is largely used for irrigation.

The model consists of over 1500 nodal points and channel reaches which serve to simulate the runoff from sub-catchments and route flow through channel reaches. The modelling system provides a tool for managing water resources in each sub-catchment, including the attenuation resulting from more than 125 reservoirs in the region. ArcView GIS and satellite imagery have been used to develop the model interactively.

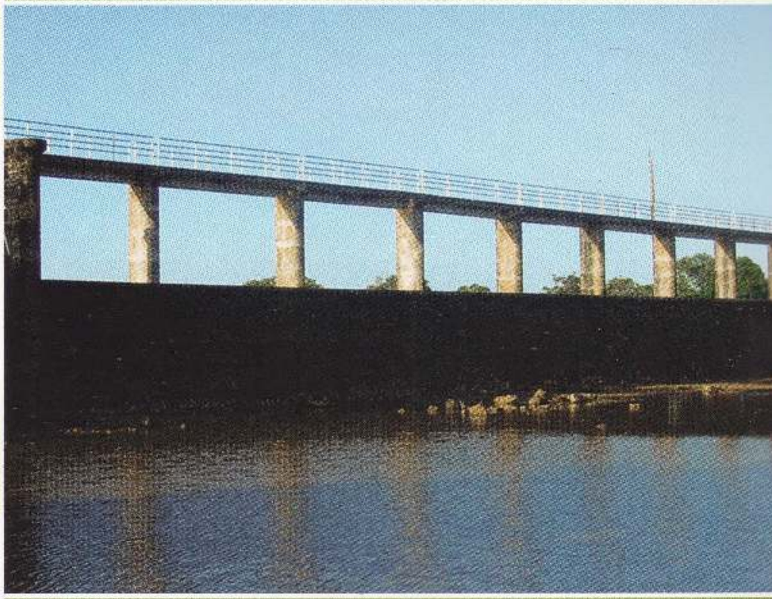


CATCHMENT MODEL OF IRANAMADU RESERVOIR AND LAND USE DISCRIMINATION

KANAGARAYAN RIVER BASIN



EXAMPLE OUTPUT SHOWING MODELLED DISCHARGE AT IRANAMADU



IRANAMADU RESERVOIR

Currently work is underway for additional data collection to refine the model and to study the contaminant issues in the region.

UNNICHCHAI RIVER BASIN

The Unnichchai reservoir impounds the water of the Magalvattuvan River in the Batticaloa region. The source of the river is in the forest reserves in Mahabaiula and its elevation is about 400 m above mean sea level. The total catchment of the drainage basin is 346 km^2 and the reservoir impounds the water from a catchment of 275 km^2. The storage capacity of the Unnichchai reservoir is 50 million m^3 and the impounded water is solely used for irrigating over 4000 ha of land downstream.

A catchment model has been developed using the HYDRO-1D model to assess the surface run-off to the reservoir and to study the potential for storing more water by raising the dam. The model has been successfully calibrated but to exploit its potential in future a comprehensive data collection and monitoring of river flows are vital.

UNNICHCHAI RIVER BASIN

UNNICHCHAI RESERVOIR

UNNICHCHAI RESERVOIR

RENEWABLE ENERGY

RENEWABLE ENERGY

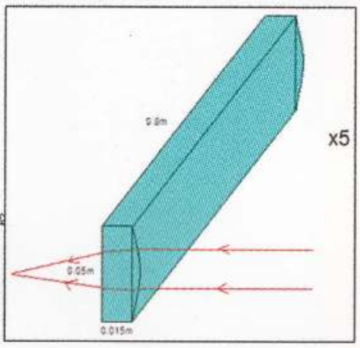
As part of our ongoing research activities at the University of Surrey we have been involved in methods for harnessing of renewable energy and their potential application in Sri Lanka. We focused on the potential for hydropower using low head turbines, wind and solar energy. In Sri Lanka the annual rainfall over the mountainous region is over 3000 mm. The major rivers in the upper catchments offer great potential for hydroelectric schemes. Micro-hydro systems have been in existence since the early part of the 20th century. Over 500 small hydroturbines have been installed in the central and south-west region with capacities varying from 5 to 1500 kW. We have explored the possibilities of using concentrators (lenses and mirrors) for harnessing solar energy.

DATA SHOWING HOW THE AMOUNT OF ENERGY PRODUCED DEPENDS ON THE SIZE OF THE LENS

Average energy from sun	20000	kJ/m²/d
This is equal to:	231.48	Watts/m²
Which is the same as:	0.023148	Watts/cm²
Average air temp:	27	°C

This table shows how varying the length, height and thickness of the lens, changes the energy produced and weig

Height (cm)	Thickness (cm)	Length (cm)	Surface Area (cm²)	Power (kJ/d)	Watts	Weight (kg)	Watts/kg	Litres of water per day which would be raised to 90'C.
5	1.5	80	400	400	4.63	1.5	3.1	1.5



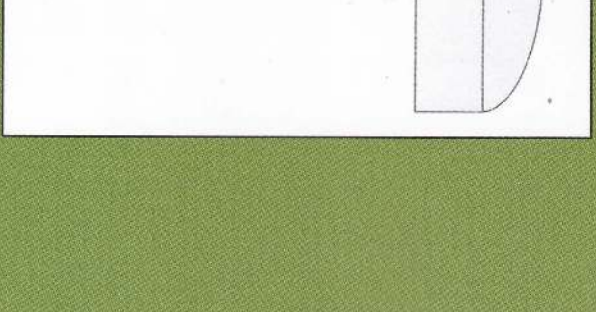
This table assumes that the thickness of the lens increase proportionally to the height. This may not be the case as we could reduce the thickness, causing the focal point to shift backwards, futher from the lens.

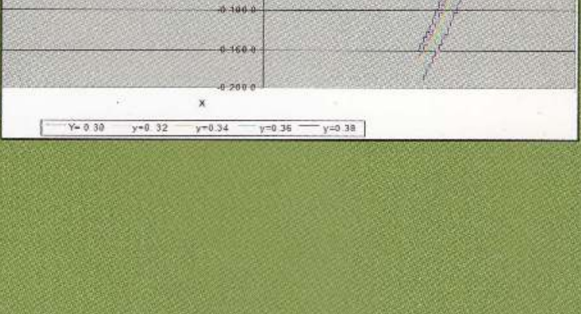
It also assumes that the lens and pipe heat the water at 50% efficiency.

The weight of all lenses listed is a percentage of the actual weight as I have not included the curve weight.

The final example is different. In this suggestion I take a small thin lens, which is more efficient per unit weight. This small lens will not produce enough water but if we line 5 up next to each other we could produce 7.5 litres of water and the weight would only be 7.5kg. With a pipe running behind each lens this could be very compact as the focal point could be very close to the lens. It may also increase the efficiency of the heating as 5 pipes would have a greater surface area to just 1 pipe. Another advantage to this is that with varying household sizes a different number of lenses could be used.

DESIGN OF LENS PROFILE FOR VARIOUS FOCAL POINTS USING A PROGRAM DEVELOPED BY MOTT MACDONALD





HISTORIC EVOLUTION OF WATER RESOURCES DEVELOPMENT

The history of settlers in the northern, eastern and north-western provinces of Sri Lanka has been linked to the water resources in the region and the fertility of the lands. In pre-historic periods Mesolithic people occupied almost all parts of the island. They spoke different languages, all of which were replaced as a consequence of elite dominance in the Early Iron Age (EIA) and Early Historic period by the Prakrit language in most parts of the island, especially in the south and the centre, and by the Tamil languages in the north-west, north and north-east (Indrapala, 2005).

THE BRAHMI INSCRIPTION ON THE SEAL OF THE EIA CHIEF, ANAIKODDAI, JAFFNA

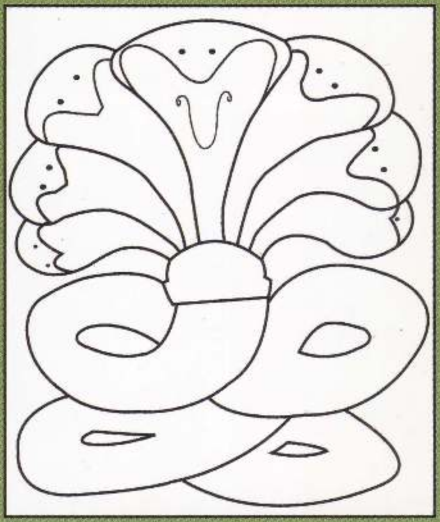
(Photo: February 2005, by K. Sanchayan)

The historic development of water resources and the innovative ideas on hydraulic concepts by the ancient settlers are commendable. The Vavunikulam, an ancient reservoir which was originally built in 163 BC is an example of the skills these people had in building reservoirs. The publication titled 'Design of Small Dams', by the United States Bureau of Reclamation (1987) states:

'An earthfill dam completed in 504 BC was 11 miles long, 70 feet high and contained about 17 000 000 yd^3 of embankment'

AN ANCIENT RESERVOIR WHICH WAS ORIGINALLY BUILT IN 163 BC AND RESTORED IN 1954

SEVEN-HEADED COBRA SYMBOL



Stone carvings of a seven-headed cobra have been found in numerous ancient irrigation works in Sri Lanka. Historians accept that this symbol represents the ancient inhabitants of the island who were called Nagas (cobra). Nagas have been identified as settlers in the Northern region of Sri Lanka. The only epigraphic evidence for their existence is the temple Nagadipam (Island of Nagas) in Jaffna District.

Exploitation of water was not limited to surface water but also extended to groundwater. The area of the Jaffna Peninsula is 1000 km^2 and currently has over 100 000 wells.

It is a general belief among historians and archaeologists that the settlement in the Jaffna Peninsula commenced from the Early Iron Age (1000 BCE) and not from the Mesolithic Period. This belief stems from the assumption that the early settlers would have needed hard tools to exploit the water from the limestone aquifers in the region. The groundwater model set up for the Jaffna Peninsula at the University of Surrey is being extensively tested to study the presence of perennial springs in the peninsula in pre-historic periods. Very limited agricultural activities, reduced population and possible forest covers as well as climatic conditions are considered in the model simulation. These tests will be a precursor for confirming the existence of settlement before the EIA and the findings will be supplemented by further archaeological studies in the region.

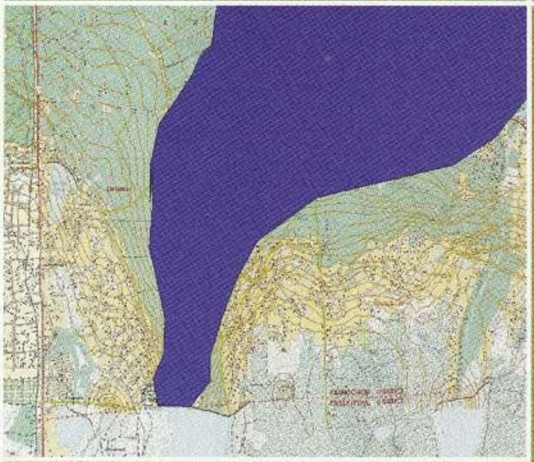
DAM FAILURE ANALYSIS

The Kanagarayan River basin has a catchment of 901 km^2. Its source is near Vavuniya from where it flows north for over 60 km before entering Iranamadu reservoir and eventually falling into the Elephant Pass Lagoon. The flow in the basin is mainly dependent on the seasonal rainfall from the north-east monsoon. Most of the basin is covered by forest with some parts of it used for agriculture. There are settlements below reservoirs and isolated villages.

IRANAMADU RESERVOIR

GATED SPILLWAY

The Iranamadu reservoir and spillways are in a state of disrepair due to lack of funding. If the dam fails the consequences would be catastrophic and an area of over 100 km^2 could be inundated resulting in loss of life, and destruction of infrastructure and large tracts of farm lands. HYDRO-1D has been used to assess the potential implications of dam failure.



DAMBREAK ANALYSIS: PREDICTED AREA OF INUNDATION

CLIMATE CHAGE

CLIMATE CHANGE IMPACTS ON GROUNDWATER RESOURCES IN THE JAFFNA PENINSULA

The groundwater resources of the Jaffna Peninsula, Sri Lanka, constitute an example of aquifers subjected to severe and excessive pumping. Groundwater is the prime source of water for agricultural development in the peninsula, but its potential is limited as over-abstraction from the aquifers results in saline intrusion. The recharge to the groundwater in the peninsula is almost entirely from rainfall percolation and the climate is characterised by distinct dry and wet seasons. A three-dimensional groundwater flow model has been applied with the view to assess the impacts of the climate on the groundwater resources system in the area. Two different future scenarios have been used to evaluate the climate change impacts in the peninsula and were compared with a scenario of the existing conditions. The first scenario examined the effects of increasing the rainfall and the temperature, and the second scenario considered an additional increase in sea level and runoff. The results showed that during the dry season, water levels increased in the middle of the aquifers but were almost the same in the coastal areas. On the other hand, during the wet season, there was a significant increase in the water levels. Furthermore, the model showed that a significant quantity of fresh water ends up in the sea through seepage and through the lagoons. Consequently, the results demonstrated that the aquifers can be used as underground reservoirs to store the excess water in the rainy season and to satisfy water demand in the dry season. In addition, the changes in rainfall and temperature were identified as the predominant factors of impact, while changes in sea level rise and runoff were found to be only of secondary influence for the groundwater resources. It was concluded that climate change could improve the existing condition of the aquifer in the peninsula under a capable and efficient water management strategy.

LOOKING AHEAD

The on-going research activities will provide the basis for identifying sustainable methods to exploit the water resources in the North-East Province of Sri Lanka. Energy provides a vital link to water development and is necessary for the progress of the community. Renewable energy such as solar energy as a potential source is explored. The research study also focuses on harnessing the renewable energy within the capability and economic affordability of the communities. The findings of this research and the hydraulic and water quality models developed under the research activities for over two decades can bring considerable benefits to other regions of Sri Lanka and other countries worldwide.

It is vital that all the organisations involved in development activities should invest more in investigations and research activities because the water resources systems in the region are very complex. Our research activities have focused on sustainable solutions which achieve the following:

- Respect for social needs and traditions
- Introduction of more sophisticated technology to understand the processes behind water science
- Conservation of water resources within the basin and utilising them before exploring alternative solutions
- Understanding of the sanitation and pollution issues and their implications in the sustainability of the water resources in the region
- Promotion of procedures and engineering solutions through training and teaching
- Recognition of the talent and capability of the local communities.

With the above objectives we will continue to protect the environment and ensure that the state of the art is maintained.

Simulation *INNOVATION*

Conservation **SANITATION** Basin Management

ENERGY **EVOLUTION**

RISK ASSESSMENT CLIMATE CHANGE

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