

The Role and Development of Mini Hydropower in Sri Lanka

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ABSTRACT

Mini hydro plants were first installed in Sri Lanka at the end of the 19th Century, to provide mechanical and dc power to the tea estates. By the middle of the 20th Century grid supplies had reached the tea factories and, by 1970, most of the mini hydro plants had fallen into disuse. In the 1980s a weak grid almost entirely dependent on hydro-electricity and a number of dry years, caused prolonged periods of power shortages and interruptions to the electricity supply. These occurred all over Sri Lanka and, in particular, in the rural areas where the tea estates were situated. This, among other reasons, lowered the quantity and quality of tea production, and caused considerable economic difficulties in a country whose main export is tea. Managers of the tea estates started to look for more reliable, stand-alone sources of power. A number of feasibility studies of mini hydropower were undertaken on the estates but very few led to plants being installed.

This thesis contends that mini hydropower is an appropriate and needed source of energy on the tea estates in Sri Lanka. It looks at the history, politics, geography and hydrology of Sri Lanka in the context of their affect on hydropower development in Sri Lanka. It discusses the process of tea manufacture and the suitability of the use of mini hydropower as a source of energy in the factory, as a source of rural electrification for the estate workers and as a diversification by selling surplus to the Electricity Board. Previous feasibility studies in mini hydro power, both international and national, are considered and appraised.

This information was mainly collected on extended field visits to Sri Lanka. Over twelve months was spent in the country gaining the knowledge and expertise that was embodied in software used to survey a considerable number of sites in the tea estates. The further knowledge gained in this surveying process is discussed, results are given and conclusions drawn which suggest a strategy and methodology for the expansion of the mini hydropower capacity and industry in the tea estates of Sri Lanka.

“Let not one drop of water reach the sea without first serving man”

King Parakramabahu

12th Century King of Ceylon

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ACRONYMS

- ADB: Asian Development Bank
- AVR: Automatic Voltage Regulator
- BOI: Board of Investment
- BOO: Build-Own-Operate
- BOT: Build-Own-Transfer
- CEB: Ceylon Electricity Board
- CECB: Central Engineering Consultancy Bureau
- CIDA: Canadian International Development Agency
- DEU: Department of Electrical Undertakings
- DTI: Department of Trade and Industry (UK)
- DFCC: Development Financing Corporation of Ceylon
- ELC: Electronic Load Controller
- FAO: Food and Agricultural Organisation
- GDP: Gross Domestic Product
- GNP: Gross National Product
- GoSL: Government of Sri Lanka

- GTZ: Deutsche Gesellschaft fuer Technische Zusammenarbeit (German Agency for Technical Cooperation)
- IGC: Induction Generator Controller
- IMF: International Monetary Fund
- IRDP: Integrated Rural Development Programme
- IT: Intermediate Technology
- JEDB: Janatha Estates Development Board
- JVP: the People's Liberation Front
- LECO: Lanka Electricity Company
- LECO: Lanka Electricity Company Ltd.
- LTTE: Liberation Tigers of Tamil Eelam
- MEP: People's United Front
- MHP: Mini Hydro Power
- MTIP: Medium Term Investment Plan
- NDB: National Development Bank
- NGO: Non-Governmental Organisation
- NIC: Newly Industrialised Country
- ODA: Overseas Development Agency
- PPA: Power Purchase Agreement

- SLFP: Sri Lanka Freedom Party
- SLSPC: Sri Lanka State Plantation Corporation
- UNDP: United Nations Development Fund
- UNP: the United National Party

UNITS AND EXPRESSIONS

kWh: Kilowatthour

MWh: Megawatthour

GWh: Gigawatthour

TWh: Terawatthour

LV: Low voltage

MV: Medium voltage

HV: High Voltage

Definitions

Hydropower categorisation

Hydropower schemes have been categorised throughout this thesis as follows

- Mini hydropower is 100kW to 5MW
- Micro hydropower is under 100kW

Notes about currency

The prices in this thesis are in 1993 prices, unless otherwise stated, and therefore exchange rates from 1993 are used. These were:

- GB£1= 72 Rupees (Sri Lanka)

Notes about Units

SI Units have been used throughout this thesis unless otherwise stated.

1. INTRODUCTION

Abundant water and suitable terrain make Sri Lanka an ideal place for mini hydropower development. Between 1900 and 1960 this potential was recognised and exploited by the colonialists, with over 400 micro hydropower schemes being installed on the tea estates to run the factory machinery and meet domestic demand for electricity. However by the late 1980's very few of these plants were still operating. There was a need in Sri Lanka for more generating capacity, and the owners of the tea estates were interested in stand alone sources of power. This resulted in a number of mini hydropower surveys but few installations. By the 1990's there was growing pressure on the Sri Lankan government, on the Ceylon Electricity Board, and on the managers of the tea estates to find a way to decrease the current energy shortfall and also to invest in the tea estates.

The thesis evaluates the technical considerations and economic benefits involved in rehabilitating existing mini hydropower sites and installing new mini hydropower sites on the tea plantations in Sri Lanka. It contains an analysis of why previous surveys to construct or refurbish mini hydropower plants have failed and makes recommendations for criteria to ensure the success of collaborations to install mini hydropower schemes in Sri Lanka in the future.

The author spent eleven months on a field study in Sri Lanka where she acquired the relevant information and background knowledge to make informed judgements about sites and proposals for the establishment of mini hydropower schemes. The author was part of a collaborative project, funded by the Department of Trade and Industry, between turbine manufacturers Gilbert Gilkes and Gordon and the University of Edinburgh Energy Systems Group, to study the feasibility of rehabilitating mini hydropower plants in Sri Lanka. She expanded the project to examine the role of Intermediate Technology and the Ceylon Electricity Board and the needs of the tea

industry. This was achieved by meeting and discussions with the participants and by visiting numerous tea estates in Sri Lanka.

As part of this project a Knowledge Based System was written in software to appraise the technical and economic feasibility of mini hydropower plants. It was started by the author in the first year of her research and then developed by the group in Edinburgh. It was populated with information obtained by the author and evaluated in the field in Sri Lanka and in the UK.

1.1 Initial Concept

The initial proposal for this thesis was based on undertaking a feasibility study in conjunction with the turbine manufacturers Gilbert, Gilkes and Gordon, who supplied around 400 small turbines to the tea estates in Sri Lanka prior to 1960. As owners of the manufacturing drawings for these machines the company felt that it was uniquely placed to participate in a mini hydropower rehabilitation program for the tea plantations. Therefore they wished to collaborate in a feasibility study that would assess the number of sites which could be restored, determine a merit order for refurbishing, upgrading and re-equipping them and be used to establish a development programme which was economically viable for the plantation owners. Such a study would be the focus for this Ph.D. project, based in the Energy Systems group (in the Department of Electronic and Electrical Engineering) at Edinburgh University which has a long standing involvement with mini hydropower in the United Kingdom and abroad and also close associations with Gilkes.

1.2 Background Study for the Project.

In order to work successfully in a different country, and particularly one that is developing, it is necessary not only to understand the technical nature of the project but also to understand the culture in which the operation takes place. As will be shown in the course of this work, schemes have failed because the contractors did not

understand the infra structure and cultural background of the country. Therefore to undertake this work the author learnt some of the language, Sinhala, and studied the history and politics of Sri Lanka which are outlined in Chapter 2. She also obtained a detailed knowledge of tea production methods as described in Chapter 3.

1.3 Development of Decision Support Software

The Energy Systems Group at Edinburgh University has considerable expertise in decision support software and knowledge based systems, as well as a proven record in hydropower engineering in developing countries [Doig,1994], [Randell,1992]. It was believed that such a suitably designed software package could be applied to the systematic evaluation of mini hydropower potential in Sri Lanka. Therefore, during her research, the author collaborated with other members of the Energy Systems Group to produce a knowledge based software package, which is now used in the field to evaluate the potential of new mini hydropower schemes. Initially, the software package was conceived as a useful tool that could be used to assess the rehabilitation of existing plants. However, analysing the results of the feasibility study convinced the author that the potential for development lay in new sites or in upgrading of sites, and not in rehabilitating existing equipment. The reasons behind this decision are discussed in Chapter 7 and Chapter 8.

1.4 Data Collection

Initially, questionnaires were developed to obtain the information necessary to populate the database and construct salient questions for the decision support system, the answers to which were critical in determining the technical and economic feasibility of improving sites. Such information included the security and nature of the hydrology, extent of damage to civil works, proximity of grid supplies, existing and projected electricity demand, reliability of existing supplies, purchase and

avoided costs of grid electricity, the condition of the plant if it existed and other relevant data. The methods of data collection are described in Chapter 6.

The software was developed and populated with relevant data so that it could then be used to give a technical and economic assessment of new sites. A description of this software and its use is given in Chapter 5. The results of using it on site during a second field trip to Sri Lanka and on pilot assessments in Scotland are discussed in Chapter 7.

1.5 Feasibility Study

The author spent eleven months in Sri Lanka from September 1993 to August 1994, designing the questionnaires and visiting the tea plantations, government offices, non-government organisations (NGOs), manufacturers, suppliers, banks and university departments to obtain the information and understanding required for this task. The methodology and calculations for the study are described in Chapters 6, while the results from the feasibility study and the conclusions about the viability of rehabilitating the plant and the evaluation of new sites are given in Chapter 7.

Several important features arose from the feasibility study which changed the direction and the scope of this thesis.

The first remit was to carry out a hydrological reassessment and report on new and existing catchment areas to confirm the security of water resources. As reported in Chapter 6, obtaining accurate hydrological data is a major problem in underdeveloped countries like Sri Lanka, and it is necessary to calculate flow rates of the rivers from the data available and evaluate the sensitivity of the proposed scheme to any inaccuracies in the measurements.

The author surveyed and reported on the condition of civil works, penstocks, power houses, electrical and mechanical equipment, switchgear and control systems at over thirty-five schemes on the tea plantations. The results of these surveys are given and

discussed in Chapter 7. During her visits she obtained information so that she could assess the energy demand on the estates and examine other competing energy forms, to determine the true role for the mini hydropower plant as a local and possible national power source. In order to make recommendations concerning the finance, plant, and manpower required to install necessary civil works, penstocks and electrical and mechanical equipment, including outline design, specification and cost estimation for new schemes, she had to make an extensive survey of the infrastructure for supporting mini hydropower in Sri Lanka. The mini hydropower schemes at present operating in Sri Lanka and results of previous studies are analysed in Chapter 4. The methodology for obtaining the data on suppliers and costs is given in Chapter 6. Selected results and an assessment of the opportunity for using local materials, labour, and local manufacturing facilities are discussed in Chapter 7.

The above data together with discussions with the Ceylon Electricity Board, banks and NGOs enabled the author to report on the feasibility of upgrading the hydropower schemes to supply present estate demands, provide electrical power for local consumption on the estate, and export to the grid. The results of this work are discussed in Chapter 7.

The analysis of mini hydropower installations and previous feasibility studies together with the results of her own feasibility study enabled her to develop criteria for the future development of hydropower in Sri Lanka, and these are given in Chapter 4.

The development of the software package enabled the evaluation of different technical and economic options for new development to be carried out in the field together with a sensitivity analysis on factors such as the change in the rainfall, tax incentives, inflation rates, etc. Output from this program is shown in Chapter 7. Analysis of the results from this assessment enabled technical and economic criteria

for the successful installation of new hydropower schemes to be added to the infrastructure recommendations given in Chapter 4, and these are discussed in Chapter 8.

1.6 Initial Predictions and Final Results

The original remit for this research was based on the understanding that over 100 tea estates had operational mini hydropower plants providing electrical power to the factories, and at least another 100 estates had either mini hydropower plant that had fallen into disrepair and disuse or become obsolete through age, and that these plants would only require minimal reinstatement to restore the power source. However, as shown in Chapter 7, the cost of rehabilitating these plants is not a cheap option.

Rehabilitation schemes for the tea estates were thought to be attractive to the Ceylon Electricity Board (CEB), who face increasing difficulty in providing sufficiently robust supplies to outlying areas as urban demand increases around Colombo and other state capital towns. Connection of upgraded mini hydropower plant would reduce demand from the grid and could contribute electrical energy to the grid and reinforce it locally. However, as explained in Chapter 7, this has both safety and control standard implications, so connection cannot just be implemented in a straight forward manner.

At the start of this research it was believed that if only half of the sites on the tea estates were found to be worth further investment this would represent a total mini hydropower plant capacity of around 15 MW, with the individual plants being in the 500kW to 5MW range. As research for this thesis has shown the problems with developing mini hydropower in Sri Lanka are many and complex. The opportunities for the establishment of mini hydropower programmes are not as simple and attractive as originally envisaged, and an important strand of this project has been the development of criteria that must be satisfied if a scheme is to be successful.

1.7 Structure of Research and Thesis

The thesis considers a number of issues:

- Why, in a country with abundant mini hydropower potential and a proven end use for such power, has there been comparatively little installation of mini hydro plants?
- Why did the surveys that were carried out in the 1980's fail to result in any installations of mini hydropower plants?
- What are the necessary components for a successful methodology for mini hydropower feasibility studies and development? Are these applicable in Sri Lanka?
- Why is the option of new hydropower schemes on the tea estates seen as more attractive than rehabilitating old plants?
- Is there a role for software that performs feasibility studies in Sri Lanka? What are the criteria and methodology needed for such software?
- What are the infra structure requirements in Sri Lanka for mini hydropower development?
- What is the way forward for future mini hydropower development in Sri Lanka?
- Are the results transferable and relevant to other countries?

The above sections describe the work and aims that were involved in the research. The structure of the work was not linear and this is also reflected in the thesis. Figure 1.1 attempts to show the design and approach of the work and how it is

reflected in the structure of the thesis. The initial groundwork to understand the geography, history and politics of Sri Lanka, the process of tea, and the reasons why other surveys of mini hydropower had not been very successful in Sri Lanka is explored in Chapters 2, 3 and 4. This background was used to collect data in Sri Lanka, to determine the methodology and calculations needed for a software program to survey mini hydropower sites in Sri Lanka, and test the software on the sites. It was a feedback loop as the more data that was collected, and as experience on the sites and in Sri Lanka increased, so the program changed. This in turn was fed back into the approach for data collection and criteria for assessing mini hydropower schemes. Chapters 5, 6 and 7 thus refer to each other in a similar manner.

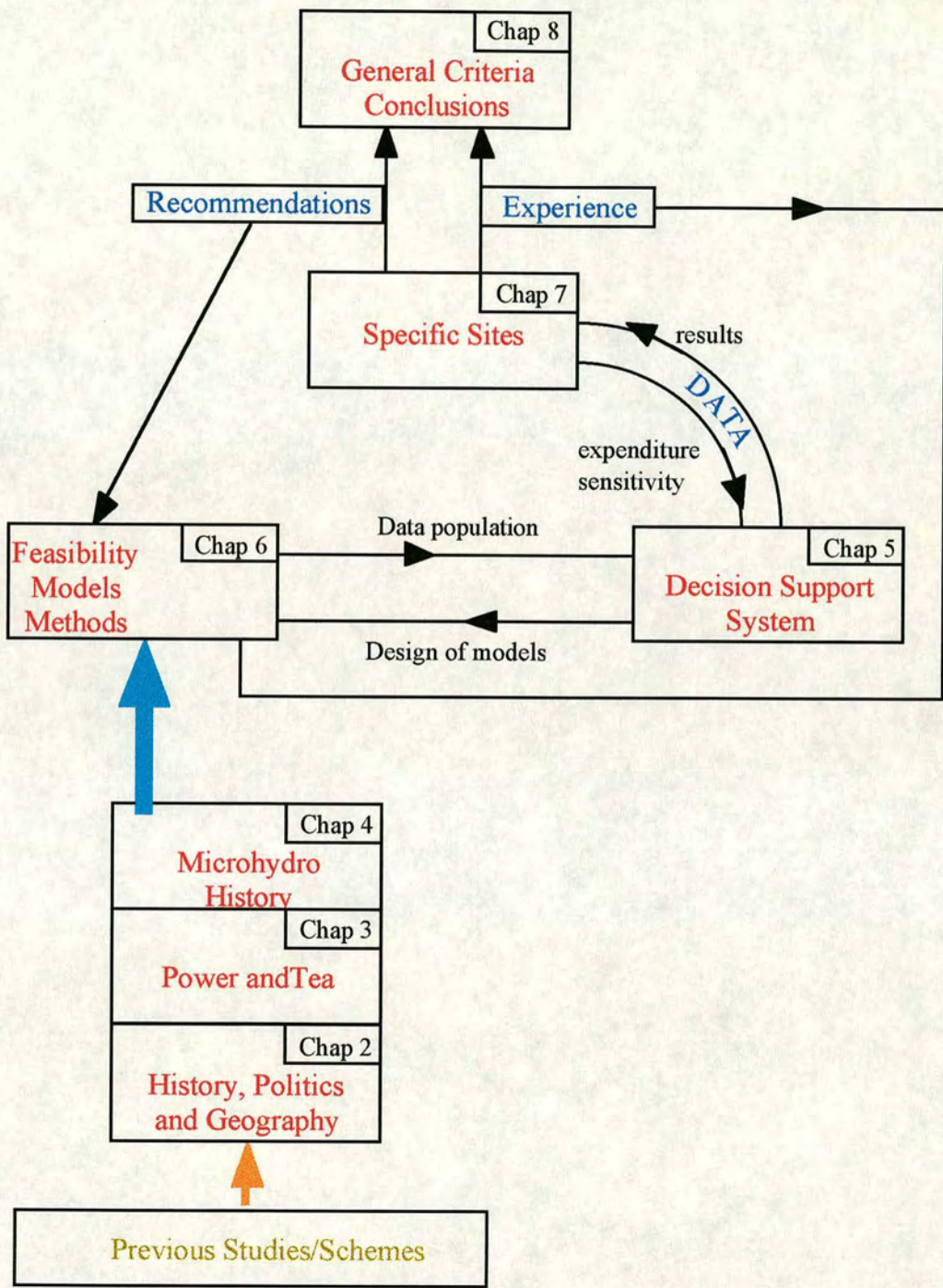


Figure 1.1: Structure of research and thesis

2. FACTORS AFFECTING THE ENERGY PROFILE IN SRI LANKA

The climate, geography, geology, topography and hydrology of a country influence the available natural resources. The history, politics, economy, internal infrastructure and industrial status affect the extraction of these natural resources and ultimately the fuel consumed in the generation of electricity for the country. These factors also determine the demand for electricity and its pattern of use. Electricity supply and usage are fundamental for the growth of less developed countries.

This chapter describes each of these factors, their inter-relationships and subsequent influence on the current supply of and demand for electricity in Sri Lanka. In particular it will introduce and set in context the requirement for the development of mini hydropower in the rural areas.

2.1 Historical Perspective

Sri Lanka is a tropical island lying between 5-10° North of the equator with an area of 65,600 square kilometres, as shown in Figure 2.1. It extends 435 km from North to South and 235 km East to West. Until the 12th century AD Sri Lanka was divided into a number of kingdoms, ruled by a succession of kings. Anuradhapura was the capital from 4th century BC to 10th century AD and Polonnaruwa took over this role from the 10th century AD to the 12th century AD. The country contains one of the oldest hydraulic irrigation schemes in the world. The era from 500 BC to 12th Century AD was known as the hydraulic civilisation due to the tanks or 'artificial lakes' that were constructed over the country to develop irrigation channels and enable agricultural settlement in the dry areas [NRESA,1991]. The majority of the population lived in the Southeast, with the North and the Central Hill area being scarcely populated.

After the 12th century, because of wars, incompetent rulers, and disease, the basis of the civilisation collapsed and the irrigation tanks and channels fell into disuse. The balance of power then shifted away from the Southeast towards the hill country and Kandy became the capital in 14th Century AD, while the three main kingdoms were Jaffna (with a population descended from South Indian Tamils), Kandy and Kotte [De Silva 1981]. In the 16th century the colonialists started to arrive, with the Portuguese in 1505 and the Dutch coming in 1658. Their interests were to take control of Sri Lanka as a valuable exporting market and to introduce Christianity to a predominantly Buddhist and Hindu country. In 1796 the British expelled the Dutch and gained control of the island and remained there until Sri Lanka gained independence in 1948. Legislation at the time allowed the land to be directly controlled by the colonial administration. Coffee, coconut, rubber, and later tea plantations were established by the British, as well as a communications network of roads and railways linking the cities, plantations and sea ports. During this period the official language was English although Sinhala was the dominant language of the population. In 1948 Sri Lanka, or Ceylon as it was then known, became an independent member of the British Commonwealth [Spencer, 1990].

The effects of the successive centuries of colonial rule have left Sri Lanka with economic and political difficulties that have limited the industrial and infrastructure expansion of the country [De Silva, 1981].

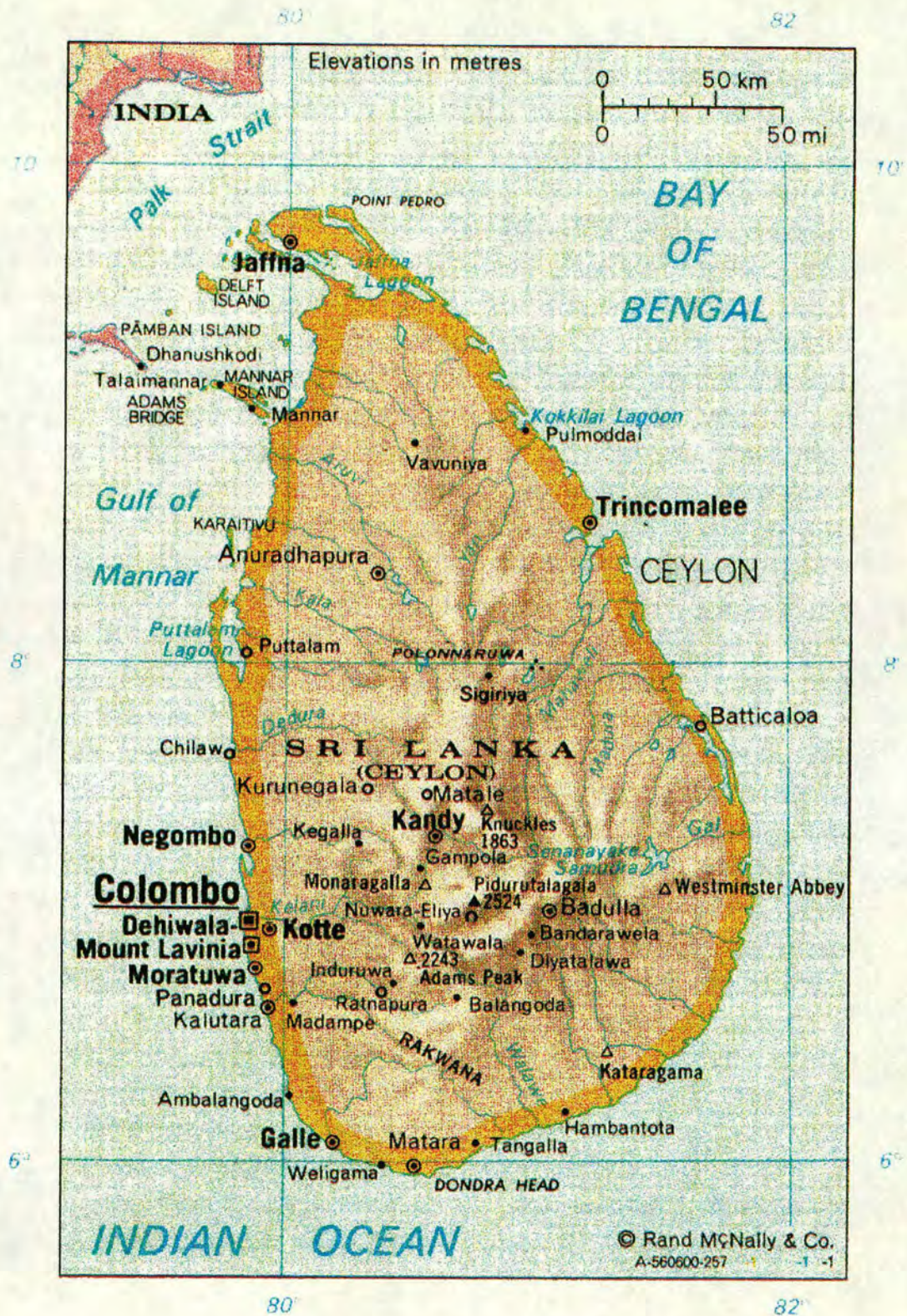


Figure 2.1: Map of Sri Lanka showing towns and cities

2.2 Political Background

The period since 1948 has been politically volatile, with unrest, riots and civil war marring economic, social and technological progress. The first independent party was the United National Party (UNP) under D. S. Senanayake, who refused to allow the Indian Tamils working on the estates to become Sri Lankan citizens. The UNP ruled, under different leaders, until 1956 when the MEP (People's United Front) was elected with nationalistic support based on its promise to make Sinhala the official language, Buddhism the official religion and to discriminate positively in favour of the Sinhalese for government and public sector employment. The Tamils were isolated further by these measures. In 1965 the Sri Lanka Freedom Party (SLFP) was elected under the leadership of Mrs. Bandaranaike. This period also marked the initial decline and deterioration of the economy with private enterprise being restricted and significant parts of the economy (including the plantation sector) being nationalised. In 1970 there was a political revolt led by students and the Marxist party of the People's Liberation Front (JVP) took power. A considerable number of people were killed in uprisings and this, together with food shortages and no immediate prospect of improvement in the economy, resulted in the re-election of the UNP in 1977. The Jaywardene government then pursued a liberal open economy aimed at sustaining economic growth and increasing employment [Dissanayaka 1994]. At the same time the Tamils, resentful at their forced alienation and lack of political influence, formed a party, the Tamil United Liberation Front, initially campaigning for an independent state in the North (known as Eelam). Failure of this political campaign and growing unrest led to the formation of a terrorist guerrilla faction, the Liberation Tigers of Tamil Eelam (LTTE). Despite the UNP making some concessions, such as recognising Tamil as a national language, the relationship between the Sinhalese and the Tamils continued to deteriorate until 1983, a year in which there was again widespread rioting. This was the start of the civil war that is still in progress. The year's 1987-89 were marked by further uprising from the JVP and its supporters, after their activities were violently curtailed following the election

of Mr. R. Premadasa as leader of the UNP in 1987. Premadasa was assassinated in 1994 and elections held later that year saw the return to power of the People's Alliance (of which the SLFP is the dominant party), under the presidency of Mrs. Chandrika Kumaratunga .

From 1977 to the present time the Tamil unrest and military activities have continued, and no solution has been found for this situation. The result has been political and economic destruction.

2.2.1 Tamil situation

The civil war in Sri Lanka is a complex ethnic, social and religious problem. It is outwith the scope of this thesis to discuss the cause and effect but references are comprehensive [Spencer 1990] and [Economist Intelligence Unit 1993]. In statistical terms the civil war has claimed at least 50,000 lives since 1983. While the major fighting has been contained to the North and Northeast, terrorist explosions have reached most of the rest of the country, including bombings in the capital, Colombo, in 1996 and 1997. Apart from the humanitarian and social consequences, the situation has also had severe effects on the economy and financial management of the country. These effects can be considered within the contexts of tourism, investment, war and rehabilitation:

- **Tourism:** Sri Lanka has the assets of a beautiful and culturally interesting country, warm climate, and friendly people to support a healthy tourist industry. Package holidays to the coastal resorts of Galle and Matara are widely advertised. German and UK tour operators are promoting Sri Lanka as a holiday destination and Sri Lankan companies have diversified into tourism. Despite this, during the unrest of 1985-89 tourists seldom visited the country. Even now the growth in the tourist industry is slow and currently accounts for only about 2% of the GDP through foreign exchange earnings

[IPS[1],1994]. Although the civil war is mainly fought in the Jaffna peninsula and the East coast, recent urban guerrilla bombings in the capital are discouraging leisure and business travellers.

- **Investment:** As a result of the civil unrest and the deteriorating economy, investment by expatriate companies is minimal and inward investment is restricted because of the poor economic position.
- **War :** The direct costs of keeping an active and mobile army and fighting in the North amount to 4% of the GDP or 25% of all government spending [IPS[1], 1994]. However the indirect costs of loss of export revenue, rebuilding damaged property and restoring destroyed infra-structure caused by the war make the overall costs significantly higher.
- **Rehabilitation :** Once the conflict is resolved, future investment will involve the rehabilitation of the North and East, including rebuilding, re-connecting services, re-establishing an industrial and agricultural base and providing a communications network. There is no electricity grid in the North of Sri Lanka, and the diesel plant at Chunnakam is not in operation. Any electricity used is from private diesel generators.

In political terms the question of how to resolve the Tamil situation remains a crucial one, with successive governments trying both peaceful and military means. As yet no solution has been found and a quick ending to the conflict does not seem likely. This also means that there is only limited likelihood of foreign investment and the detrimental impact of the war on the economy and morale of the country is set to continue.

2.3 Demographic Pattern of Population

The population of Sri Lanka is 18.4 million (1994) and consists of the following ethnic groups: Sinhalese: 75%, Tamil: 16%, Moors: 8% and minorities (Burghers, Chinese, Europeans) less than 1%. The religious breakdown is in proportion to the ethnic groups with 70% Buddhists, 15 % Hindus and the rest Muslim and Christian [Central Bank of Sri Lanka, 1993].

Sri Lanka, with 260 people per square kilometre, is one of the most densely populated areas in the world. Most of the population is concentrated in the Southwest and Central areas. The majority also live in villages with 22% staying in urban areas [Central Bank of Sri Lanka, 1993]. This demographic pattern explains the dominance of the agricultural sector in employment and economic terms. The population is expected to reach 25 million by the year 2050 putting even greater strain on land and water resources [NRESA, 1991].

2.4 Geographical Background

A description of the topography, climate and hydrology of Sri Lanka helps to explain the development of agricultural irrigation, land drainage, use of water power and patterns of power generation across the country.

2.4.1 Topography

Sri Lanka has five distinguishable geomorphic areas: the Central highlands, Southern coastal fringes, the Southwest hill area, the East and Southeast plains and the North central lowlands.

Sri Lanka can also be divided into three zones depending on the total and seasonal distribution of rainfall; the wet, intermediate and dry zones as shown in Figure 2.2. [National Atlas of Sri Lanka, 1986]. The wet zone can support agriculture without irrigation whereas in the arid dry zone agriculture is restricted to irrigated areas.

Elevation, climate and soil geology influence agriculture and rural industry. Rural electrification has occurred in all areas although conflict in the North and East has restricted the progress made in these regions. In the wet and intermediate zones there has been complementary development of rural industry and mini hydropower.

The wet and intermediate zones cover the Southwest and Central hill country and is the origin of all the major rivers in Sri Lanka. It is flanked by mountains, rising up to 2,524 metres. The land is planted with rubber, eucalyptus or pine trees, with few natural forests left. Tea planting has reduced the natural forest cover from over 70% by area in the year 1900 to under 9% today [Mendis, 1993]. In the tea growing areas the clearance of original forest cover, the type of soil, the rainfall intensity and gradient of planted slopes have caused considerable loss of the arable top soil.

Improved land and crop management are reducing this erosion, but there is an estimated loss of between 40-70 tonnes/hectare/year from the top soil [NRESA,1991]. Erosion has a serious effect on areas that depend on rural agriculture and industry. Nutrients in the top soil are washed away leaving the remaining land barren and dependent on fertiliser. The irrigation channels become less effective as they become filled with silt. Agricultural productivity and yield are thus reduced. The same erosion also affects all levels of hydropower generation, from micro to large, as the deposited sediment reduces the flowrate of streams and rivers, causes problems with the turbines as well as collecting behind the dams and reservoirs. This must be considered when assessing the viability of hydropower schemes and is discussed in the next section.

River Basin



Figure 2.2: Map of Sri Lanka showing the different zones and the major rivers

2.4.2 Climate and hydrology

Sri Lanka has a climate similar to that of other South Asian countries being dominated by the pattern of the monsoons. The temperature remains fairly constant throughout the year in the lowlands and coastal areas (26 - 28°C), but varies in the highlands from around 15°C in January up to 25°C in April and May. This creates ideal conditions for tea growing, as described in Chapter 3. There are two monsoon seasons:

- **South-west monsoon.** This is expected to occur from the middle of May until September, and the rain falls on the South-western areas. The East and North remain dry and hot during that time.
- **North-east monsoon.** This is due from December to February and the rain falls in the North and East and North-eastern mountain slopes. During this period, the Southwest is dry and sunny.

The two inter-monsoon periods, October to November, and March to mid-May feature showers throughout the country.

Depending on the topography and exposure to prevailing winds some rainfall in the wet zone is predictable and heavy, averaging 2500-5000 mm a year with an average runoff ratio of over 65%. The rainfall is well distributed throughout the year in this zone (rarely less than 130 mm a month). This can be compared with Scotland that receives a monthly average of 90-160 mm of rain. The rainfall in the dry zone is less constant and mainly falls October to January (averaging 1500 mm annually and an average runoff ratio of 30%) with an average rainfall of less than 50 mm a month in the dry period [Arulanantham, 1990].

There have been analyses of the pattern of rainfall in the past but no conclusive evidence has been offered about the cause of the trends, or predictions made of rainfall behaviour in the future. It has been found that rainfall has decreased in the hill

country, and this is linked partly to the deforestation of the area to clear the land for tea planting. There has been a corresponding increase in the rainfall/runoff ratio [Berugoda, 1991].

Sri Lanka is dependent on water for domestic consumption, irrigation and agriculture, and for large and small scale hydropower. There are 103 river basins [National Atlas of Sri Lanka, 1986]. The rivers are perennial in the wet zone, with the rivers never completely drying up, and seasonal in the dry zone. The only area with an official water surplus is in the Western wet zone.

The rainfall affects the flow of the river which in turn affects the amount of siltation present in the river. Siltation occurs when the water is either at rest or flowing below the velocity at which sediment is transported. The sediment falls out of suspension and collects as silt. This is a serious problem in most of the tea growing areas and affects the agricultural use of the land and its hydropower potential. The silt builds up in reservoirs and the capacity of the storage impoundment is reduced. This is noticeable in many of the big dams in Sri Lanka; the Polgolla reservoir had lost 44% of its capacity through silt by 1988, twelve years after commissioning [NRESA, 1991], and similar problems are already evident at the other reservoirs. In run of the river mini and small hydropower schemes the diversion weirs and intakes are also affected by silt.

The government has taken measures to optimise watershed management by encouraging better irrigation methods and rehabilitation of the existing irrigation systems, improving drainage and flood protection, and supporting small hydropower projects.

2.4.3 Land-use and agriculture

In common with most developing countries, Sri Lanka has an agriculturally based economy with over 70% of the population living and working in the rural areas. The

economy was traditionally that of a tropical area and tea, rubber and coconut still provide a tripod of exporting commodities and agricultural products that contributes 25% to the country's GDP [NRESA, 1991].

The land use in Sri Lanka differs in the dry and wet zones. In the wet zone there are three uses of the land, determined primarily by the altitude of the area and also by history, social and economic factors. Coconuts and paddy are cultivated in the lowlands (under 200 metres), rubber is grown in the elevations between 200-900 metres, and is often interspersed with tea which is the dominant crop above 900 metres. Coastal agriculture includes paddy fields for rice, rubber plantations and coconut groves as well as tea, planted in smallholdings, and spice gardens.

Rural industries, especially those based on tea and rubber, require electricity supplies for the processing of the particular commodity. The tea and rubber plantations are in areas of high rainfall and usually are at higher altitude. The availability of a high water runoff and suitable topography has enabled the development of hydropower at a substantial number of estates and plantations. However these plants are all in the micro to mini hydropower range and the majority are disused. The demand for electricity on the estates has increased considerably in recent years as the methods and machinery for crop production have changed. The effects of the reduced reliability of rural electricity supplies on the processing of the crops have renewed interest in expanding small and mini hydropower capacity in the plantation areas.

2.5 Economy and Natural Resources

Sri Lanka is a developing country with a Gross Domestic Product (GDP) per capita of \$453 and a Gross National product (GNP) per capita of \$526 in 1994 [IPS[1], 1994]. This is greater than countries such as Bangladesh and India but is lower than other South Asian countries such as Malaysia, Thailand and Korea. In the 1960's Sri Lanka had a higher economic growth rate than these countries, but this has fallen recently, as a result of the civil strife described earlier. Sri Lanka's current aim is to

reach the target of an 8% economic growth rate, and this is also part of the ESAF agreement with the International Monetary Fund (IMF). However the average annual growth rate from 1990-93 has been only 5.6%. [IPS[1], 1994]. Some of the reasons for this are:

- **Debt Servicing.** This is 6% of the GDP and 29% of government expenditure.
- **Defence related expenditure.** This is 4% of GDP and 25% of government expenditure
- **High inflation.** This is running at 11-12%

In addition to the factors above the agricultural sector has not performed up to the government's expectations. It is accepted that countries trying to achieve NIC (Newly Industrialised Country) status should exhibit sectarian growth in factory based manufacture, financial services and tourism. Sri Lanka has an established garment industry and, until the recent intensification of the civil war, had expanded its tourist industry. However agriculture remains an important basis of the economy, and the country has seen a decline in the agricultural industry. While the overall economy has been growing at 5.6% per annum, the agricultural sector has only expanded at 1.2% and the three main exporting areas within agriculture (tea, coconut and rubber), have contracted at -0.2%, -1.7% and -4.7% respectively [IPS[2], 1994]. Figure 2.3 shows the contribution that each sector makes to the GDP. If the agriculture sector had achieved a 5% growth then the overall growth rate target of 8% could have been reached. In the case of tea, although production has increased by 10%, the increased Cost of Production (COP) and high interest charges have caused all of the estates except two to make a loss in recent years. The specific economic contribution that tea makes to the economy and GDP is discussed in Chapter 3.

GDP at constant (1982) cost prices for 1993

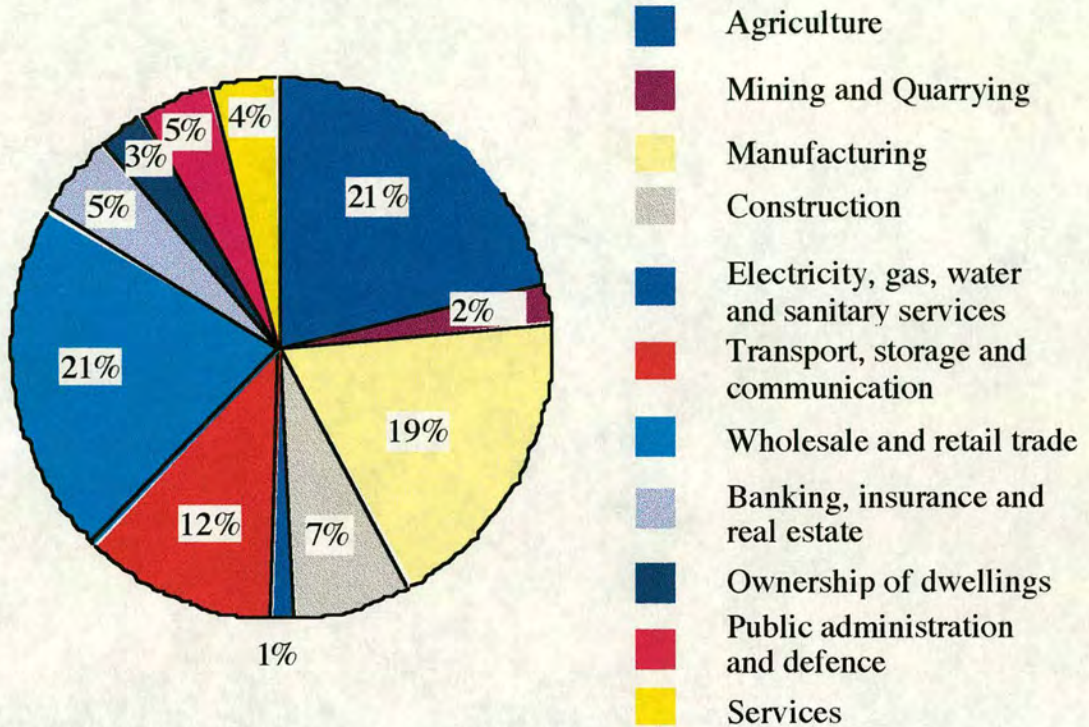


Figure 2.3: The percentage contribution that each sector makes to the GDP in Sri Lanka in 1993 [IPS[2], 1994]

2.6 Energy Resources

Sri Lanka has no known resources of fossil fuels (coal and lignite) and obtains its primary energy mainly from biomass, which is largely firewood, (70%), petroleum and oil (20%) which is imported, and hydro electricity (10%) [NRESA, 1991]. The increasing oil prices have halted the move towards using oil for household purposes, so wood remains the principal domestic energy fuel. As the population has grown the land/person ratio has decreased from 1.84 hectares per person in 1901 to 0.37 in 1991 [Berugoda, 1991] which not only limits the land available for cultivation but also speeds the destruction of the forests for fuel. The growing awareness of the effect that deforestation can have on the climate and environment has caused

governments to favour policies proposed to minimise the rural consumption of fuel-wood. This has led to rural initiatives using small scale hydropower for domestic energy use, as discussed in Chapter 4.

2.6.1 Oil

The oil refinery at Sapugaskanda can process enough oil to supply most of the domestic market, with its main crude oil supplies coming from the Middle East. The transport sector uses most of this, approximately 60%. In domestic consumption the hydrocarbons used are mainly kerosene and LPG gas with 76% of all households using kerosene for lighting in 1994 [Central Bank of Sri Lanka, 1994]. Industrial usage of oil is small except when it is required for thermal generation, used in oil-fired generators, during drought periods.

2.6.2 Biomass

Biomass is used as a cooking fuel in 94% of Sri Lankan households [NRESA, 1991]. Over 80% of the biomass fuel is freely available within a mile radius of the consuming household. Industries that produce tea, rubber, desiccated coconut, bricks and tiles also use biomass for firing and drying.

2.6.3 Large and medium scale hydropower

In 1950 Sri Lanka built a hydropower station at Laxapana with a capacity of 25 MW and marked the birth of the National Grid. The dates and chronological order of the commissioning and building of the major dams and hydro plants in Sri Lanka are shown in Table 2. 1 [Siyambalipitiya and Samarasinghe, 1993] and are discussed below. The history of the small scale hydro plants is discussed in Chapter 4.

Year/Project	Station	Installed MW	Historic Energy GWh/year **	Expected Energy *
Initial Stations				
1950-58	Laxapana	50	269	289
1962-65	Wimalasurendra	50	122	112
Maskeliya Oya				
1966-69	Polpitiya	75	367	427
1971-74	New Laxapana	100	458	491
1978-88	Canyon	60	129	161
Mahaweli Ganga				
1976	Ukawela	38	158	177
1981	Bowatenna	40	55	53
Accelerated				
1984	Victoria	210	605	726
1986	Randenigala	122	273	378
1988	Kotmale	201	197	482
1990	Rantembe	49	273	378
1986	Samanalawewa	120	N/A	357
Medium Scale Plants				
1963	Iginiyagala	11	N/A	27
1969	Udawalawe	6	N/A	8
1988	Nilambe	3	N/A	12

Table 2. 1 Details of the major dams and hydropower stations in Sri Lanka

* These figures are from the CEB and are calculated assuming average rainfall conditions.

** Historic Energy, where available, is from the time of commissioning to 1993.

Initial Stations

The first station at Laxapana took 40 years from initiation to completion [Jayawardhane, 1993], while Sri Lanka was still under colonial rule. The next 75 MW was installed by the CEB (or DEU as it was known then).

Mahaweli Gang and Accelerated Mahaweli Ganga Project

The Mahaweli Master Plan was a plan to promote food self sufficiency (by providing irrigation to paddy fields) and to exploit available hydropower. It had been planned by the United Nations Development Programme (UNDP) under the Food and Agricultural Organisation (FAO) in 1968 and was envisaged to take 30 years. However in 1977 the newly elected President Jayawardene, with a vision of Sri Lanka being run on the same lines as Singapore, decided that the project would take 6 years. It was then called the Accelerated Mahaweli Project. It was a joint venture to provide electricity and irrigation requirements using the longest river in Sri Lanka. The Plan includes 65% of the installed hydro capacity in Sri Lanka, but its operation is governed by irrigation demands that assume priority. The water is used to irrigate the paddy fields and the fact that the law states that “irrigation requirements have to be satisfied under all operating conditions” means that the hydropower stations are not necessarily operated in the optimum way [Siyambalipitiya, 1995]. This accounts for the low expected energy from the hydropower plants given in Table 2. 1.

Samanalawewa Project

After the completion of the Accelerated Mahaweli Programme the CEB decided to implement the Samanalawewa Dam, from a proposal submitted by Balfour Beatty and funded by the British Overseas Development Agency (ODA). There have been acute technical problems with this dam, mainly leakage from the reservoir, and a variety of solutions have been tried including extensive grouting. In 1992 the right abutment of the dam was blown out due to terrorist action and the power station

now operates as a run of the river scheme. The latest proposal is to 'wet blanket' the dam, to restore the capacity of the scheme, by pouring concrete over it.

The majority of the projects were funded, engineered, constructed and installed by foreign companies and governments; the Kotmale funded by the Swedish government, the Victoria and Samanalawewa by the British, the Randenigala by the Germans and the Maduru Oya by the Canadians [Jayawardhane, 1993].

The problems with large scale hydropower plants include loss of generation capacity due to the falling level of the reservoirs (due to drought), siltation, land slippage, and, to the 'irrigation priority' at the Mahaweli schemes. The performance of the stations is also below what would be expected; a system plant factor of 44% is reached, compared to a system plant factor of around 60-66% in developed countries [Siyambalipitiya, 1993]. There is no instant solution to these problems and they will have an increasing detrimental effect on generating capacity. Small scale hydropower plants have similar problems from land slippage and siltation, but the effects can be contained or repaired more easily and are less environmentally damaging.

2.6.4 Thermal options

The present thermal plants in Sri Lanka are shown in Table 2.2. The grid operator decides the thermal-hydro mix once the release of the reservoirs (to meet the irrigation requirements) is known. The water in the upper reservoir is assigned a monetary value (which equals zero if any reservoir is at spill level), and as the stored water is drawn down the value of the remaining water increases until (for instance at drought times) it reaches the cost of generating from the cheapest thermal plant (the diesel). This decision process continues by including the oil stations until finally the gas turbines will be started [Siyambalipitiya, 1995]. If, as was the case in May and June 1996, the reservoir levels drop further, then blackouts and system outages are the necessary action.

Plant	Installed Capacity MW	Historic Energy (GWh/Yr.)
Kelantissa-Gas	120	312
Kelantissa-Oil	50	249
Sapugaskanda-diesel	80	439
Chunnakam-diesel *	10	0

Table 2.2 Thermal plants in Sri Lanka

* Chunnakam diesel station is located in Jaffna and is presently out of service due to the political situation in the North.

2.7 Future Energy Options

The cost to the tea industry of the loss of electricity supplies will be considered in Chapter 3, but the overall financial loss, to the economy as a whole, due to power shortages affecting the industrial sector, has been estimated at Rs 33 per kWh lost [Methsiri, 1992]. More plant capacity is obviously required, and the options are to expand the present hydropower plants or change the current energy mix and build more thermal plants. Table 2.3 shows the recent proposals and estimated energy specific costs. [Siyambalipitiya, 1995]

2.7.1 Thermal plant expansions

Since 1984 the CEB has been recommending the construction of a coal plant near Trincomalee, in the East of the island, with an installed capacity of 300 MW. The coal would be imported from Australia or South Africa. However environmental objections have caused the construction to be postponed indefinitely. The proposed plant would have provided about 25% of the system demand (in an area that is, at

present, a security risk), which is above the optimum capacity for a single power plant on any system [Siyambalipitiya, 1995]. Another coal burning site may also be constructed on the South coast and there is the possibility of adding 110 MW more capacity to the diesel plant at Sapugaskanda. Gas fuelled systems currently account for 120 MW of capacity and about 30 MW is recommended for future development [CEB[1], 1995].

Plant	Capacity	Specific Costs	Specific Costs
	MW	Rs/kWh	p/kWh*
Hydro			
Ging Ganga	49	1.9	2.5
Broadlands	40	2	2.6
Upper Kotmale	248	2.1	2.8
Uma Oya	150	2.1	2.8
Moragolla	27	2.5	3.4
Belihul Oya	17	3.1	4.1
Kukule	144	3.16	4.2
Thermal			
Coal (South)	150	2.4	3.1
Coal (East)	150	2.2	2.9
CCGT	68	2.6	3.4
Diesel	20	2.5	3.3
Gas Turbine	22	4.6	6.1

Table 2.3 Future plans for large scale hydropower plants and thermal power stations

- These prices are at 1994 exchange rates

2.7.2 Large and medium scale hydropower expansion

It is estimated that there is 870 MW of exploitable medium and large scale hydropower energy available in Sri Lanka [CEB & GTZ, 1989]. The CEB has short-listed the sites that they consider feasible, but as yet there has been no further surveys or steps taken towards their construction.

2.7.3 Alternative sources

At present the only sources and use for alternative energy is in the MHP sites, a few battery charging sites and the use of photo voltaic cells for rural electrification. The latter two are discussed in 2.8.4. Wind energy is an option especially on the East Coast and estimates have put the potential for wind energy at 200 MW [Siyambalipitiya, 1994]. A 40 MW incinerator plant using coconut husks and household waste from Colombo has been suggested with an estimated 250 GWh of annual energy, and a wave power generator is being discussed. Table 2.4 shows the estimated specific cost for these alternative sources [Siyambalipitiya, 1995]. It is seen that in comparison with the cost of hydropower and thermal power (Table 2.4) these are expensive options at the present time.

Energy Type	Specific Cost Rs/kWh
Waste Incinerator	4.7
Solar	6.3
Wind	6.5
Wave Power	5

Table 2.4 Specific costs for selected alternative energy sites in Sri Lanka

2.8 Energy Profile

The installed electrical capacity is, at present, 1409 MW with large scale hydropower constituting 80% of the total (1137 MW), and the gross generation being 4365 GWh per annum [CEB [1], 1995].

The growth of installed capacity, split into thermal and hydropower units is shown in Figure 2.4

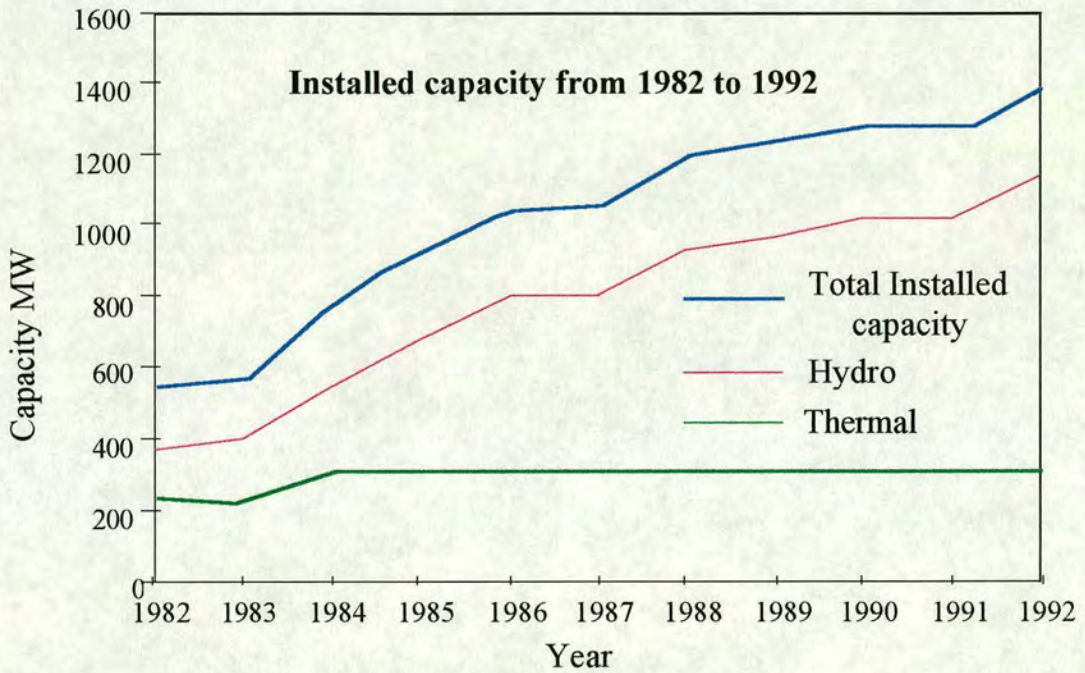


Figure 2.4: Graph of Installed Capacity in Sri Lanka, showing the contribution made by thermal and hydropower capacity.

Sri Lanka’s electricity system is predominantly hydropower based with the thermal generating plants used as back-up rather than adding to the base load available capacity. It is an energy constrained system as the ‘fuel’ is rainfall which has a probabilistic occurrence, [Siyambalipitiya, 1996] as distinct from the capacity constrained systems which operate in the UK, where the generation of most of the plants (being thermal) can be accurately predicted. In Sri Lanka, the electricity industry is vulnerable to droughts due to its reliance on hydropower units.

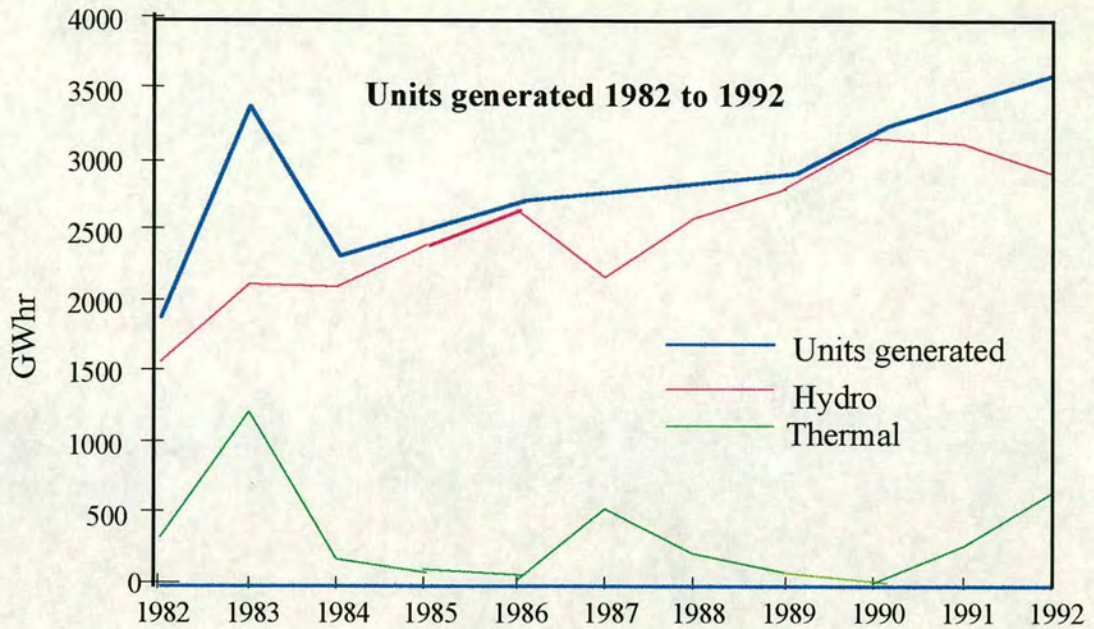


Figure 2.5: Hydropower and thermal generation

Figure 2.5. shows that most of the additional thermal units were used during 1980-1983 and 1987 when there were severe droughts and power shortages throughout the country.

2.8.1 Energy use and consumption

The annual electricity demand growth rate soared in the 1970's peaking at 12% in 1977, slowed down slightly in the '80s, and in the 1990's was 8-10%. [Sambalipitiya, 1993]. The annual demand growth rate for electricity has been consistently higher than the growth rate of the GDP. This is in contrast to developed countries such as Ireland (taken as an example since it is of similar geographical size, although with a bigger land/person ratio) where the electricity consumption per capita was 3,766 kWh [EUROSTAT Energy Yearly Statistics, 1993] and the electricity demand growth rate was less than 2%.

Sri Lanka has a high electricity demand growth rate and the percentage consumption of consumption between the different sectors is shown in Figure 2.6. The demand is expected to continue to rise because:

- Increasing prosperity has led to a demand for Western consumer electrical goods.
- The need to encourage tourism will lead to a rise in the commercial sector demand for air conditioned building and other western amenities.
- Technological changes where computers, fax machines and machines replacing jobs previously performed manually will cause an increase in electricity demand in the industrial sector.
- The continuing expansion of the rural electrification programs.
- The main benefits of electricity in the form of lighting and air conditioning are not yet available to the bulk of the population.

Political problems in Sri Lanka with the civil war in the North and the unrest in the 1980's have also had an impact on the demand for electricity; the northern peninsular of Sri Lanka has been without communication or electricity for the past three years, but this area, which has a population of around 800,000, must be included in future demand forecasts. The CEB predicts a generation requirement of 8850 GWh by the year 2000, which would imply a need for around 500 MW of additional capacity [CEB & GTZ, 1989].

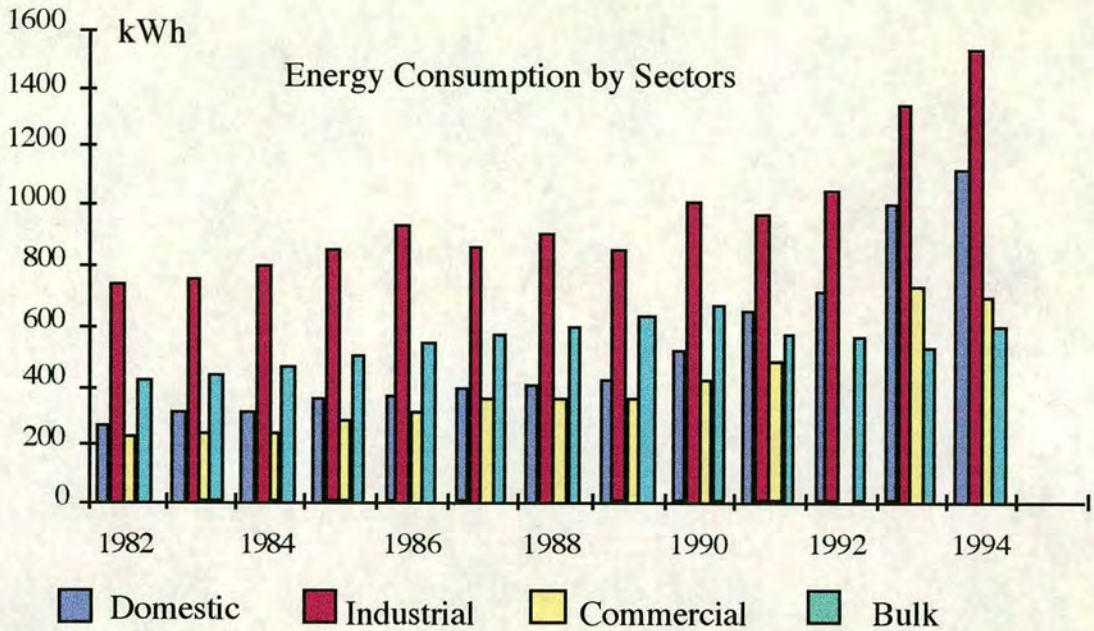


Figure 2.6: Electricity consumption by sectors

2.8.2 Administration of the transmission, generation and distribution systems

Until the advent of the grid the generating system in Sri Lanka consisted of small generators and isolated networks operating across the country. In the 1950's the responsibility for the transmission and generation was taken over by the Department of Electrical Undertakings (DEU), which later became the CEB. Most of the distribution network was managed by local councils and authorities until 1983, when the company, LECO (Lanka Electricity Company) was formed by the CEB and the Urban Development Authority. LECO and the CEB have since taken over almost all of the distribution services and network in Sri Lanka, and over 80% of all electricity sold is from the CEB and 20% from LECO [CEB & GTZ, 1989].

The CEB is a vertically integrated organisation and is responsible for maintaining and monitoring all the generation, transmission and distribution of its electricity in Sri Lanka, and also for predicting the future demand for power and planning future power stations and projects. The CEB uses an electricity demand forecast based on trend analysis and an economic analysis using the GDP and population increase as

the main variables. However these forecasts have proved inaccurate and have severely under-estimated the demand in most years.

The CEB is divided into six divisions or departments, each with an Additional General Manager responsible for the particular department and overall control held by the General Manager. The six divisions are:

- Planning : in charge of system expansion and policy
- Projects: implementing planned projects
- Generation: management of the generating stations and transmission network
- Distribution: management of the distribution network
- Finance Division: financial services to the above divisions
- General Services Division: technical support to the above departments

Along with other government organisations in developing countries, work is often delayed and postponed due to bureaucracy, civil strife and a reliance on aid to fund projects. This results in the continuing shortfall between electricity supply and demand which has been further exacerbated in recent years by the unreliability of the monsoons culminating in droughts. The subsequent loss of capacity at a time of increasing electricity demand has caused power shortages that are unacceptable, and this has led to the CEB implementing new policies to try and improve the situation.

One development has been the establishment of an Alternative Energy Section, whose aims are to look at sustainable sources of energy, environmental considerations, conservation measures and to work together with local organisations, NGOs and companies to help achieve these aims. It led, in 1992, to a change of

policy regarding grid connection for small generators, with the CEB offering Rs 2.6/kWh and free feasibility studies for small hydropower sites.

2.8.3 Transmission and distribution

Figure 2.7 shows the present grid network of power stations and substations [CEB, 1993]. The majority of the substations and transmission lines are concentrated in the major cities of Colombo, Kandy, Trincomalee, Ratnapura and Anuradhapura; away from the areas of dense population the grid network is far more dispersed, and the total lengths of transmission lines and distribution cable has not increased significantly in the past few years. The Sri Lankan power system incurs high losses averaging 23% of the power transmitted, with some rural networks losing over 40% of transmitted power. The large line losses are attributed to the relatively low level of investment in the transmission and distribution system.

The cost of connecting dispersed consumers to the grid is an acute problem in countries like Sri Lanka, where the length of the necessary transmission lines makes the connection cost uneconomical. This has sustained interest in installing stand-alone generating plants.

CEYLON ELECTRICITY BOARD

POWER STATIONS & C.E.B. PROVINCIAL BOUNDARIES

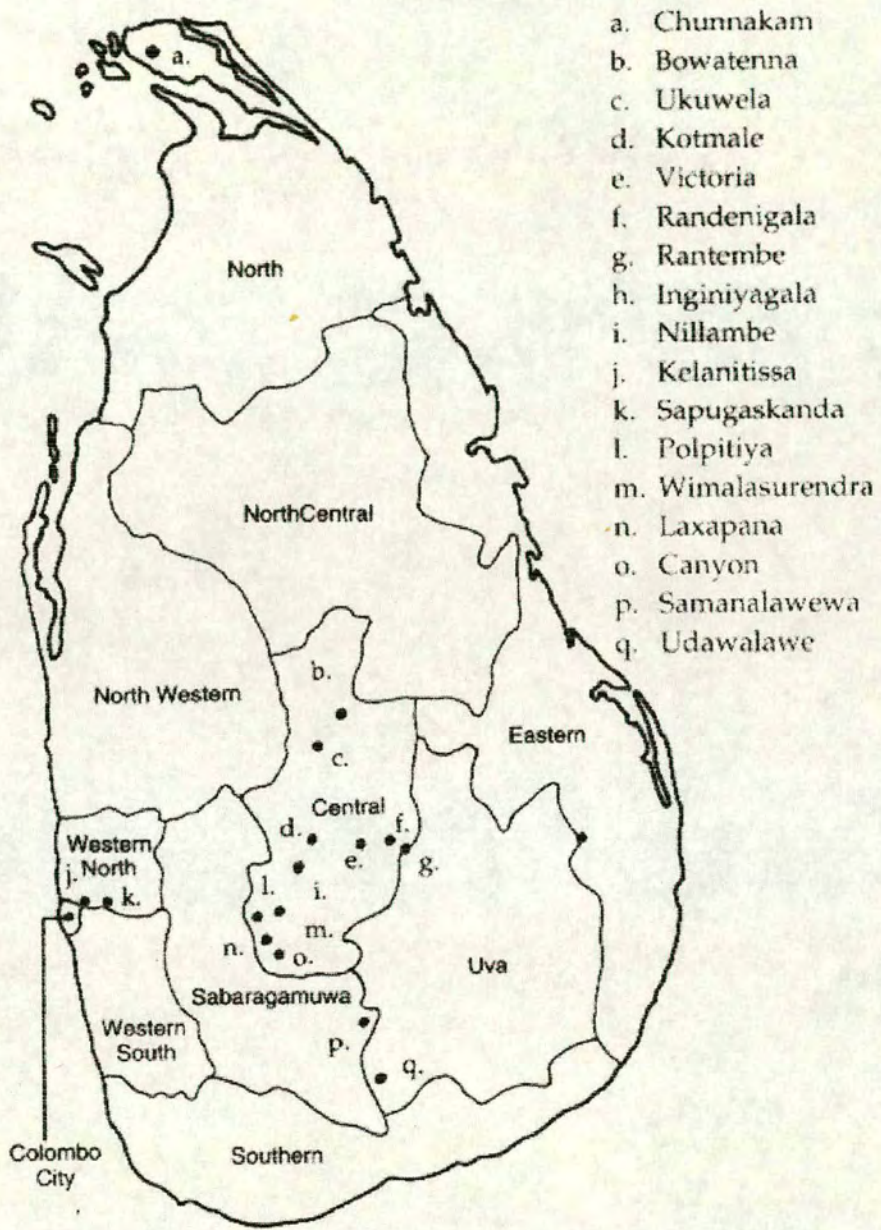


Figure 2.7: Grid network in Sri Lanka

2.8.4 Rural electrification

There are around 25,000 villages in Sri Lanka, housing about 70% of the population. Rural electrification was initially undertaken and operated under the auspices of the local authorities, but in 1969 became the responsibility of the CEB, funded with annual government grants. In 1977 the Asian Development Bank and the CEB collaborated to plan a more structured approach to village electrification, with the result that the number of villages electrified and connected to the national grid is about 12,000. However not all houses in the villages can afford a connection even though a distribution supply is available close by, and the total percentage of households with an electricity supply is about 45%, mainly in the urban areas. Only about 20% of the rural households have electricity [Tissera, 1989]. This is due to:

- The high capital cost.
- The dispersed nature of the villages and households so that line extension is not often feasible.
- Low financial returns and high maintenance costs.
- Very low load factors of between 2-43 %, with an average of about 7%.

In common with other developing countries the government grid connected schemes tend to work only when there are a number of industrial and commercial consumers. It has been found that rural electrification schemes in the rice and coconut areas have more productive end users than in the rubber or tea areas, as there are more industrial and commercial consumers in the former areas. More obvious perhaps is that only the higher income families are likely to have electricity supplies due to the high cost.

This leaves a considerable part of the community without electricity either through lack of income or access problems. One way of addressing this problem is through local village level micro hydropower schemes. The micro hydropower schemes that

have been implemented have achieved comparable success, so far, by involving the villagers, working out acceptable tariffs and trying to provide electricity to as many households as possible.

There are two other methods used to electrify rural areas, the most important is the Prashakthi lighting unit that is a chargeable battery connected to fluorescent lights. There are around 1,000,000 such units in Sri Lanka, used for lighting and to run TV sets. In addition there are about 1,000 installed solar photo-voltaic panels.

2.9 Future Energy Initiatives

There will be an energy crisis in Sri Lanka unless measures are taken to build new plant, reduce current consumption by energy conservation programs and implement a reduction in transmission losses. Since March 1996, due in part to the failure of the Southwest monsoon, all parts of Sri Lanka, including Colombo, have had regular power cuts lasting between 2-8 hours. The CEB must meet electricity supply and demand in the future. Its priorities and aims are to:

- **Extend present capacity.** In the long term this must involve thermal plants, such as coal and gas. In the short term the construction of small scale hydropower plants is a priority.
- **Reduce transmission losses.** A target of 10% transmission losses has been set.
- **Extend the Rural Electrification Programme.** This must be done both on a government and private basis.

Sri Lanka also needs to identify a set of distinct energy policy aims and objectives that specify :

- the optimum generation plant and energy mix to meet future electricity demands.
- an environmental policy that includes conservation, demand-side management and improvements in the efficiency of industrial and domestic equipment and appliances.
- new pricing strategies. In common with other developing countries the tariff structure has been established to subsidise the small domestic consumer, and in order to be commercially viable, this has meant cross subsidising from other industrial consumers.
- a critical mass of engineers and economists to build up the expertise needed to develop and run the hydropower and electricity industry, instead of relying on internationally financed projects funded by expats.

3. ENERGY USAGE AND ECONOMICS IN THE TEA INDUSTRY

Sri Lanka is synonymous with tea. The tea manufacturing industry has critical political, economic and social importance in terms of its contribution to export revenue and sector employment built on a historical world-wide reputation. The industry has been declining in recent years, as its production costs have risen to exceed the price obtained at the tea auctions, and as a result, the world market for Sri Lankan tea has been decreasing. The contribution that tea has made to export earnings has fallen markedly, from over 60% between 1950 to 1965 to around 30% in the 1980's to only 14% in 1990 [Mendis, 1990]. This has led to government and private initiatives to try and revitalise the industry.

The apparently different processes of tea cultivation and mini hydropower generation share similar requirements, in terms of land, topography, climate and rainfall. Rainfall is the determining factor in both areas, with the slope of the land and the need to conserve the soil also being important. The majority of the tea is grown in the central hill country, the area which also has the greatest potential for the development of mini hydropower. Tea plantations flourish on terraced, sloping hillsides with stable soil distribution and controlled irrigation. The best areas for tea cultivation are rolling hillsides or mountainous ridges with the rainfall travelling rapidly down the mountain in an extensive network of rivers and streams. Inundation of the land to produce large impoundment's of water would reduce the area that could be used for tea planting. As a result run of the-river hydro schemes in the small to mini hydropower range are the most appropriate for the production of a rural, agricultural electricity supply. The tea industry has a direct use for hydropower either to directly drive or to supply electricity to its processing equipment. The government's concern with meeting future electricity demand and to develop its remaining hydropower potential has provided an opportunity to promote initiatives

to benefit both the tea industry and to develop mini hydropower (MHP) in Sri Lanka. In addition to the direct benefits that mini hydropower will bring to the tea industry, the development of such schemes will also reinforce the rural transmission system. The CEB, government, tea industry and rural consumers are all keen to improve the current rural electricity system through the development of distributed mini hydropower.

This chapter describes the tea industry and the inter-related benefits of the development of mini hydropower for the tea industry and Sri Lanka. The history of the tea estates is important as it was the requirement of the tea industry for mechanical power that introduced micro hydropower plants to Sri Lanka. Recent developments in the management and operation of the tea plantations are leading to opportunities to increase the installed capacity. The electrical energy costs incurred in the tea manufacturing process are a substantial percentage of the total cost of production, and are likely to increase if the industry diversifies or buys new technology for the tea manufacturing process.

3.1 History of the Tea Industry

The planting of tea, as a cash crop, was started in Sri Lanka by a Scotsman James Taylor, at the Estate of Loolecondara, in 1840. At this time coffee was the major plantation crop in Sri Lanka, but after a coffee blight destroyed most of the island's coffee plantations in the 1860s, tea succeeded as the country's major export crop. The land used for tea cultivation has increased from 6,000 hectares in 1882 to 220,000 hectares in 1995 [DTI, 1995]

Under colonial rule the estates were strictly controlled. Money was spent on importing the latest tea machinery and turbines to drive the equipment and provide mechanical power to the estates. A railway line to the tea plantations was constructed and vast areas of the jungle were cleared to increase the area available for cultivation. Obtaining labour proved to be a problem since the native Sinhalese

refused to work in the poor conditions and hostile terrain for the low pay that was offered. Indian Tamils were imported from South India and subsequently changed the demographic pattern in the Highlands of Sri Lanka. The estates were managed and owned (including responsibility for the shipping and distribution of tea as well as the actual manufacture of the tea) by national retailing agencies from Britain, including Thomas Lipton, Brooke Bond and James Finlay. By 1948 over 66% of the tea sector was owned by companies based in London and British controlled agency houses in Colombo [Rote, 1986]. However, after this period the effects of independence, heavy duty taxes, high prices and unfavourable exchange rates caused the decline of the British companies that owned and managed the tea estates. Land reforms in 1972 restricted private ownership to areas of less than 50 acres, and further reforms in 1975 nationalised all estate land owned by private companies that had not been affected by earlier legislation. This gave the government control of 63% of the plantation sector. Most of this land was in the Mid and Up Countries (defined in Section 3.2) and over 95% of all tea estates were under state control [Humbel, 1991]. The tea plantations were distributed between the Janantha Estates Development Board (JEDB) and the Sri Lanka State Plantation Corporation (SLSPC), operating under five regional areas with designated estates in each region:

These reforms were intended to improve the productivity of the tea industry but the political drive that had initiated the reforms was not supported by a structure that provided the technical assistance or financial infrastructure to facilitate it. The estates survived due to high government subsidies, but upkeep and maintenance were limited. Tea bushes were not replaced with younger stock on a rolling basis. Factory machinery was not maintained and there was no investment in new technology. Land conservation and fertilisation was not carried out on many estates. A powerful union emerged which caused over-employment and excessive wage bills, until labour costs accounted for 70% of the cost of production [Humbel, 1991]. Since 1975, due to the over expansion of the rural electricity system and no re-enforcement of the grid, the electricity supplies to the estates have been very unreliable. Crop wastage due to

supply failure during processing has caused a significant loss to the tea industry. All of these failures were compounded and intensified until, by the early 1980's, almost none of the estates returned a profit [DTI, 1992].

The quality of premium and lower grade tea fell until the cost of production at many established estates exceeded the prices obtained at sale. This is further discussed in Section 3.4. The subsidy required from the government during the 1980s was a considerable burden on the already limited financial reserves of the country. Dissatisfaction about providing this level of subsidy coupled with demands from lending institutions such as the World Bank caused the government to restructure the state managed plantation sector to try and make it more competitive and economically viable. The government decided to retain ownership of the estates and award contracts for commercial operation and management to private companies. Since 1992, 449 of the 502 tea plantations have been managed by 22 private companies. These companies were originally given a five year lease, but this was extended to 30 years in 1995. The remaining 53 plantations were considered to be financially unfit for private management, so they remained in the public sector. In 1995 the government offered the management companies ownership of the estates if they bought 51% of the shares. The poor financial position of the companies meant that only four of the companies had taken advantage of this offer by March 1996 [Lilly, 1996]. However the ADB and the World Bank stipulated that the estates must be privatised in order to receive funds from these organisations and so the government has decreed that all estates will be privatised by 1999.

3.2 Geographical Location of the Tea Estates

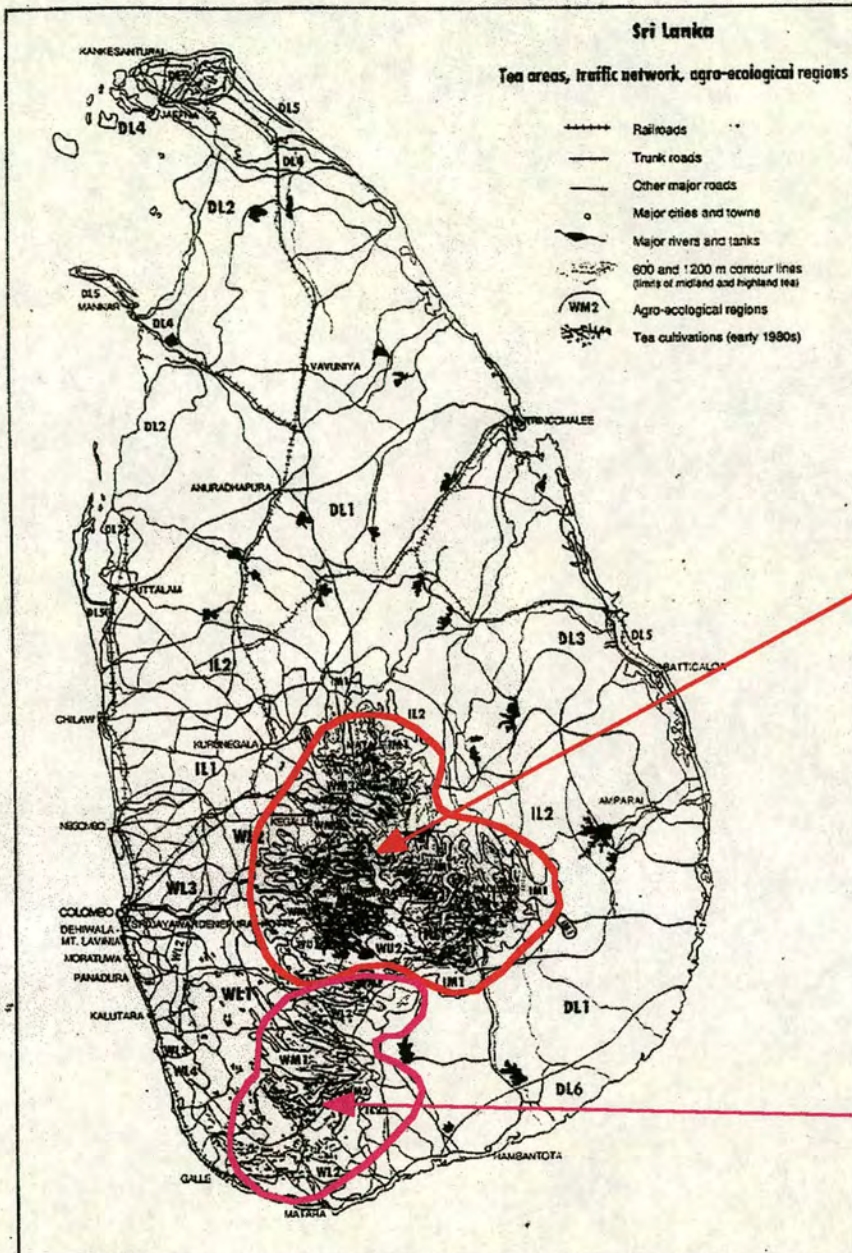
Tea can grow in various soils, climates and at different altitudes [TRI, 1986]. The crucial factor is rainfall, with an average requirement of 1200-3000 mm per year. An even annual distribution of this rain is also important, avoiding seasonal variations, and a minimum fall of 50 mm every month is required. The ideal ambient

temperature is 18-25°C and severe temperature fluctuations during the day are unsuitable. Strong, dry winds damage growing plants. An acid soil of pH 4.5 to 5.5 is a significant criterion along with a requirement for good drainage and soil permeability [Eden, 1958].

The climate, soil and geology in certain areas of Sri Lanka are suitable for tea cultivation, as shown in Figure 3.1. The areas are characterised by elevation, rainfall and soil type. By elevation alone the areas can be divided into 3 categories [Humbel, 1991] and these areas also produce unique tea characteristics, in flavour and colour, as well as different yields and quality.

- Up Country: the elevation of the estate is above 1200 metres. It is considered that the highest quality tea in Sri Lanka is produced in these plantations. Yields are also high.
- Mid Country: tea is grown between 600-1200 metres. These teas lack the flavour and quality of the high grown teas and yields are low.
- Low Country: tea is planted at elevations below 600 metres. The yields are high due to the terrain but the quality and flavour are lower.

The Low Country consists of lower and undulating hills with an average rainfall of between 1500 and 2500 mm, mainly due to the inter-monsoon rains. However some of the areas around Ratnapura receive as much as 5000 mm. The main problems in the Ratnapura area are soil erosion and landslides, both of which are hazardous for tea planting and MHP development. In the Low Country an average dry period of about three months is expected. The terrain in the Mid and Up Country is steep and mountainous and receives a higher rainfall of between 2000-3500 mm [National Atlas of Sri Lanka, 1986]. The central hill area in Sri Lanka receives rainfall from both monsoons so, apart from a dry period of about 3 months, tea can be planted all year.



Up and
Mid
Tea
Area

Low
Tea
Area

Figure 3.1: Map of Sri Lanka showing areas of tea cultivation

The land in the Mid and Up Country areas is steep but is not prone to landslides or earth slippage. Soil erosion is a crucial problem in all the tea areas. Section 2.4.2 describes how soil erosion, in particular sedimentation, severely affects the performance and efficiency of hydropower schemes, but soil erosion also decreases agriculture yield, as the top soil contains nutrients necessary to the growth of the plant. The result is a lower yield and poorer quality tea.

The variation in the elevation, soil and climate in these three regions result in distinctive types of tea. The energy consumption and patterns in these areas is also different, as discussed in Section 3.3.1.

3.3 Manufacture of Tea

The land relief, climate and hydrology of the hill country is ideal for tea production and generation of electricity by mini hydropower. The tea production process requires cheap, reliable electrical energy and the tea companies could benefit by generating and exporting power to the local transmission system. An overview of how tea is produced is included to illustrate the parts of the production process that require electricity. Figure 3.2

There are two methods of manufacturing tea in Sri Lanka; the Orthodox method and the CTC method. They are similar in most of the stages, differing only in the machinery used to break up the leaves. A production flowchart is shown in Figure 3.2 [Willson & Clifford, 1992] with the estimated electricity consumption used in each process.



Figure 3.2: Flowchart of tea manufacturing process

* MT refers to kilograms of finished product - Made Tea.

Manufacturing process:

- 1) The tea plant, *Camellia sinensis*, is plucked by the tea-pickers as a ‘flush’ shoot with the top 2 leaves and the bud and transported by tractor and trailer to the factory.

- 2) After picking, the tea leaves are withered. This is a drying process, which can either be done naturally by placing the leaves in wide troughs near windows so that the wind can dry them, or by circulating air at a constant rate and temperature using electric fans. If the moisture content of the ambient air is too high then the surrounding atmosphere must be (electrically or otherwise) pre-heated by several degrees to dry it. Withering takes 6-10 hours in the hill country, and can take up to 14 hours in the low country. During this process the caffeine content increases, the larger, more prominent molecules are broken down, and the membranes become more permeable. The leaf is then rolled and cut to break up the leaves, release enzymes in the leaves and so produce the required chemical reactions. The action of the rollers is to compress and turn the leaf over in continual motion for about 40 minutes. On being discharged from the roller, the leaf is a compressed mass and is broken up in the sifting process which involves two machines, a roll breaker and a sifter.
- 3) After rolling, breaking, and sifting fermentation takes place; this is probably the most crucial process as the quality of the tea depends upon its fermentation time and temperature. The fermentation process starts as soon as the leaf has been broken down in the roller. The broken leaf oxidises and then polymerises to form the flavour giving ingredients Theaflavins and Thearugibins which should be in a ratio of 1:10 for quality tea. Fermentation takes around two hours and must be carefully controlled.
- 4) Immediately after fermentation, the leaves are fired using drying equipment (which is usually fuelled by wood or oil) for 15 minutes to stop fermentation and to reduce the final moisture content of the tea to 3%.
- 5) Finally the tea is graded as shown in Table 3.1 according to its particle size and quality, using mechanically operated sieves with meshes of different sizes. It is then packed for shipping and dispatching abroad.

	Name	Mesh size in mm
FBOP	Flowery Broken Orange Pekoe	1. 70-2.00
FBOPF	Flowery Broken Orange Pekoe fannings	0. 60-1.18
BOP	Broken Orange Pekoe	0.85-2.00
BOPF	Broken Orange Pekoe Fannings	0.50-0.85
OP	Orange Pekoe	1.70-2.00
Dust	Dust (normally in tea bags)	0.42-0.50

Table 3.1: Grades of Tea produced in Sri Lanka [TRI, 1986]

3.3.1 Electricity Consumption in the Tea Estates

The energy needed to process a kilogram of tea has increased over the years. This is mainly due to the use of electric fans rather than the ambient atmosphere to wither the leaves [Hislop, 1986]. As previously mentioned tea is grown in three areas in Sri Lanka but the overall manufacturing method is similar in all regions. However, to produce the distinctive regional teas, the individual processes involved in the manufacture are implemented slightly differently. Withering generally takes longer in the low country with withering usually occurring during the night and manufacturing taking place the following morning. Less pressure is also applied on the rollers during rolling. In the highlands the withering period is shorter but usually requires more heat and the manufacturing process generally starts around 1 am. The higher load on the rollers and also the increased domestic consumption due to the colder climate means that more electricity is consumed in the hill countries [Van Der Knijff, 1990].

The author undertook an energy audit at several of the tea factories. The machinery used in a typical orthodox tea factory is shown in Table 3.2 with the power ratings and speed. This factory, the Mayfield factory in the Kotagala plantations, Figure

3.3, is used as a specific example in Chapter 7. It is an up-country tea factory processing on average 250,000 kilograms of tea per annum with an energy usage of 300 MWh per annum.

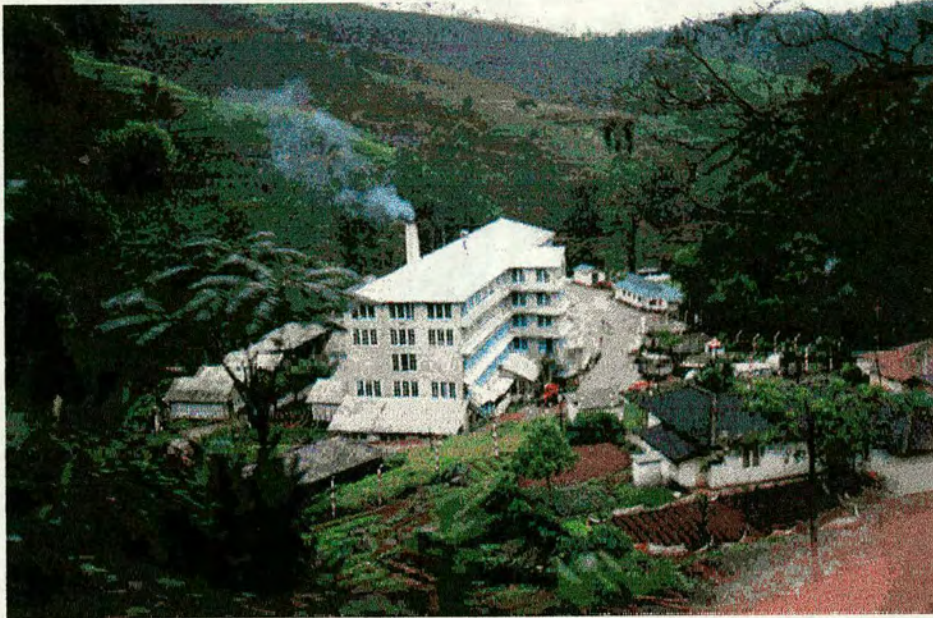


Figure 3.3: Photo of a typical tea factory (Mayfield) in the Up country



Machinery	HP (kW)	Number	Speed (RPM)
Withering			
Troughs (small)	5 (3.7)	7	935
Troughs (large)	7.5 (5.6)	8	960
Rolling & Cutting			
Rollers	15-20 (11.2-15)	4	1400-1440
Rollbreakers	1.5 (1.1)	2	925
Rotorvane	15 (11.2)	2	1440
Ballbreaker	1.5 (1.1)	2	1425
Conveyor	1(0.7)	2	1430
Firing			
Drier	10-20 (7.5-15)	1	1440
Fan	2 (1.5)	1	1440
Circular saw	10 (7.5)	1	1440
Sifting/Packing			
Chota Sifter	2 (1.5)	2	925
Myddleton sifter	2 (1.5)	1	1400
Michie Sifter	1.5 (1.1)	1	1400
Teacutter	1 (0.7)	2	960
Terry nipper Cutter	1 (0.7)	2	960
Winnower	5 (3.7)	1	1400
Stalk extractor	2 (1.5)	1	1425
Dust fan	2 (1.5)	1	1440
Leaf elevator	2 (1.5)	1	960
Packer	3 (2.2)	1	1440
Sprinkler pump	10 (7.5)	1	1440
Humidifier	2 (1.5)	2	960
Conveyor	2 (1.5)	3	950

Table 3.2: Machinery and average factory demand used in a Sri Lankan Orthodox Tea Factory [Mayfield Factory, 1994]

The operations require the following power and usage:

- 1) Withering: this requires 8 to 20 troughs using air fans which have a capacity of between 5-10 kW. The process takes between 8-14 hours depending on location. The power needed to run the withering machinery is therefore typically between 40-160 kW and the energy between 400 and 2,000 kWh per batch.

In the Mayfield factory there are 15 troughs with a total capacity of 78 kW per batch.

- 2) Rolling: this requires 2 to 8 machines each with motors of between 15-20 kW. They are normally run continuously for 8-10 hours. An estimated 30-160 kW of power is required for this process, and between 240 to 1600 kWh per batch.

In the Mayfield factory there are 4 rollers with a capacity of 86 kW in total.

- 3) Fermenting : this requires electrical fans to blow hot air from the burning fuel over the leaves. Two fans of between 10-20 kW are used and are run between 3-8 hours each day. The fermenting process requires between 20-40 kW and between 30 to 160 kWh per batch.

In the Mayfield factory the fermenting equipment consists of two drying fans and requires a capacity of 31 kW and between 60 to 180 kWh per batch.

- 4) The final process of sorting, grading and packing the tea : this needs various sifters and packers with small electrical motors with a total capacity between 15-30 kW. They normally run for around 4-6 hours.

In the Mayfield factory the sorting, grading and packing uses machinery with a total capacity of 15 kW.

The maximum amount of energy is consumed during the withering, rolling and drying stages. The rolling and fermenting is performed after the withering so a typical factory demand would peak at 65-230 kW. Peak factory demand at the Mayfield factory is around 160 kW.

Calculations by Hislop [Hislop, 1989] and Van Der Knijff [Van Der Knijff, 1990] put the total tea processing energy requirements at 0.7 kWh and 0.9 kWh per kilogram of made tea respectively. The author calculated from data of crop production against electricity consumption given in Figure 7.3. that the electricity consumption averages 1.2 kWh per kilogram of made tea in 1995.

Tea is a batch process but the sequence of the operations must be continuous. The interruption of the process, through power cuts causing the fans and rolling and cutting machines not to run, can lead to premature fermentation and ruin the crop. Fermentation is the fundamental process in tea manufacture, as the chemical reaction that takes place produces the colour and flavour of the tea [Humbel, 1991]. Temperature and fermentation time is thus critical. Delays of 1-4 hours lower the quality of the tea in the withering troughs and rollers so that the tea in the dryers continues fermenting and needs to be thrown away. Long delays can result in the loss of the whole crop [Hislop, 1986].

Electricity consumption in the Sri Lankan tea estates is high compared to those in India which use about 0.45 kWh/kg of tea [Van Der Knijff, 1990]. The reasons for this are partly due to smaller factory capacity, but the operation of the equipment below design capacity and poor efficiency are more important causes.

The tea estates in Sri Lanka require a reliable and economical source of electricity. As the tea estates are not situated in the cities but in the rural areas, power shortages and interruptions are more frequent and for longer periods of time. The tariffs are expensive with the peak rates often coinciding with the maximum factory load. The average production of a medium sized tea factory is around 500,000 kg of made tea

per annum (the larger factories have capacity to produce 1,400,000 kg per annum), which is approximately 1350-3050 kg of made tea per day. In 1996 with an average of 6 hours lost per day over a 2 month period or about 300 hours in total, and current tea prices averaging Rs 100 per kilogram, the loss to the companies can be up to several million rupees.

3.3.2 Comparison of expenditure in various activities of tea production:

During the surveys data was collected on the expenditure of different sections of the tea estate. Table 3.3 shows a comparison of the cost of the various activities in a typical tea plantation.

Component	% of Cost of Production
Overheads	10 %
Labour	70 %
Energy (including electricity)	10 %
Fertiliser	5 %
Packing	5 %

Table 3.3: Percentage Breakdown of Cost of Production of tea

It is seen that energy, including electricity, only accounts for approximately 10% of the cost of production, so in normal production the electricity costs are small. However as explained in Section 3.3 the quality of the tea is critically dependent on the drying process, and so breakdown and shortages in the electricity supplies, even for a short period, can halt the crop production and has a major effect on the commercial viability of the estate. What is required is a reliable source of electricity; given the state of the grid as discussed in Section 2.8.3 the concept of a secure, stand-alone electricity supply is very attractive.

3.4 Economic Implications for the Tea Industry

It is outwith the context of this PhD to analyse, in great detail, the effect that the plantation sector has had, in social and political terms, on Sri Lanka but the reader is referred to texts by [Smart, 1988] and [Kurian, 1982]. However the current economic situation of the tea industry has helped to produce the present circumstances where the development of mini hydropower plants for the tea plantations is needed and is appropriate.

The market price for tea depends primarily on its supply and demand. This has been declining over the last two decades as the world production of tea has grown at a faster rate (averaging 3.1% in the last ten years) than world consumption (averaging 2.2% in the last decade) [International Tea Committee, 1992]. Tea production is concentrated in Asia, with India producing a third of the total world output and Sri Lanka and China each producing a sixth. However, other countries such as Kenya and Indonesia are beginning to increase their market share. Sri Lanka is the main exporter of tea as India has a large domestic market, that absorbs most of its production.

In economic terms, the overall demand for tea is relatively fixed and this has led to a fairly inelastic market, and until about 1960 the demand for the quality teas made in Sri Lanka was also inelastic. However, in the last ten years more producers in countries such as Kenya and Bangladesh have entered the market causing the demand for Sri Lankan tea to become increasingly elastic. The income generated from Sri Lankan tea exports has fallen from over 50% in 1972 to 30% in the 1980's to 21% in 1992 [Sri Lanka Tea Board]. This is due to:

- The decreasing price that the tea has been fetching at the weekly tea auctions¹, (Figure 3.4) along with the falling tea production. Sri Lanka's tea production fell by 4% in 1992.
- The low labour productivity in Sri Lanka with the average yield of made tea per worker being between 24-46 kg per day compared with 48 kg per day in Kenya and 80 kg per day in South India [International Tea Committee 1992].
- The low yields compared with other countries. The plucking average in Sri Lanka was 14 kg/hectare per worker in the high grown estates compared with 25 kg/hectare per worker in South India [International Tea Committee 1992]

The high Cost of Production in Sri Lanka, which has been increasing steadily, against the falling market price as shown in Figure 3.4. World bank surveys in 1991 put the COP in Sri Lanka around \$1.87 compared to \$1.39 in South India and \$0.94 in Kenya [De Silva, 2/4/96]

The overall problem, in marketing terms, is that in the 1980's Sri Lanka produced a high quality tea designed for the leaf market but the demand has switched to tea-bags which can be filled with lower grade teas. Sri Lanka was positioned in the good every-day tea market not the superior tea market and this has exacerbated the economic problems for the tea trade.

¹ Tea is sold in Sri Lanka through weekly auctions in Colombo, brokers and the London tea auctions. Only about 10% of the tea manufactured in Sri Lanka is used for domestic consumption [Sri Lankan Tea Board, 199]

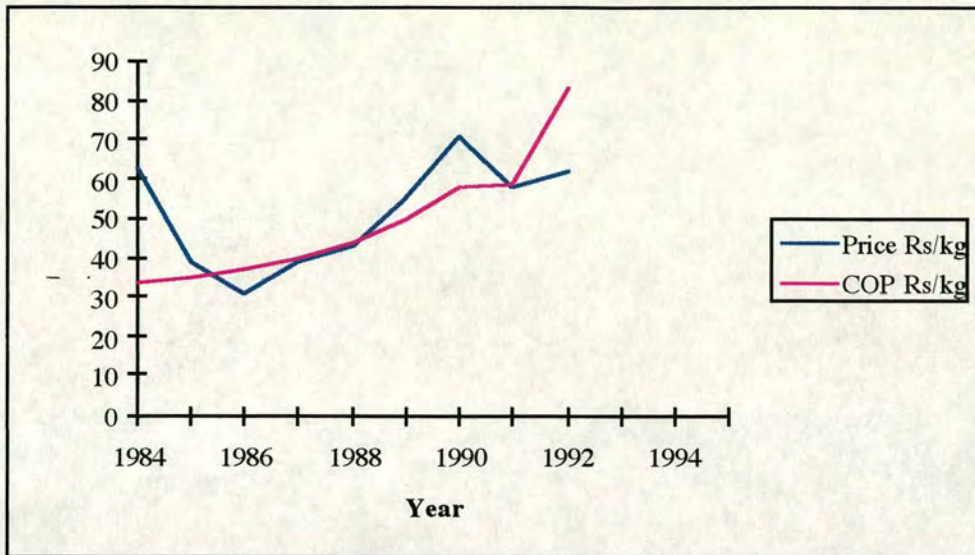


Figure 3.4: Market price and Cost of Production for tea [Central Bank of Sri Lanka, 1993]

Although the decreasing demand for Sri Lankan tea and the general decline of the world tea market are not factors that can be changed quickly, the Government's decision to give the management of the estates to private companies was intended to improve the financial state of the estates. The companies were mostly from financial backgrounds with limited experience of the tea industry. The management companies were faced with a fairly pessimistic outlook, an old industry which required substantial financial input in terms of new stock and machinery, and predictions of a continuing decrease in the price and demand for Sri Lankan tea [Economist Intelligence Unit 1993].

In 1993 and 1994 all but two of the companies operating the estates suffered high losses because:

" Private direction and control was intended to raise the productivity, improve product quality, attract private investment and reduce the burden of state corporation on the government budget with a view to eventually moving to full

diversification. In reality limited control and low rates of return have meant that companies are reluctant to risk making the much needed capital investment" [IPS [1], 1994].

Since then there has been an improvement in the running of the estates with the management companies investing with the intention of eventually acquiring an equity stake in the estates. There is an understanding of the issues and actions needed to improve productivity and make the tea industry viable in Sri Lanka.

- **Increasing Yields.** This can be achieved by intensive infilling of unplanted land, accelerated re-planting, improved land management and agronomic practices, with optimum use of fertiliser, improved equipment and diversification of production.
- **Lowering the Cost of Production.** The main components of COP for tea are given in Table 3.3. However reducing the COP for tea is a complicated task as the two largest variable components are labour and fuel costs. The union will make it difficult to reduce wages or decrease the labour force in the near future but labour productivity can be more efficiently employed and used in diversified activities. The monetary losses to the tea industry through electricity shortage have been calculated in Section 3.3. The management companies are keen to lower the cost of electricity and reduce the likelihood of power shortages. The rehabilitation of the existing micro hydropower schemes on the estates or the construction of new mini hydropower plants is seen as attractive and feasible because such plants have worked in the past and are now likely to be more reliable than the grid in satisfying local demand.

Some companies are attempting move away from manufacturing using the orthodox method and explore new but related markets. Green tea production gives an

opportunity to sell into different markets especially in other parts of Asia. Green tea involves no fermentation so a continuous supply of electricity is not as critical. Some factories are converting to CTC (Cut, Tear, Curl) production which produces a lower quality tea but is acceptable for tea bags and provides 'more cups per kilogram of tea' than the Orthodox method of production. Other plans include turning factories into hotels and attracting the tourist industry. The recent changes in CEB policy and the concerns of the government over future power generation has led to some companies considering the possibility of exploiting the water resources on the estates and constructing MHP plants on a commercial basis to sell electricity to the grid. This is discussed in Chapter 7.

3.5 Future Prospects for the use of Hydropower in the Tea Industry

While the share of Sri Lankan GNP held by the tea product continues to decline, this sector is still significant in economic and social terms. The gross income from the export of garments (textile industry) may be higher than the gross income from tea but the net income from tea is larger as tea is indigenous to Sri Lanka and does not require the same percentage of imported raw materials as the garment industry. The management companies need to make the tea industry competitive and one of the priorities is to decrease the COP of tea. This must include lowering the cost of the electricity and having reliable, independent, back-up power supplies to reduce the crop wastage that results from power outages. Diesel generators are expensive especially in outlying areas where the cost of transporting the fuel is very high. Hydro plants have the advantage that although initially expensive, once they are installed the running and fuel costs are virtually zero. In most cases the tea cropping seasons coincide with the monsoon seasons and maximum rainfall so would require maximum electricity during the times when a hydro station would be operating at its optimum capacity as illustrated in Chapter 7. Figure 3.5 shows the long term view that should be taken with regard to investing in mini hydropower.

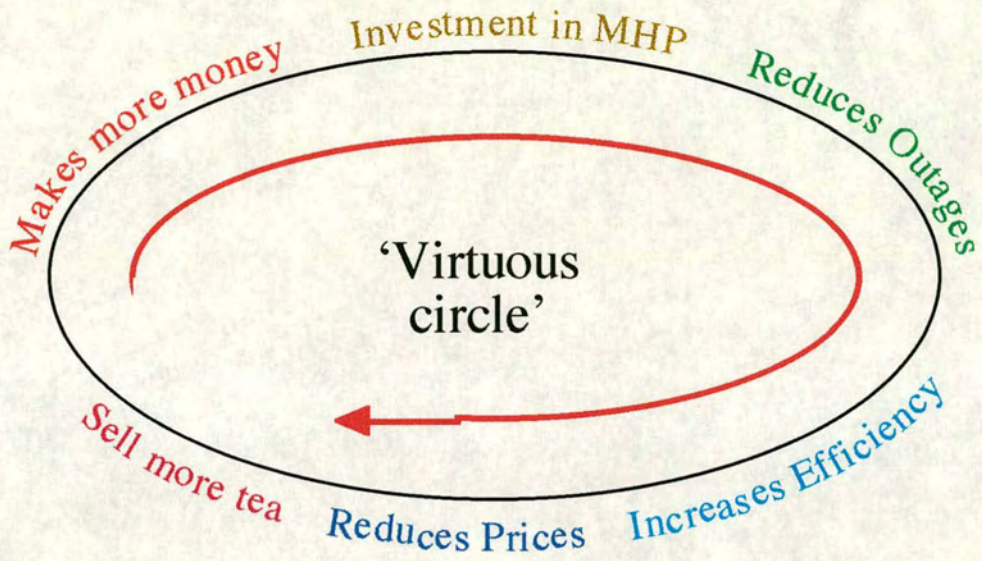


Figure 3.5: Installation of mini hydropower plants can set up a virtuous circle where the initial benefits produce surplus for re-investment.

4. MINI HYDROPOWER IN SRI LANKA

The present installed mini hydropower capacity in Sri Lanka is around 150 MW, providing about 350 GWh a year. The resource that is still available to be exploited for mini hydropower is estimated to be about 100 MW [Siyambalapitiya, 1993].

The necessary pre-requisites for the successful operation of mini hydropower plants are good hydrological and topographical conditions, an end-use for the energy produced that generates income and the financial means to construct the sites. Sri Lanka has abundant rainfall and suitable land relief, and would seem to have the demand for energy in the areas where MHP could be developed, a number of developers with access to external funds, and the organisational framework and structure to support the technical and financial requirements. The reasons why there has been comparatively little development of MHP, especially in recent years, are explored in this thesis. To set the scene, a chronological description of the MHP installations and surveys is given in Figure 4.1, and this leads to the discussion of why the development of MHP has not been as successful as would be expected.

Date	Event	Sites
1900-1959	Turbines first installed on tea estates	Gilkes and UK manufacturer
1950-1970	Arrival of Grid to sites	MHP plants abandoned
1980-1986	IT and IDRP Installations	Hapugastenne Allupolla Uda Radella Seetha Eliya
1983	Chinese Installations	Loinorn Dunsinane Labookellie Wattegodde Bogawana Kotiyagala Campion Weddemulle
1984-1985	Cansult surveys	No Installation
1986-1988	Salford/Binnie surveys	No Installation
1984-1989	GTZ Masterplan surveys	Letter of intent for 7 sites
1993-1994	GTZ Masterplan	Biwater and Sthrothert awarded construction tender
1992-present	CEB offer purchase electricity tariff and free feasibility studies for MHP plant	Dickoya Scheme grid connected and Talawakelle due to be connected

Figure 4.1: Dates of important events, installations and previous surveys from 1900-1994

4.1 Initial Installations in the Tea Estates

The first turbines were installed by the British in the early 1900's at the same time as the colony started its tea plantations [Wijeratne, 1992]. During the period 1902-1959 the tea and rubber planters installed a total of 428 mini hydropower plants, with one manufacturing company, Gilbert Gilkes and Gordon based in Kendal, England, supplying 319 turbines [Gilkes, 1987]. The original mini hydropower schemes were constructed to provide mechanical and electrical power to the estates and were an invaluable source of power. The output power was in the range of 6 kW up to 300 kW, averaging 40 kW, which met the peak demand of a typical factory at the time. Most of the sites were run of the river, or had minimum storage. The plants were typically medium head, resulting in steep and sometimes long penstocks with fairly low flowrates. The majority of the turbines at the smaller sites were Pelton or Turgo Impulse turbines. At larger sites, under the same medium heads or at lower head sites Francis turbines were installed. At some of the older sites the now obsolete Vortex turbines were installed on low heads. Table 4.1 shows the percentage of types of turbines installed by Gilbert Gilkes and Gordon during this time.

Turbine Type	Number Installed	Percentage
Pelton	136	43%
Turgo Impulse	101	32%
Francis	53	16%
Vortex	26	8%
Other	3	1%

Table 4.1: Percentage of turbine types installed by Gilkes from 1902-1959 [Gilkes, 1987]

Initially the original turbines were used to drive the factory machines using line shafts at low speeds. The replacement of mechanical shaft power from these machines by dc electric motors caused a demand for electrical energy, and many of the turbines were converted to drive dc generators and/or line shafts. In addition dc distribution systems were also used to provide lighting for the staff bungalows and factory offices. The first hydropower plants were situated in the factories so that they drove directly, or via belt systems, the line shafts to the machinery. The new plants that were installed after the demand for power had shifted from mechanical to dc electrical were located below the factory so that more hydraulic head was available. However, the cost and the losses involved in the dc transmission lines meant that the maximum distance that the powerhouse could be from the factory was typically between 800-1000 metres [Hislop, 1986]. Until about 1950 the maximum demand of a typical factory was sufficiently low for the powerhouse to be located in or near the factory, rather than moving it further below the intake of a scheme to increase the head and generate a larger amount of power.

All the electrical and mechanical machinery was imported from Britain, and the cast iron and fabricated steel for the penstocks and other parts of the civil works came from the UK or India. The weirs, channels, headrace, tanks and spillways were largely constructed using earth and rubble with the labour employed from the estates.

4.1.1 Grid connection and the tea estates

At the start of the grid connections in the 1950s and up until the 1970s, there was a surplus of generating capacity [Hislop, 1986]. The CEB and the government encouraged owners of private generating plant, such as the mini hydropower stations in the tea estates, to use grid electricity supplies. As seen in Section 4.1, the early hydropower plants supplied dc power, so the tea estates were offered government grants to subsidise the cost of purchasing transformers and thus could switch from dc to ac power. A favourable tariff scheme was also implemented that gave cheap

subsidised supplies to the tea estates and stimulated demand. The factories were changing their machinery from mechanical line shaft drives to electrically run equipment, so that the offer of cheap and reliable grid electricity caused estates to opt for grid connection rather than upgrade their mini hydropower plants. By 1970 almost all of the tea estates had become connected to the grid and over 75% of the mini hydropower plants were abandoned. A few of the estates had diesel generators but the majority were entirely dependent on the grid for their electricity. There followed a ten year period of relatively reliable electricity supplies when supply exceeded demand. However towards the end of the 1970s there was a major drought and most of the large hydropower dams were severely depleted of capacity. All of the country was subject to several hours of power cuts every day. Because they were of lower priority than city areas, the duration and frequency of the power shortages were greater in the rural areas and hence in the tea estates.

By the late 1970's the primary reason why the estates had decided to buy grid electricity in the first place, which was because it was a cheap and reliable electricity supply, was no longer valid. The tariffs increased by 300% in 1981 (from Rs 0.5/kWh all through the 1970s to Rs 1.5/kWh in 1981) along with a 150% increase in kVA charges [Hislop, 1986]. Since the demand now exceeded the supply, there were frequent interruptions to the electricity supply that caused further loss of revenue by lowering of the quality of the tea or loss of the crop as described in section 3.3.1.

In the 1970's the estates were under JEDB and SLSPC control. Estimates of the lost tea revenue from the power shortages, and the increasing tariffs, were sufficiently financially threatening to cause the two State Plantations to consider ways of improving the reliability of the electricity supply to the factories and, at the same time, lowering the cost of production. It was suggested that they should look at the possibility of rehabilitating some of the old mini hydropower plants on the estates or increasing the capacity of the operational schemes. The majority of the turbines and generators had been sold for scrap when the original hydropower plants on the

estates were abandoned but, the civil works usually remained fairly intact. Civil works account for a large proportion of the total cost of a MHP plant and there was a general feeling among the plantation managers that, where the civil works required little repair, rehabilitation of the old schemes would be relatively inexpensive. In these circumstances they believed that a number of schemes should be investigated.

There was initial interest from the government and the CEB in the potential of mini hydropower generation. The CEB constructed a pilot project at Kegalle in the early 1980s that was grid connected. It was a joint collaboration with a Tasmanian company, Tamar Designs (and support from a local company, Hydro Systems, Colombo) and the site was developed with UNDP funding. Figure 4.2 shows photographs of the scheme that consists of a 20 kW Francis turbine, of a simple design, with manual guide vanes and inlet valve. It was connected to an induction generator by a transmission belt. It had a high capital cost of Rs 105,000/kW that was compared, at the time, to the Rs 50,000/kW that was the average cost of the hydropower plants being installed under the Mahaweli Project [Hislop, 1986]. The plant had technical problems, ran sporadically for two years and is now disused. The CEB lost interest in constructing any more grid connected plants, and did not actively encourage the attempts of the SLSPC and JEDB to rehabilitate mini hydropower plants.

At this stage the CEB also stated that they would not buy any surplus electricity from a private supplier. The main reason for this was their concern that the stability of the grid would be reduced if induction generators were used [Private Communication 1, 1994]. This is further discussed in Chapter 7.

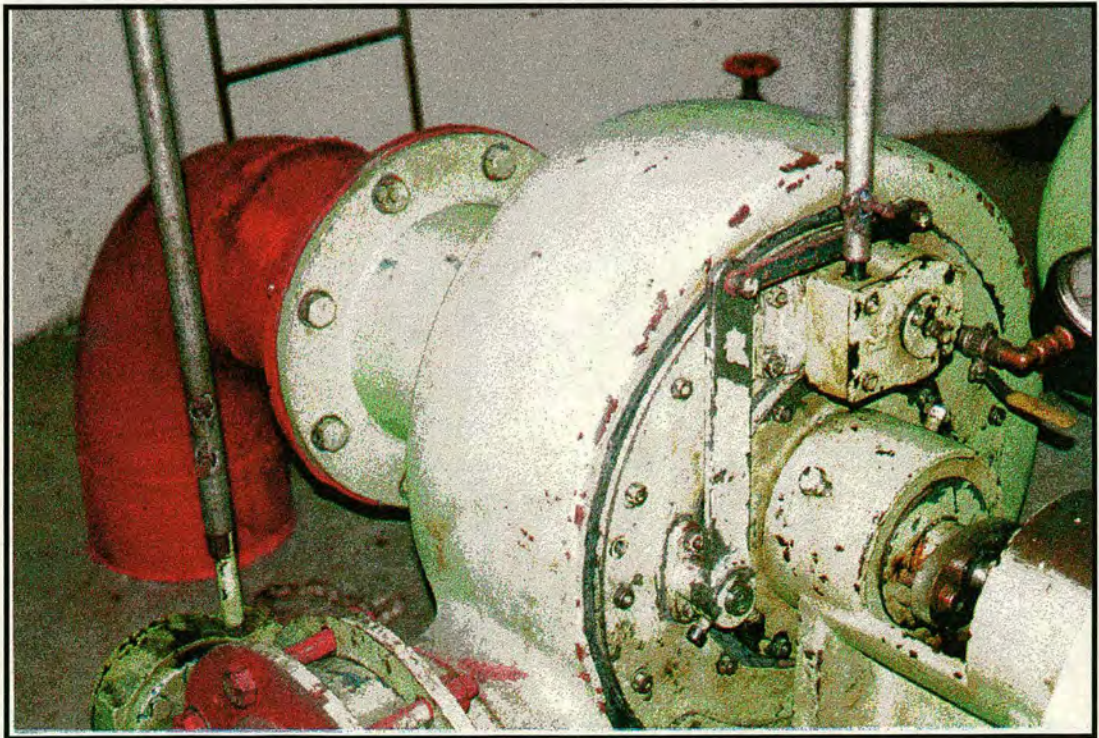


Figure 4.2: 20 kW scheme at Kegalle; powerhouse and turbine

The JEDB and SLSPC maintained strong support for rehabilitating the schemes on the estates. A power supply that could operate independently of the CEB owned grid was an advantage to the management. The estate administration had to rely on minimum funding from the government to pay for services such as electricity, and individual estates were threatened with being cut off from grid supplies [Hislop, 1986]. The estate corporations hoped that the government or private organisations would invest in the cost of rehabilitating old plants on the estates, and thus provide a reliable and independent power supply with minimum running costs. In 1983 a detailed investment programme for all tea plantations, the Medium Term Investment Plan (MTIP) which was to be funded by the Asian Development Bank and the World Bank, contained proposals to upgrade mini hydropower plants.

4.2 IT/IRDP Collaboration

At the end of the 1980s the interest in the rehabilitation of the mini hydropower schemes was rekindled. A British based charity, Intermediate Technology, sustained this interest and have made considerable progress in the development of mini and micro hydropower in Sri Lanka. Intermediate Technology (IT) was established in England in 1965 by Dr. E.F. Schumacher who believed in small sustainable technology for overseas development. They have been active in Sri Lanka since the early eighties and set up an office in Colombo in 1989. Their main areas of work are in agro-processing, to try to improve the overall capability and efficiency of small food technology, in rural manufacturing which encourages traditional trades and crafts such as blacksmith work and in energy development which is concerned with the development of alternative sources of energy, in particular those suitable for rural environments, as well as looking at ways of improving current energy usage.

IT had gained experience in Nepal and Colombia of installing micro hydropower turbines in isolated villages, and were primarily interested in electrification of rural villages in Sri Lanka. However, they saw that the tea estates could offer an

opportunity to apply and test the mini hydropower schemes that they had designed in collaboration with Evans Engineering and GP Electronics in the UK. Evans Engineering was working on vertical multi-jet Pelton turbines and GP Electronics on Electronic Load Controllers (ELC). The tea estates had existing civil works and the support of the plantation corporations for mini hydropower development so, they seemed an ideal place to try to establish a hydropower engineering market and to test the capability of their turbines. IT saw the estates as a controlled area for practice before putting turbines into the villages [Hislop, 1986]. They also hoped there would be potential social benefit to the workers in the estates, in terms of providing lighting and hot water. The ballast load in the governors was usually rings that acted as water heaters.

The first project undertaken by IT was at Hapugastenne in 1982 with a unit cost of Rs 6700/kW [IT, 1984]. The plant at the rubber factory (60 kW) was rehabilitated by fitting an ELC in place of the mechanical governor and overhauling the turbine and civil works. The main problem with the Hapugastenne estate is the geology of the site. The area of Ratnapura is prone to landslides and earth slippage, which results in the penstock shifting and silting up of the turbines. A site visit in July 1995 showed that there were stability problems with the ELC, especially when the load was light. The turbine in the rubber plant was still operational but was only producing about 30 kW compared to its rating of 60 kW. Although no turbine was installed at the rubber factory this project led to two mini hydropower plants being commissioned, one at Alupolla (125 kW) on the neighbouring estate to Hapugastenne and the other at Kataboola (60 kW). These schemes required new turbines, generators and governors. The Alupolla site also included a new diversion, penstock and civil works. Both these plants have experienced problems. Alupolla has a 125 kW Evans 4 jet vertical Pelton turbine with a large diameter pulley that drives a belt onto a vertical generator, (Figure 4.3.) It was commissioned in 1984 and in twelve years has run for less than a year [Wilkinson, 1995]. The plant at Kataboola consists of a 60 kW three jet Pelton driving a vertical generator. The main problems in both cases have been

connected with the generators and AVR's. The generators were designed for use with diesel engines with direct shaft drives. However, as diesel engines run at higher speeds than mini hydropower turbines, gearing or belt driven systems had to be used. There were problems with the belt manufacturers, and the belt that was eventually used required a much higher tension than expected which has caused problems with the bearings.

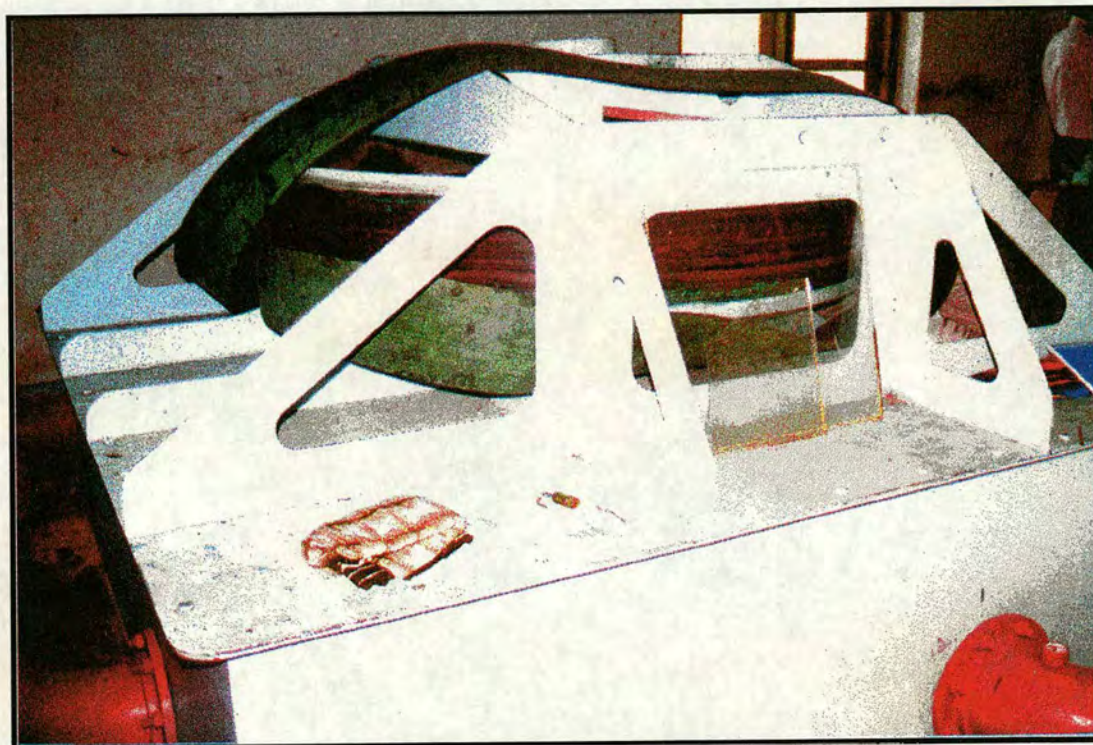


Figure 4.3: Alupolla scheme, 1995

The AVR's were also not designed for the variation in frequency and voltage that occurs with a factory load, or equipped with over and under voltage and frequency trips. This is an important consideration because if the grid fails and the factory load is low the speed rises and if there is no overspeed detection and trips are not fitted, the windings of the alternator can burn out. The ancillary electrical equipment,

including the AVR and ELC, was supplied with minimum protection specifications and met few of the normal construction standards, as specified in G59 [G59, 1991].

A collaboration between the Dutch charity, IRDP (Integrated Rural Development Programme), and IT installed two schemes in the 1980s. The function of the IRDP is to help improve the welfare of the workers, and a pre-requisite for the hydropower projects was that all profit made on the electricity savings had to be put into a welfare fund to finance estate welfare projects. This applied for the first six years, after which the estate received a proportion of the revenue. A 25 kW station at Uda Radella was rehabilitated at a unit cost of Rs 12,000/kW and the site was running satisfactorily in 1996 [Private Communication 2, 1996], although problems with the ELC have been reported. A new 60 kW site at Seetha Eliya was built at a unit cost of Rs 30,800/kW. This site is currently undergoing conversion for grid connection. A further nine sites were developed and over forty more were surveyed but were not constructed. This was due to misunderstanding and political tensions that grew between the IRDP and the estates management over the implementation of the welfare benefits and distribution of income from electricity savings [Perera & Munasinghe, 1992].

The majority of the projects that were carried out between 1975 and 1984 were UK managed with a team from Britain working in Sri Lanka during this period. The positive objectives were to:

- **Develop a technical base with knowledge of small-scale hydropower.** One of IT's aims while in Sri Lanka was to try to establish a group of local engineers capable of managing entire projects, including the hydrological surveys, site surveys and technical appraisals, turbine manufacture and assembly of other components. They experienced problems finding engineers with the technical ability, although they have appointed local staff capable of conducting

site surveys and assessing micro hydropower sites. They have trained a Sri Lankan electrical engineer to assemble the GP Electronics ELCs that are an integral part of most of IT's hydropower schemes.

- **Encourage interest in small hydropower development.** The IT section concerned with hydropower development is widely respected and has considerable influence throughout Sri Lanka. They are active in promoting mini hydropower and rural electrification by hosting conferences and meetings to encourage this. They are also partly responsible for the formation of a Hydro Forum that advises and promotes hydropower throughout the island.
- **Establish village electrification using micro hydropower.** IT's Rural Electrification Program has achieved considerable success, and by 1996 had supplied twenty villages with electricity using an IT 4 jet Pelton turbine direct driving an induction generator controlled by an Induction Generator Controller (IGC) [ITDG, 1994].

In recent years Intermediate Technology has not made much progress with rehabilitating or installing new hydropower plants in the tea estates, beyond maintaining a keen interest and an influence in developments. They have not rehabilitated or constructed any new plants in the tea estates since 1984. The reasons for this have been due, in part, to their work in the village micro hydropower schemes that has concentrated most of IT's resources and time in recent years. Other factors have been that their turbines and electrical equipment are more suited to low capacity sites (under 50 kW) and the difficulty in finding suitable engineers and tools to do the installation and carry out subsequent repairs. IT has also been disappointed in the way that very few of the foreign surveys led to the installation of successful indigenous plants, as discussed in the next section, and as a result is wary of trusting non Sri Lankan enterprises.

4.2.1 Rural village electrification

The reasons for the success that IT has had in setting up micro hydropower schemes to supply electricity to villages are worth investigating, because they shed light on the criteria for the success of micro hydropower developments in Sri Lanka, which is one of the areas investigated in this thesis.

IT's aims in Sri Lanka for micro hydropower development were twofold [Hislop, 1986]: to design, test and establish a local manufacturing source for an integrated micro hydropower generator, and to produce energy 'that would be used to increase village incomes by raising agricultural productivity'. During and after the early work in the tea estates their efforts were channelled into specific village electrification programs. Figure 4.4 shows the earliest turbine manufactured by a villager in 1980.

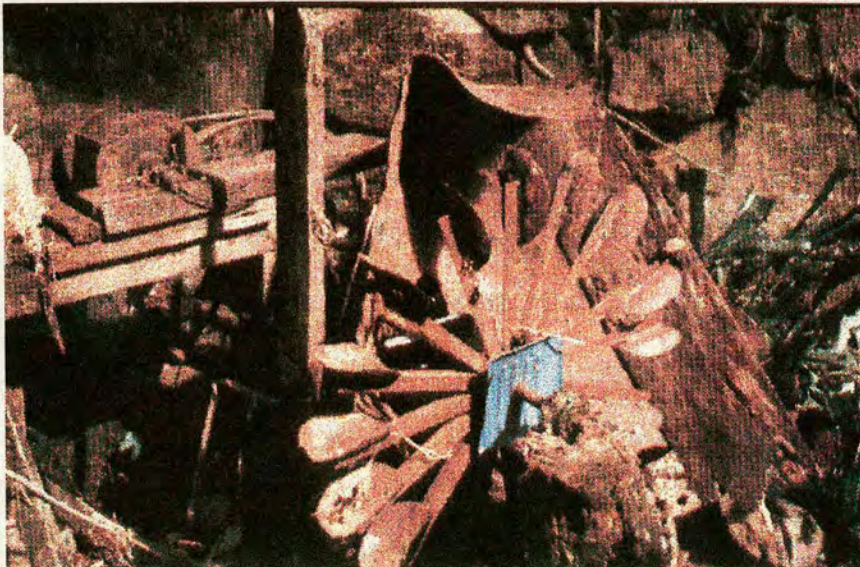


Figure 4.4: First village turbine made in Sri Lanka

This work is now dominant and successful. The best sites have been ones with a reasonable base load during the day and evening supplying both domestic and small industrial loads. IT is also concerned with the management and organisational structure of providing micro hydropower schemes in which village participation has been a major factor. The projects in the villages have been both technically and

financially successful, but involve a higher level of engineering and a different economic and organisational framework to the ones in the tea estates.

The local capacity in Sri Lanka to design, install, operate and maintain a micro hydropower site at village level is proven. The machinery is in the micro hydropower range and can be manufactured locally. The turbines are of simple design using bronze casts from molten scraps. They are typically 4 jet impulse machines, and IT has established eight manufacturers [ITDG, 1994]. The induction generators are often induction motors that are controlled by Induction Generator Controllers (IGC). Figure 4.5 shows a typical turbine and generator for a 3 kW Pelton designed for a village scheme. The civil works are designed to be installed by the villagers; the penstocks are usually PVC pipe and the channels and tanks are made from rubble and stones.



Figure 4.5: Typical IT village micro hydropower turbine and generator

The economic costs for such a scheme are high, at around 75,000 to 125,000 rupees per kW [Perera & Jayawardane 1993] as the hydropower technology is not subject to high economies of scale. They have been implemented at ‘marginalised’ communities where there is little chance of grid connection within the next 5 years. These schemes are evolved with maximum village participation and by the formation of potential

electricity consumers into an Electricity Consumers Society, which is responsible for the administration, supervision and management of the schemes. The tariff is based on an economic assessment of the village. This includes the generating capacity of the plant, the income and the living standard of the villagers, and how the benefits and costs should be divided [ITDG, 1994].

Funding for these projects has come from communities themselves (who raise 50%), from organisations in Sri Lanka such as Rotary Clubs, and from UK sources.

4.3 Other Foreign Projects and Surveys

The potential benefits of rehabilitating and constructing new MHP plants in the tea estates attracted the attention of overseas aid agencies. Figure 4.1 gives the chronological order of the surveys, and Table 4.2 and Table 4.3 list the sites, installed capacity and cost per kW of all the constructed sites and those surveyed. The costs/kW of the different schemes reflects the amount of rehabilitation or refurbishment required.

In 1983 the World Bank funded a series of rehabilitation projects in the Hatton region that were carried out by Chinese consultants, as shown in Table 4.2 [Fernando, 1990]. When they were implemented nine out of the ten projects used Chinese turbines and generators, employing primitive electronic load controllers. Lorinorn used Australian machinery. They are all run of the-river plants and are not grid connected.

The installations on these sites have not been very successful in a number of ways. The equipment has been technically inferior to the original British machinery, for example Figure 4.6 shows the generator at Labookellie that is an old diesel alternator. Problems with the AVR's have been experienced at all the sites, with components burning out and being fixed locally with inappropriate parts, or the hydro plants unable to be operated until spares were procured. At one stage none of the sites were

in operation, a situation that has caused resentment and a distrust of foreign involvement. There has been no follow-up from the Chinese in terms of technical support when the plant or components fail, nor were any spare parts provided.

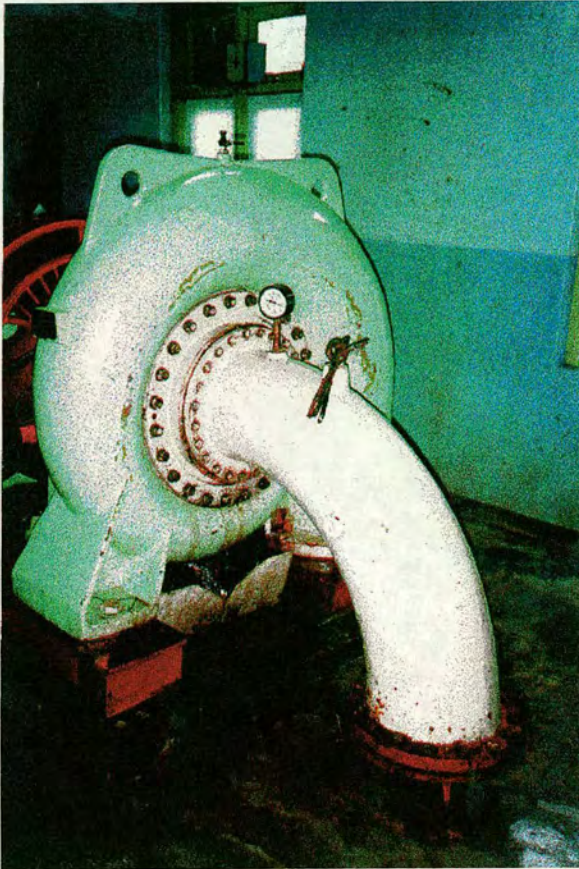


Figure 4.6: Generator at Labookellie installed by Chinese consultants

The Chinese were the only foreign consultants that actually constructed any hydropower plants in the tea estates between 1980-1995. The rest only reached the feasibility stage.

MHIP Project	Plant Capacity (kW)	Actual unit Cost (Rs/kW)
Installations		
Kegalle (New)	20	105,000
IT		
Hapugastenne	60	6,700
Alupolla	100	
Kataboola	60	13,300
IT/IRDP		
Uda Radella	25	12,000
Seetha Eliya (New)	60	30,800
Chinese		
Bogawana	115	13,000
Kotiyagala	70	33,000
Campion	40	20,250
Loinorn	125	24,800
Dunsinane	274	
Weddemulle		
Wattegodde		
Labookellie	100	

Table 4.2: Table of all installed sites between 1982 to 1986 with installed capacity and cost per kW where available

In 1984 a survey was funded by the Canadian International Development Agency (CIDA) at a cost of \$250,000. The consultants were from a Canadian company, Cansult Ltd. They looked at a total of fifty-four abandoned hydropower sites and proposed to renovate and upgrade seventeen of them. This involved rehabilitating seven independent sites, and creating five 'mini-grids' by rehabilitating ten sites and transferring the generated power to forty other sites using 13.2 kV transmission lines.

The sites are shown in Table 4.3 [Cansult, 1984]. The cost of this project was \$21.5 million with Sri Lanka to provide \$7.7 million, which made it unfeasible. Some of the technical and economic conclusions and recommendations have been questioned. The amount of revenue that would have to be raised was considered over optimistic (especially as at this point the CEB was not prepared to buy any excess). The hydrological calculations used a coefficient based on flow measurements taken during the two wettest months, October to November, of only one year and are considered too high. These individual surveys have been ignored since they are not seen as being technically robust or reliable. The full survey took nine months with a field study of two months from senior field staff. The final report did recommend training Sri Lankan engineers, but this was not included in the final cost.

In 1984 the British Overseas Development Agency (ODA) commissioned UK consultants, Binnie and partners with Salford Civil Engineering Ltd, to carry out a survey as part of an aid project to assess the feasibility of rehabilitating mini hydropower schemes on the tea estates. This was in response to the Sri Lankan government's proposal to rehabilitate 140 micro and mini hydropower plants as part of its Medium Term Investment Plan. The loan terms were that Sri Lanka was to provide matching funds to the £5.5 million coming from the British Government. The UK money was a loan at 13% interest over a 10 year repayment period. Another condition was that all the consultancy work and the electrical and mechanical equipment were to come from Britain. The consultants recommended eight sites in

the Ratnapura area (under SLSPC control) and in the Kandy/Nuwara Eliya area (JEDB control) [Salford & Binnie 1986].

The Salford survey was technically proficient, but it did not progress past the feasibility stage due to political and bureaucratic reasons within Sri Lankan organisations. In the 1980s the CEB was not encouraging the building of mini hydropower plants, arguing that the projects in the Salford Survey were not financially viable and that the funds could be used more beneficially elsewhere. However the Internal Rates of Return estimated for the Salford projects were between 8-18%, and so economically attractive despite the CEB not offering to buy surplus electricity [Salford & Binnie, 1986]. The NGOs raised objections about the dominance of the foreign component in the surveys, stating that no effort had been made to see if any of the electrical or mechanical equipment could be made locally, and that they had alienated some of the other local agencies working in the field [Perera & Munasinghe, 1992]. The whole process took over two years, from the start of the negotiations with the ODA and the Sri Lanka government to the submission of the final report by Salford and Binnie. Over this period the costs of the project had increased substantially and there were no matching funds available in Sri Lanka, so the project was never initiated. It is a good example of a communication breakdown between a donor and benefiting country. The foreign consultants were competent but the necessary groundwork was not established in terms of involving local expertise. This factor is analysed further in Section 4.5.

The Cansult and Salford studies were two major surveys and neither resulted in any installations or sites being developed. During this period there were other smaller surveys, both local and foreign, but again these did not result in any MHP schemes being built.

Project	Plant Capacity (kW)	Estimated Cost Rupees
Cansult 1984 MHP		
<i>Individual stations</i>		
Hagalla	188	45,000
Girindiella	140	59,000
Uda Radella	150	50,000
Rasagalla	300	26,000
Alupolla	390	51,000
Niriella	160	39,000
Cecilton	250	51,000
<i>Mini Grids</i>		
MG1: Nichola Oya	450	71,000
MG2: Carolina, Bin Oya	788	58,000
MG3: Fairlawn	1775	44,000
MG4: Logie, Talawakelle,	4002	41,000
MG5: Hapugastenne	1500	36,000
ODA 1984		
Hapugastenne	300	22,000
Lellopitiya	50	99,000
Cecilton	55	92,000
Delta	40	121,000
Loolecondera	80	67,000
Mooloya	65	80,000
Balangoda	120	47,000
Hope	90	60,000

Table 4.3: Table of major surveyed sites between 1982 to 1986 with installed capacity and estimated cost per kW

In 1984 an agreement was made, between the German and Sri Lankan governments, to draw up a Masterplan for the Electricity Supply of Sri Lanka. The consultants were GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit) who donated foreign labour and equipment. The survey was carried out in Sri Lanka with the CEB providing local labour and office space. The project took three years to complete from its start in April 1986. Its aim was to analyse critically the entire electricity supply system of Sri Lanka, including the transmission network, and then undertake feasibility studies on several mini hydropower projects. At the time the rehabilitation and upgrading of existing mini hydropower sites was not a direct concern of the CEB so the Masterplan did not consider these sites. The work concentrated on undeveloped sites of which sixty-two were identified with capacities between 0.5- 15 MW, with an overall total of 300 MW. Twelve of these sites were surveyed in detail [CEB & GTZ, 1989].

Nine of the hydropower plants surveyed eventually went to tender in 1994, and Biwater of the UK was awarded seven contracts and Strothert Power Corporation from Canada gained two. The installed capacity of the Biwater plants was to have been 40 MW, with the largest being in the Nuwara Eliya region with an installed capacity of 11.7 MW and the smallest in Ratnapura with 1.9 MW. They were to have been constructed under a BOT¹ contract at a cost of \$60 million or \$1500/kW [CEB, 1995]. It is reported that there have been environmental objections raised and

¹ BOO and BOT projects are schemes designed to involve the private sector, both local and foreign, in infrastructure development. BOT (Build-Own-Transfer) is when the private contractor constructs, finances and operates a project until the project costs have been recovered. After this the ownership of the facility is transferred to the particular government. BOO projects are the same but the ownership of the facility remains with the private contractor for the lifetime of the project [SIDI, 1993]

there is doubt as to whether the projects will actually be implemented [Private Communication 2, October 1996].

4.4 Recent Developments

In 1992 the continuing droughts and problems with providing a reliable stable generating system along with the commercialisation of the tea estates caused the CEB to change their attitude towards private generation and the use of mini hydropower. They started offering:

- Free feasibility studies for sites (whether rehabilitation, upgrading or greenfield sites) under 0.5 MW.
- Loans through the Peoples Bank for household wiring.
- Free technical advice.

They also started encouraging grid connection for small private generators by offering a buy in rate for the energy produced of Rs 2.6/kWh, or Rs 3/kWh if over 1 MW.

Several surveys have been carried out by the CEB but none have been implemented. This is due, in part, to a lack of available funding and the high interest rates in Sri Lanka. It is also felt that site surveying is not an integral part of an Electricity Board's remit. The CEB has set up a Pre-Electrification Unit (PEU) to deal with the technical requirements for grid connection, electrical safety and protection standards. This is a necessary role for an Electricity Board and cannot be performed by outside industry. However, feasibility studies and surveys for generating plant can be carried out by consulting companies, and should be encouraged as part of a country's hydropower industry. The role of the CEB and hydropower engineers is different and should develop as independent and supporting bodies.

Two sites have been recently constructed to take advantage of the CEB's offer to buy electricity. One entrepreneur, Mr. Abyawicksinghe, of Vidya Silpa company has built a 1 MW plant at Dickoya, shown during its construction phase in Figure 4.7 This was done using Chinese equipment and taking advantage of the Board of Investment tax relief. It is a design involving three double penstocks leading to six Turgo machines. Political contention has also affected the connection of this machine with the CEB and Mr. Abyawicksinghe engaged in a battle over its technical safety. The plant was originally required to comply with the G59 standards, but the problems with finding suitable and compatible equipment was financially impossible, so it ultimately fell below the criteria set by G59 [Lilly, 1996]. However, it was connected in 1996 and is reported to be operating satisfactorily [Private Communication 3, October 1996].



Figure 4.7: Site under construction at Dickoya, 1995

Another plant at Talawakelle is due to be connected to the grid soon. It is a four jet Pelton with a capacity of 120 kW, controlled by an ELC [Perera, 1995]. Comparisons with what has happened to the other multi-jet Peltons could be unfair, and the whole project is still waiting for permission from the CEB to supply the grid with the excess power.

The delays and problems with the recent plants have been technical and bureaucratic. The requirements of G59 have highlighted the lack of suitable technical standards for small generating plants. There have been delays in compiling a standard for grid connection. The quality of the grid is also a problem as is the state of the transmission lines that have not recently been replaced or upgraded. Bureaucratic issues have arisen due to the changing nature of power generation. The CEB has been an autonomous body in the power sector so are reluctant to give up their state monopoly and influence. This has led to some stalling on power projects with the first Purchase Power Agreement (PPA) taking over 12 months to complete, with a final agreement still being set up. The PPA will not include a 'Take or Pay' clause (i.e. the CEB do not promise to take all energy produced at the plant regardless of whether it is required at that time) but should have a price tariff structure to include a capacity charge and an energy charge [Lilly, 1996].

Surveys in the tea estates are also continuing with the companies recognising the long term savings in electricity costs. However the financial state of the companies is a serious barrier to the enthusiasm that the companies have towards MHP generation being converted into actual sites. The companies are ambivalent about their economic future in an industry that faces heavy competition and requires substantial investment. They realise the benefits of upgrading or rehabilitating their hydropower plants, but very few have the necessary capital to do this on their own.

4.5 Appraisal of Surveys and Installations to 1996

The continuing foreign and local interest in rehabilitating and building new plants in the tea estates is due to the unique factors that exist in Sri Lanka for the development of mini hydropower that are summarised below:

- **Hydrological environment.** The abundant and seasonally distributed rainfall in the wet zone of Sri Lanka has been discussed in chapter 2. The areas where the mini hydropower schemes are to be installed are not subject to prolonged dry spells. It is expected that the MHP plants would still be functional when drought is affecting the capacity of the large scale dams and reservoirs.
- **Use of power.** The electricity generated from mini hydropower plants can be used for direct consumption within the tea estates, to run the tea machinery and provide lighting and heating to the estate staff. It can be used in village electrification schemes as a source of lighting or to run small industries such as tea, rubber, cardamom drying and food processing. The power in the above two situations can be generated from stand-alone or grid connected plants. Another option that is financially attractive is to sell all or part of the electricity to the grid.
- **Organisations interested in hydropower development.** In Sri Lanka there is considerable support for the rehabilitation of existing or construction of new MHP plants. This is from small consulting and engineering companies wanting to establish a market in MHP, and from NGOs such as IT and the Janasaviya Trust interested in improving the living conditions in villages and for workers on the estates. It includes the management companies who hope to recoup electricity costs in the long term and private investors who see private electricity generation as a profitable business venture.

- **Available aid.** Aid from donor countries has been falling in recent years. However tied aid and loans linked to private sector development and environmental improvement are still available. Large scale hydropower projects have recently lost favour as being socially and environmentally flawed, but smaller scale hydropower projects have been encouraged.
- **Governmental support.** The Government and CEB are encouraging the building of MHP plants as a way to expand the available capacity and strengthen the grid in rural areas. The increasing length of the power cuts throughout the year and the pressure from the World Bank to improve the electricity system has led to a government endorsement of MHP plants.
- **Environmental initiative.** The growing global concern over fossil fuelled power stations has encouraged the building of alternative energy schemes such as mini hydropower plants.

MHP should be a successful and thriving industry in Sri Lanka and the organisations and people that would benefit directly and indirectly include:

- **Management Companies,** who would reduce the cost of production of tea by reducing electricity costs and possessing a more reliable service. Further financial gain would be from selling surplus or all electricity to the CEB.
- **Engineering and Consultancy firms.** Countries with similar MHP potential to Sri Lanka such as China and India have a thriving small hydropower industry. A similar industry in Sri Lanka would benefit employment, both in the rural areas as well as the cities, through the need for regional repair and support services.

- **The Government.** The development of MHP would benefit the government in a number of areas. The enhancement of the grid would help achieve the targeted electricity demand growth rate and assist the Rural Electrification Programme. The use of the private sector in financing and constructing such projects will encourage the development of this sector. Both these measures have been demanded by the World Bank as a prerequisite to further funding. A local industry in MHP engineering and consultancy will also boost growth and increase employment.
- **Foreign Investors** with the opportunity for either supplying equipment and expertise, by buying equity or shares in a private power generation company in Sri Lanka.
- **Domestic consumers.** These include tea estate workers and staff, who would benefit through an improved and a more reliable electricity supply.

With these advantages in terms of potential and benefit to the people, why has the amount of energy actually generated only been a small fraction of that which, according to the site surveys carried out since the late 1970's, could have been generated?

The reasons for the failure of the surveys to result in many installations are varied and complex as discussed below.

- **Communication problems.** This is particularly apparent in the foreign surveys where, as in the case of the Salford and Binnie project, the consultants alienated IT and other organisations working in the field.

- **Inappropriate technology.** Intermediate Technology acknowledged that the tea estates were a testing area for the innovative technology that they planned to use in village electrification schemes. However, it has emerged that equipment that is acceptable in terms of efficiency, reliability and safety standards in a micro hydro scheme for village domestic use may not be suitable for mini hydropower projects.
- **Lack of technical support and training.** Gilkes, during the period of their early sales in Sri Lanka, employed an agent (Colombo Commercial) who was responsible for the repair and maintenance of the plant and stocked spare parts. However, the Chinese installed machines and then left, providing no technical back up service or spare parts. The result has been a series of burnt out components that have been inadequately repaired leading to more problems. Support and training are a necessity in a country where the hydropower industry is not established and there is not the skilled engineering resources to sort out complicated faults in the electrical, mechanical or electronic equipment.
- **Inferior engineering.** The original installations of Gilbert Gilkes and Gordon machines have proved to be reliable and many are operational today. (Figure 4.8 shows a photograph of a 260 kW site at North Meddecombra Estate that was installed in 1929.) However the Chinese sites have not been reliable and an inquiry in November 1996 [Private Communication 3, 1996] revealed that only two sites were operating at all. The IT/IRDP schemes are operating sporadically but technical problems persist, resulting in considerable periods when they are not generating or are below rated capacity. Inappropriate diesel alternators were used in both instances that caused considerable loss of plant operation time. Poor electrical connections and

installations were also evident at the sites, which is potentially dangerous and has caused technical problems. It should be noted, however, that the most recent developments at Dickoya and Talawakelle are operating well, and it is hoped will continue to do so.

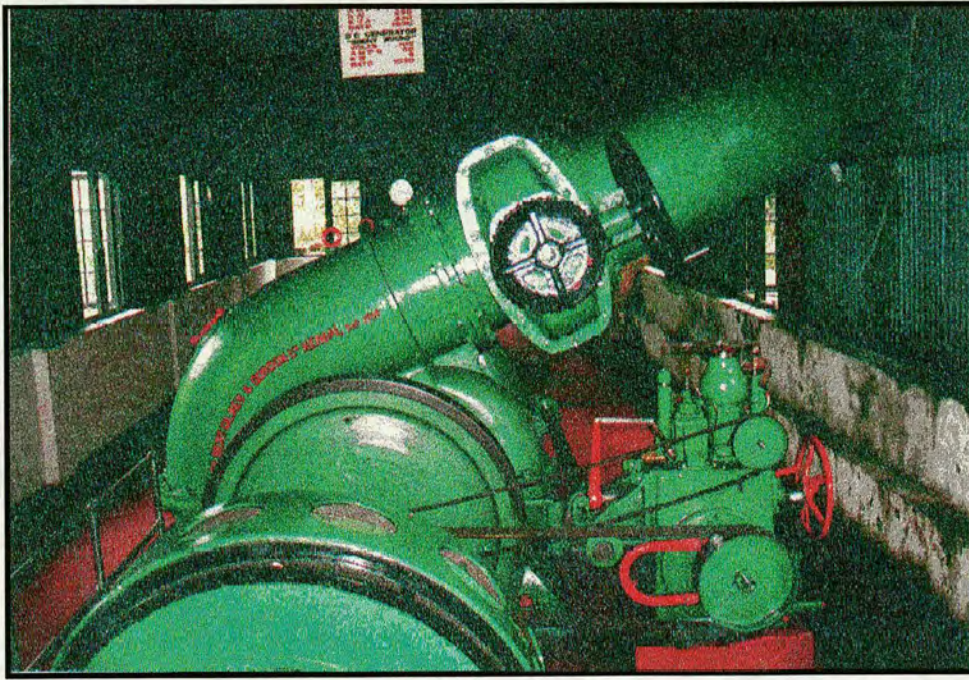


Figure 4.8: 260 kW site at North Meddecombra Estate, installed by Gilkes in 1929

- **Funding problems.** This is of major importance to any hydropower project, but is of particular influence in a developing country. The source and nature of the funding can be contentious and affect the perceived benefit of the project. The IRDP initiatives were abandoned due to differences over the use of the funds. The Salford report faced opposition from the CEB over funding allocation and the Consult study required too much in partnership funds.

- **Reliance on foreign equipment and expertise.** The lack of a hydropower industry in Sri Lanka and the reliance on foreign aid and funding led to a damaging ‘chicken and egg’ scenario. Aid funding is rarely altruistic and the donor country usually wishes to use their own engineering expertise and equipment, so that the developing country does not have the opportunity to build up their own industry. Up to a certain point this is inevitable and acceptable, but the Chinese installations and the proposals in the Salford Report caused resentment in Sri Lanka as all equipment, engineering consultancy and project management was, or was going to be, ex-patriot. Cansult also estimated that 80% of its costs would be of foreign origin.
- **Local hydropower engineering data.** It was suspected, at the time, that in the Cansult report the hydrological calculations were inaccurate but there was not the available expertise to challenge them. The recommendations from this study were never implemented but the calculations for the potential amount of power were based on a methodology that over-estimated the flow rate. The difficulty of obtaining good hydrological data is a recurring theme of this thesis (see section 6.2).
- **Politics and internal bureaucracy.** A major reason why so few surveys were implemented was due to political shenanigans and power struggles within the CEB. Their original stance of disinterest and refusing to endorse small power plants by agreeing to buy electricity meant that the surveys were financially far less attractive. This was the case with the Cansult and Salford reports. Chapter 7 discusses the economic marginality of small hydropower plants and the difference that the option to sell electricity can make to the projects' financial viability. Since the CEB was forced to accept

private power generation and has offered a purchase price for this electricity, there have been internal problems with the CEB being reluctant to relinquish their monopoly. The technical complications of connecting small plants to the grid and the writing of Power Purchase Agreements (PPAs) have caused delays. The eventual acceptance of safety standards below G59 specifications, as in the Dickoya scheme, is also a cause for concern.

4.6 Future MHP Development

This section considers the funding options that are or will be available in the future to increase the number of MHP plants in Sri Lanka

- **Private funding.** Increasing the grid purchase price will provide a further incentive to mini hydropower developers.
- **BOI investment** is another source of funding. Board of Investment (BOI) Tax incentives are various incentives offered under the BOI Act for foreign and local investors. It has been used in past schemes and could be of further benefit as the terms and conditions that allow projects BOI status could be made to favour mini hydropower and renewable energy initiatives in the future [Lilly, 1996].
- **BOT/BOO schemes.** BOO and BOT projects are schemes designed to involve the private sector, both local and foreign, in infrastructure development. BOT (Build-Own-Transfer) is when the private contractor constructs, finances and operates a project until the project costs have been recovered. After this the ownership of the facility is transferred to the particular government. BOO projects are the same but the ownership of the facility remains with the private contractor for the lifetime of the project [SIDI, 1993]. They were set up as a

method of allowing a project to raise the investment debt financing from foreign or local sources. There is no history of the success of BOO and BOT schemes in Sri Lanka and thus there is justifiable hesitation in investing in them. However, they provide a source of funding that could be utilised in the future.

- **ESD funding.** The global concerns about the environment have also encouraged the development of mini hydropower in Sri Lanka. The World Bank granted Sri Lanka an Energy Services Delivery project (ESD), which is a lending facility intended to promote small scale renewable energy [Lilly, 1996]. It aims to encourage private sector investment in power generation by channelling the lending through designated credit institutions. In Sri Lanka it has been proposed that a department is set up for the purpose of regulating, monitoring and controlling the finance. However the final allocation of the funding will be decided by the credit institutions, which will be the Development Financing Corporation of Ceylon (DFCC), the National Development Bank (NDB) and various commercial banks. The ESD has pledged US \$28 million of credit and a grant of US \$2.7 million from the Global Environment Facility (GEF²). It is proposed that two thirds of this funding will go to mini hydropower schemes, both grid-connected and stand-alone. This lending facility has arrived at an

² GEF is an United Nations initiative, which started in 1991, to provide grants and loans to developing countries for projects which would relieve the pressures on global ecosystems [Kumar, 1995]. The aims are to reduce greenhouse gas emissions, preserve biological diversity, stop water pollution, and contain the ozone layer. Mini hydro schemes meet these criteria as the use of renewable energy sources instead of conventional fossil fuel generating plants reduces the emissions that damage the ozone layer and cause global warming. Deforestation through the need of firewood as fuel also decreases with grid connected or stand alone hydro plants providing the necessary energy for cooking and heating.

opportune moment as it will provide loans at reasonable interest rates. Chapter 7 discusses the very high interest rates that have hindered the implementation of hydropower projects in the past.

There is concern [Lilly, 1996] that it is the DFCC, NDB and commercial banks that will ultimately decide what projects will be funded. There is no official hydropower body in Sri Lanka to consult about the technical merit and feasibility of proposed hydropower projects. It has also been shown in Section 4.5, and is further discussed in Chapters 7 and 8, that the success of a mini hydropower project does not depend solely on its economic and financial nature. The technical quality, design and specification should be assessed against conventional standards for reliability, ease of operation and safety, as well as recognising the local skills available, capacity of plant and circumstances in which it will operate. The criterion of understanding and learning from past problems and faults in mini hydropower projects should be met. The banks do not have the expertise to judge mini hydropower projects apart from on their economic viability. It is likely that unless projects are examined by an official technical authority the most suitable projects will not be funded.

5. SOFTWARE DESIGN - a decision support system for mini hydropower installations in Sri Lanka

5.1 Initial concept

One of the initial aims of this project was to develop a methodology, in software, to evaluate the technical and commercial potential of rehabilitating existing mini hydropower sites in Sri Lanka. The intention was that, with modification of the base information, the same software could also be applicable in other countries. The initial aim evolved into assessing the potential of new sites and examining the success and failure of previous surveys.

To evaluate the commercial potential of a hydropower site it is necessary to determine the design and then cost the turbine and generator, the civil works and the auxiliary equipment. In order to do this, data must be found for the hydrological and geographical features of the site that will determine the power and energy available. In addition, the end use of the generated energy and the value that it assumes must be established. However in developing countries measurements are frequently inaccurate and the results of previous surveys are lost or inaccessible. What is needed is a consistent and reliable method of carrying out surveys along with competent data storage handling and a dependable database. As explained in the previous chapter, the different results from a number of surveys carried out on certain sites led to a lack of credibility and trust in the results.

At the time of the field study in Sri Lanka there were various programs in use to assist with the assessment of mini hydropower schemes. They fell into the following categories:

- **Specific method:** the majority were small programs, often designed to run on programmable calculators, used to compute certain numerical

parts of a survey. For instance IT in Colombo calculated flowrate from a simple program entered into a programmable calculator.

- **IT systems:** Two packages have been written for the Intermediate Technology Development Group in the UK (see section 4.2). These programs, MICADO and MICROHYPs, were the early prototypes for micro hydropower feasibility studies, that could be used in Sri Lanka, and while innovative, need modifications and improvements to make them suitable for use in the field. For instance they were not designed for use on a laptop computer.
- **GTZ system:** This is a package capable of performing assessments on new sites. However, again it was not designed for use in the field and requires a CADMUS 9230 computer system, for which one room in the CEB offices is dedicated. This particular software works well but was written as a comprehensive package for the Master Energy Plan of Sri Lanka, so its aims are not solely to perform feasibility studies for mini hydropower.

The calculations involved in most surveys are time-consuming and fairly repetitive. If the parameters are changed even slightly (for instance the head or position of the powerhouse) many of the calculations have to be performed again. Modern developments in software, and in particular decision based support systems (DSS), that can be programmed with expert knowledge, would considerably speed up this process. There was clearly a need for a more sophisticated approach than was available at the time so, as explained in Chapter 1, the original remit for this work was to investigate if a decision based system could be written which would repeatedly and consistently assess the feasibility of rehabilitating existing micro hydropower plants on the tea plantations. This led to FOREMP (Feasibility Of REhabilitating Mini hydropower Plants) being designed and written.

The initial proposal to study the feasibility of rehabilitating or refurbishing sites was based on the fact that Gilkes have retained the manufacturing drawings for all of their turbines in Sri Lanka, and in some cases still possess patterns for castings. However, during the field study and populating of FOREMP the issue of component repair or replacement - either from the UK or in Sri Lanka - was evaluated. During this analysis the costs to refurbish some machines were calculated; for instance, new runners would still have to be cast and this was found to be a significant cost. The refurbishment costs of the machines, together with the estimates of poor economic returns from rehabilitating existing sites, made it obvious that most of the rehabilitation projects were probably not viable. This result is discussed in Chapter 7.

However, during the field study, it was realised that the original software could be developed to assess the commercial potential of new mini hydropower sites, and that this would be a valuable tool in the emerging economic and political climate for energy generation in Sri Lanka. It was therefore decided to develop the initial programme to compare the complex interaction between the technical and economic requirements for new mini hydropower projects. A knowledge based software program, the Software for the Assessment of Mini hydropower in Sri Lanka (SAM), was written over the next two years, by the author together with Dr A. R. Wallace and Dr T. Anderson. This software can run on a lap top and be taken into the field for on-site evaluation and immediate discussions with local management. The author then populated and assessed this software by examining the feasibility of developing new sites. The rehabilitation program FOREMP was incorporated as an option in SAM.

5.2 Aims and Objectives for FOREMP

The aim for the original FOREMP program was that it should be able to:

- Survey and report the condition of operational/disused micro hydropower schemes with a view to assessing the cost and economic merit of their refurbishment.
- Develop a program to work in the field that could be used and understood by an intelligent person who was not an expert in either the software or the technical, economic and organisational models behind the final output.

Therefore the first objective of FOREMP was to develop and populate the data base of a Windows-based software package containing the results of a standardised survey questionnaire that could be used as to assess the feasibility of rehabilitating disused plants.

5.2.1 Requirements from software:

In designing the software package FOREMP for this project many complex, interlocking criteria had to be satisfied. First the author had to determine the decisions that have to be made; these then imply the questions that should be asked to obtain the information needed by the knowledge base to assess the feasibility of refurbishment. The parts that make up a viable feasibility study were determined and the software was designed from these components.

The first stage in carrying out a feasibility study of refurbishing a hydropower plant requires a considerable amount of knowledge and experience, since the site-specific information required ranges from hydrology and topography, through the condition of operational or disused generating plant and civil works, to the current or projected loads in the tea factories. The heart of the software system therefore is a data base

containing such information as the security and nature of the hydrology, extent of damage to civil works, proximity of grid supplies, existing and projected electricity demand, reliability of existing supplies, purchase costs of grid electricity and condition of the plant.

To consider the feasibility of rehabilitating or refurbishing a site, the user would wish to know:

- Whether there is sufficient information or justification to merit development of that site.
- Whether the electrical and mechanical equipment needs closer examination.
- If the civil works are intact, or can be restored.
- If the site should be refurbished, should it be renewed at existing capacity, or upgraded, taking account of the site demand and prospects of energy sales out of the estate?

During a site survey the user would have to consider in detail the condition of every component of the existing scheme, such as:

- Civil works: the survey would require information about the type, material, length and condition of all sections of the civil works, including the dam (if there is one), the headpond, channels, aqueducts, spillways, penstock, anchor blocks and tailrace.
- Mechanical Equipment: the turbine and governor would need to be stripped and the condition of every component assessed.
- Electrical Equipment: the generator and switchgear require to be examined and the condition of each part assessed.

When surveying a site the surveyor would require a data-base containing a component condition assessment list linking the state of the components within the plant to costs of replacement or repair, so that a repeatable and accurate evaluation of the feasibility of refurbishment of the plant might be made. Prices for new equipment based on standard packages of turbines, generators, control and switchgear, budget price information and approximate performance details should also be available. The software should also be designed to assess how much of the plant could be manufactured (or repaired) in Sri Lanka.

5.3 Design of software

Since the beginning of computer technology there have been systems and methods designed to reduce the tedium and repetitiveness of the calculations involved in carrying out such feasibility studies. The conventional approach uses algorithmic structured programs, but this has been changing in recent years with the use of Decision-Based Support Systems (DSS), Knowledge Based Systems (KBS) and Expert Systems (ES), that adopt a heuristic approach using hierarchical objects. "Expert Systems and DSS are computer programs that give the appearance of human-like reasoning for problems requiring expertise" [Pederson,1989] and these are clearly useful in carrying out feasibility studies as envisaged above.

An earlier project by Dr Teresa Anderson [Anderson, 1993] had developed such decision support software for a project in Nepal. This program, MICADO, was written using an expert system software product, Crystal, which is not user friendly and was unsuitable for the present purpose. In Nepal the program was used to evaluate mainly hydrological and mechanical data at sawmills and flour mills; it was not used for a commercial venture since Nepal is too sparsely populated to offer the possibilities that exist in Sri Lanka where the electricity generated by a local mini hydropower plant can be supplied to the national grid.

Following this earlier experience, it was decided that the software should be written using KAPPA™, an object oriented program, which was considered to be the best product on the market in 1993 when this work was started. In the first year, the author started work on the shell, and a financial input from the DTI enabled a research assistant (Dr Anderson) to continue developing the shell and interface while the author collected data in Sri Lanka. On her return the model was constructed by analysing the data and putting it onto Excel spreadsheets that were interfaced with KAPPA™.

5.3.1 Knowledge based system

The Knowledge Based Software (KBS) was written in the KAPPA™ development system in the KAL™ programming language. It was developed on a 486 Personal Computer (PC), to operate in a Windows environment, and to be robust and portable as a 'run-time' version on a notebook PC. KAPPA™ contains three interlocking knowledge structures:

- **Knowledge Base:** this consists of the rules, functions and information unique to the particular use of the system;
- **Inference Engine :** this controls the assessment and decision process by solving the rules and equations;
- **User Interface :** this allows the user to insert data from the site object records, classifies and stores all the survey details, processes the output and displays the results and any graphical interpretations.

In this project the User Interface and the Knowledge Base of KAPPA™ were used. Excel spreadsheets were incorporated and acted as an Inference Engine. The spreadsheets were constructed to contain:

- Technical detail of plants from previous surveys and questionnaires.

- Technical detail and costs of replacement machinery and components.
- Historical hydrological data for the catchment areas containing the tea estates.
- Load usage and pattern at the tea estates.
- Performance details and costs of turbines, generators, governors, and valves.
- Design and specification detail for new civil works, switchgear and transmission equipment.
- Local costs and rates for materials and services.
- Local costs for proprietary and retail hardware.
- Commercial details of the purchase/sale of energy, inflation, interest rates and other financial indicators.

Chapter 6 details how this information was collected and the methodology used in constructing the spreadsheets. Chapter 7 gives selected examples of the survey data obtained by the author and a discussion of these results and conclusions.

5.3.2 KAPPA™

The extent of the manufacturing information, engineering experience and commercial knowledge which had to be embodied in the software for mini hydropower surveys demanded the use of an object oriented programming structure which allowed software objects to be created to represent parts and features of the mini hydropower schemes with pre-defined characteristics and behaviour. Specific items of equipment, civil works, or features of the schemes are represented as classes in the object structure. Parts of the equipment or finer detail are represented as sub-classes. Each sub-class in the object structure has another dimension attached to it known as the

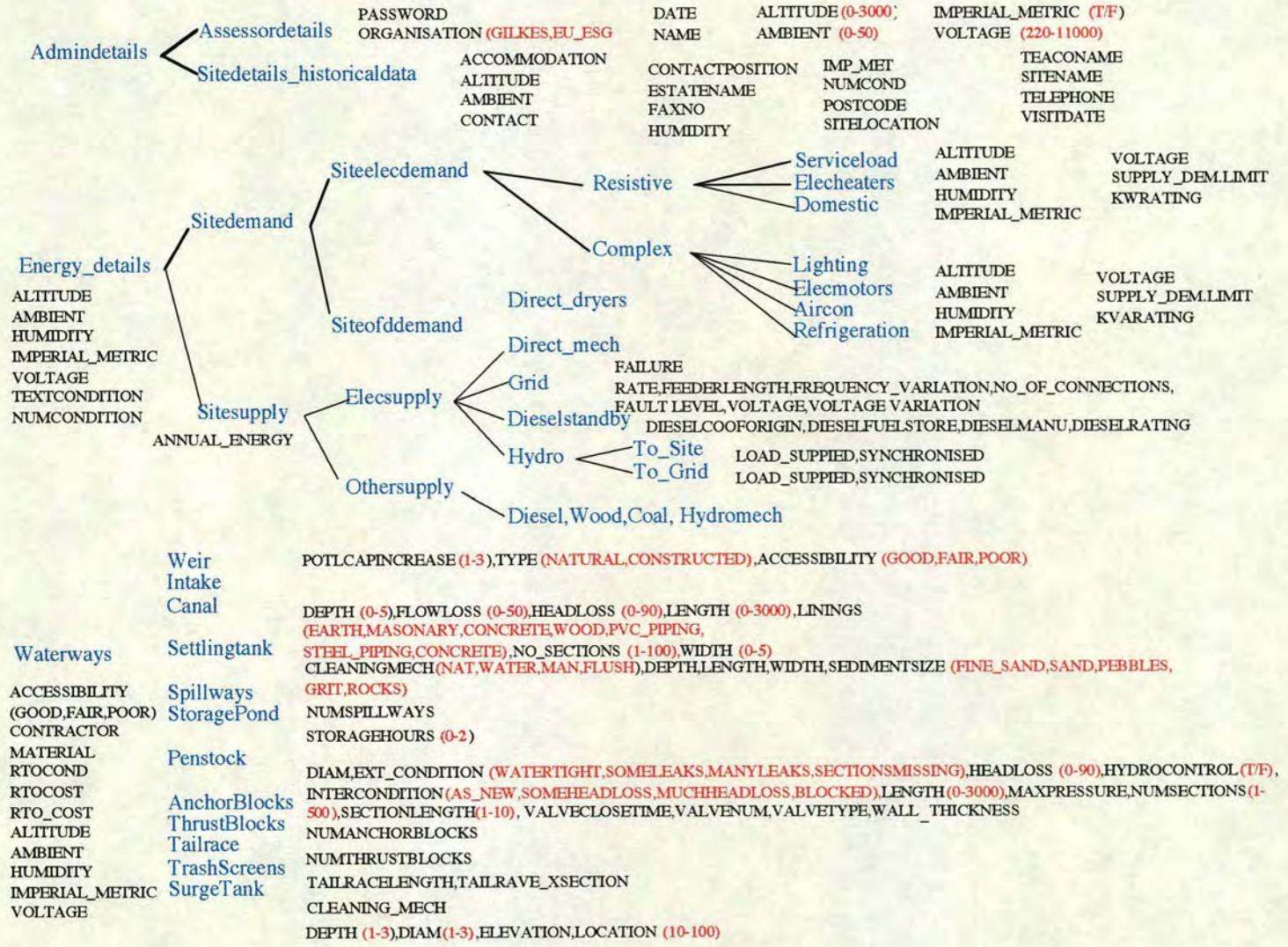
slot structure consisting of a set of data slots. Each slot is programmed with permitted types and values so that it may hold only data that is of the correct type, relevant to the class concerned. Information can only be entered or calculated in the process of a survey as a property of one of the objects in the object structure. The user is therefore constrained to enter data of the correct type, within the value range for the particular slot. A detailed description of the design process used to program KAPPA™ for administration, energy details and civil works is shown in Figure 5.1, with the classes (in black), sub-classes (in blue) and data slots (in red).

The information is then used to assess the needs of the specific site and assess the cost and hence feasibility of refurbishment using the equations in the software.

The survey process requires the user to enter core information relating to the proposed site. As the system is specific to Sri Lanka, a considerable proportion of the data is subject to fluctuation (for example in regard to the overseas prices that are subject to exchange rate fluctuation, and electricity tariffs and local costs that are subject to inflation). This kind of data is accessed through Excel spreadsheets and passed to KAPPA™ using Dynamic Data Exchange (DDE), with some of the numerical computation taking place in Excel. Logical assessments and decision processing take place in KAPPA™. Raw survey and feasibility study information may be stored in KAL files for retrieval into KAPPA™. The final survey reports are produced as Excel spreadsheets and can be printed.

All of the information is accessed by the user through a custom-designed WINDOWS™ based interface with drop-down menus and sub-menus. Most program control and data entry is by mouse-selection. Keyboard input is heavily type-trapped for spurious input and value-trapped for out-of-range errors.

Figure 5.1: The design process used in programming KAPPA for administration, energy details and civil works showing the classes, sub-classes and data slots.



5.3.3 Use of KAPPA in FOREMP

When carrying out a refurbishment survey the user can select the part of equipment to be considered and enter relevant data through a series of data entry windows. For example, if considering the deflector assembly for a Pelton or Turgo Impulse turbine then “Turbine” would be selected from the “Electromechanical Equipment” menu-bar, “Stationary Assembly” from “Turbine”, and then “Deflector Assembly” as shown diagrammatically in Figure 5.2.

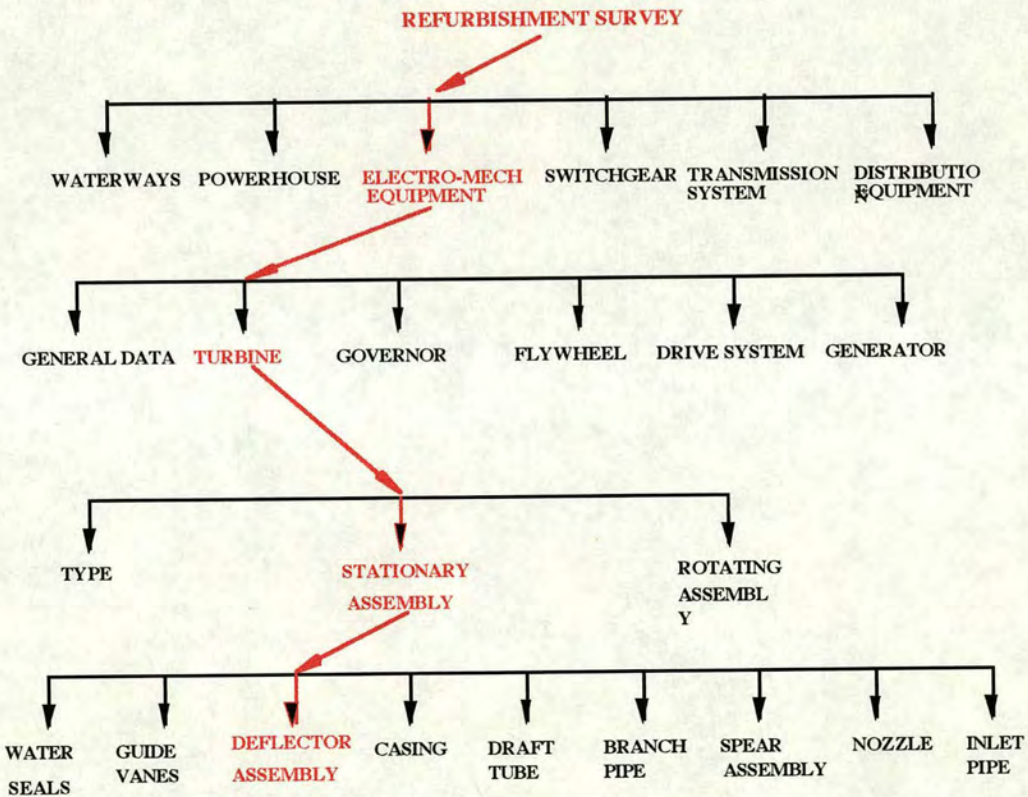
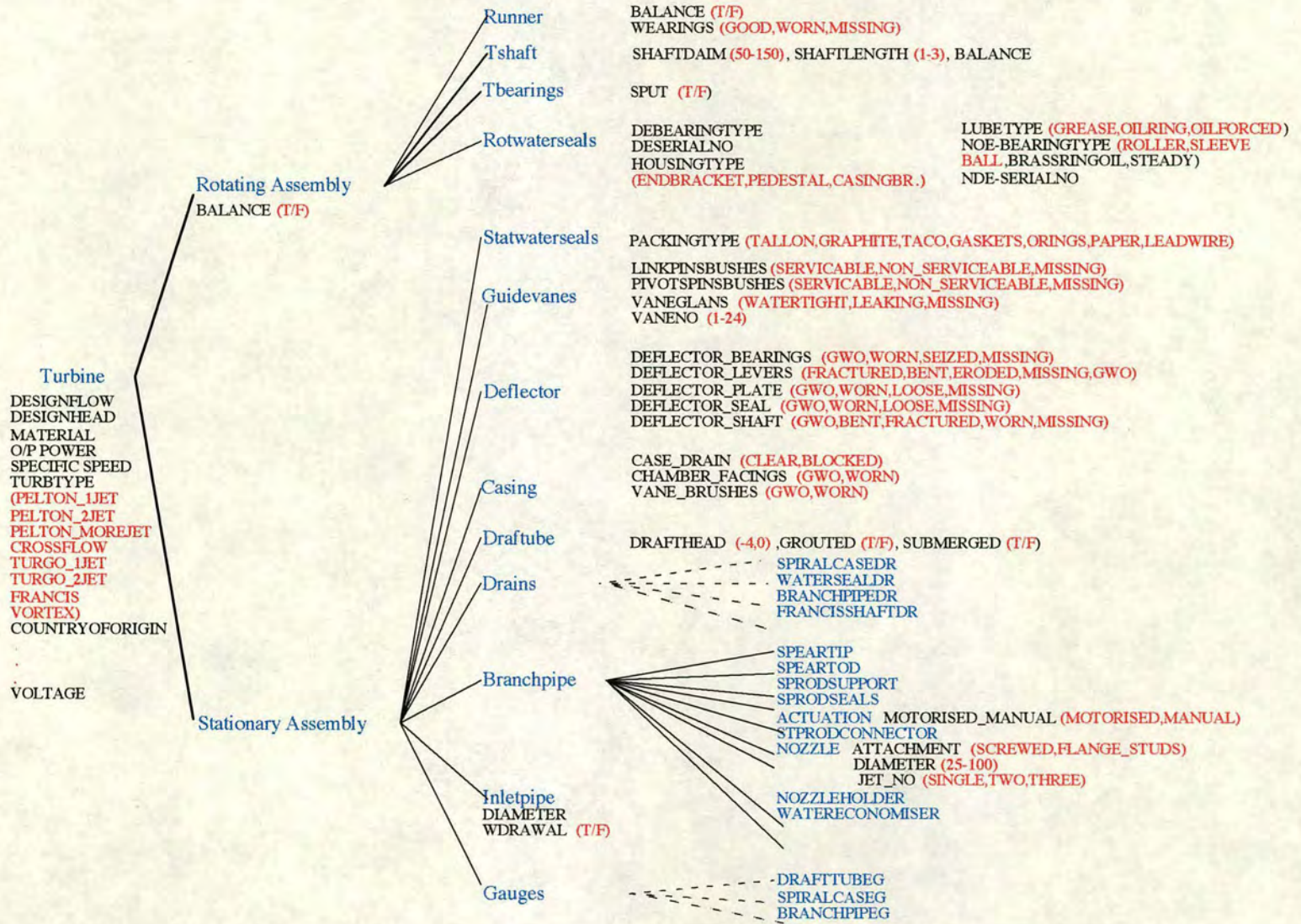


Figure 5.2: Elements of refurbishment survey

A more detailed analysis of the design process for the rehabilitation of a turbine is shown in Figure 5.3.

Figure 5.3: Detailed design for the rehabilitation of a turbine



Having reached the area of FOREMP that describes the deflector assembly all of the wearing, sealing, or enclosing components are listed. The condition of each of these components is shown as a data entry window, wherein the condition, as found on site, can be selected by mouse operation, as shown in Figure 5.4. Extent of wear, or leakage is selected from discrete levels. Where the condition may be described numerically or as a percentage, this input is made via Windows slider-bars.

Data Entry Form

Next Page
Turbine: Data Entry Form 2 for Stationary Assembly.

Deflector Bearings: General Condition <input type="radio"/> GWD <input type="radio"/> Worn <input type="radio"/> Seized <input type="radio"/> Missing <input checked="" type="radio"/> Not_Assigned	Deflector Seal: General Condition <input type="radio"/> GWD <input type="radio"/> Leaking <input type="radio"/> Missing <input checked="" type="radio"/> Not_Assigned	Casing: Chamber Facings <input type="radio"/> GWD <input type="radio"/> Worn
Deflector Levers: General Condition <input type="radio"/> Fractured <input type="radio"/> Bent <input type="radio"/> Eroded <input type="radio"/> Missing <input type="radio"/> GWD <input checked="" type="radio"/> Not_Assigned	Deflector Shaft: General Condition <input type="radio"/> GWD <input type="radio"/> Bent <input type="radio"/> Fractured <input type="radio"/> Worn <input type="radio"/> Missing <input checked="" type="radio"/> Not_Assigned	Casing: Condition of Case Drain <input type="radio"/> Clear <input type="radio"/> Blocked
Deflector Plate: General Condition <input type="radio"/> GWD <input type="radio"/> Worn <input type="radio"/> Loose <input type="radio"/> Missing <input checked="" type="radio"/> Not_Assigned	Casing: General Condition <input type="radio"/> Watertight <input type="radio"/> Leaking <input type="radio"/> Corroded_Internal <input type="radio"/> Corroded_external	Casing: Condition of Vane Bushes <input type="radio"/> GWD <input type="radio"/> Worn

Figure 5.4: Screen output for deflector assembly

The costs of repair of this component are calculated as a percentage of replacement costs and allocated to another slot “Cost of Repair” also recognising the viability of repair. Overall repair costs are calculated by summing the costs of each sub-component to the slot of the main-component one level above in the hierarchy. The above example is for one sub-component of the deflector mechanism, but there are paths offering equally detailed scrutiny of other assemblies and components, amounting to around 2000 objects.

5.4 SAM

5.4.1 Objectives and Organisation for SAM:

The objectives for SAM were to investigate and report on the feasibility of refurbishing existing schemes (incorporating FOREMP) or installing new schemes with the capacity to supply present estate demands, provide electrical power for local consumption on the estate, and export excess energy to the grid.

It has been shown in the previous sections that the amount of knowledge and expertise required for a detailed technical and economic feasibility study is considerable. The information regarding local costs and rates, as well as the cost of the foreign component in terms of the exchange rate and duties is required. These, together with data on the end uses for the power generated, are gathered and stored prior to the field assessment.

Once the information is entered then SAM can

- design, select and cost the plant;
- compute revenue;
- evaluate technically and economically a number of alternative scenarios.

SAM gives rapid, repeatable and consistent predictions and recommendations even when used by different surveyors.

The software performs two tasks:

- 1) It surveys and reports the condition of operational and disused schemes with the eventual aim of assessing the financial cost and economic merit of their refurbishment (FOREMP).

- 2) It investigates and reports on the feasibility of installing new schemes where the capacity is optimised to supply present estate demands, to provide electrical power for local consumption to the estate, and to export the excess capacity to the grid.

Over the first three years of the project the original program was expanded and the equations describing the technical, economic and managerial options were programmed into the system. It was a requirement of the software that all data that could vary as economic conditions or energy patterns changed could be easily modified and the schemes re-appraised. This allows the assessor to test the outcome of different influences on the viability of the site being considered. Macros, programmed in the spreadsheets, were written to produce economic and sensitivity graphs and data on the output screens.

The specification for a new plant includes data on the gross head, net head, design flow, exceedance flow, output power, intake length, tank length, channel length, penstock length, road length, transmission line length, turbine type, generators, factory load and duration. This and other site information is entered into the decision support software in the course of a survey. There are many local variables and site-specific issues that have a significant impact on the economic viability of mini hydropower plants. Among those which must be considered are: annual hydrology, capital costs and plant specification, daily and seasonal load patterns, plant reliability and availability, interest and exchange rates, purchase and sale tariffs.

5.5 Data Input into SAM

5.5.1 Initial screen input

The assessor must initially deal with the administrative information; the name, location, owner and management company of the tea estate are registered and then the

user decides if a logging of the components of a disused site is required (the FOREMP option) or if an assessment of a new site is needed.

5.5.2 Hydrology input

Site hydrology must be assessed before further design or costing can take place. Gross head is entered, based either on route survey or from site maps. The software incorporates three methods to establish the flow rate. The first and second alternative methods of flow estimation make use of either the rainfall or runoff figures measured at gauging stations. The third takes direct input of flow if this is known.

These methods are explained in Chapter 6. The “Rainfall Method” is standard, using rainfall data, surface area and an accepted runoff coefficient between 0.4 and 0.7 [IOH, 1982]. The user enters average rainfall for each month. If the rainfall figures are not available the “Ratio of Areas” technique is selected. The average of 50 years of flow data at each of fourteen gauging stations in the tea plantation areas have been installed in SAM. The assessor selects which gauging station lies in the same catchment as the site being surveyed, and provides the area of the catchment for the proposed scheme. The runoff from which the scheme can draw is estimated from the gauged site and the ratio of catchment areas. In each of the two methods, the monthly flows are converted into exceedance curves, from which the gross flow can be selected, based on an adjustable exceedance. The third option is to enter a flowrate for the river directly. For all three options SAM subtracts an adjustable compensation flow that can be changed by the user, but has a default of 10%.

5.5.3 Technical input

The design specifications of the turbine, generator, governor, and the dimensions of the powerhouse are all calculated by SAM, based on the head and flow determined above, and are described in Chapter 6. The dimensions of certain components of the

civil works must be entered; the length of the channels, road, transmission lines and penstock

5.5.4 Factory load and electricity consumption

In order to determine the factory energy requirements it is necessary to know its electricity consumption. The revenue from the scheme depends on the energy of tea production that were described in Chapter 3. Calculations for the base revenue and economic viability of the proposed mini hydropower plant are heavily influenced by the energy usage in the tea factory. Where the maximum load, its duration and minimum load are known, an hourly load pattern is assembled. Otherwise, average hourly loads may be calculated from annual electricity bills.

The Surveyor may either give the load pattern of the factory in terms of kilowatts consumed, broken down into hours or by giving the monthly bill details.

5.5.5 Economic and financial inputs

Since one of the aims of this project was to create and evaluate a model that could be used on site and was tailored to the specific situation in Sri Lanka, the software had to be populated so that, in the future, different scenarios could be entered whilst an engineer was in the field or collaborating with managers and economists in the office. The intention was that when the program was in commercial use, all the required data would be collected from a single site visit, entered on a laptop computer, and by changing various parameters a technical and economic feasibility study could be carried out.

Parametric and empirical cost modelling are used to estimate the cost of the civil works. Local costs are allocated to the control and switchgear, and transmission lines. SAM determines the overall scheme capital costs, and operating and maintenance costs. The capital costs of the plant are estimated in sterling and rupees

and include the costs of the intake, tank, penstock, road, line, power house, turbine, generator, switchgear and control gear.

Depending on the daily load pattern and the power being produced by the mini hydropower plant, the factory will either export or import power to or from the grid. The power produced by the hydropower plant also varies with seasonal flow. Annual revenue is calculated from the hourly factory load pattern and annual flow pattern, to accumulate avoided purchase costs and sell-out income. Net income is determined having paid interest charges, returned capital and funded operation and maintenance.

The prevailing commercial conditions are held in the decision support software and are applied to the assessment of economic viability using figures for the interest rates, cost fraction, buy in and sell-off tariffs, discount rate, exchange rates, labour inflation, and energy cost inflation. Default figures are held, as collected by the author during her field trips in Sri Lanka, but can be changed as required.

5.6 Analyses and Output from SAM

SAM allows the user to rapidly perform feasibility studies of different schemes that may be ranked in order of viability for the allocation of funds. Economically marginal schemes may be investigated to establish the sensitivity factors, and the effects of changes that could improve financial viability may be tested. The user is able to re-configure individual schemes and assess the impact on economic viability. It is also possible to assess how robust an acceptable scheme is to hydrological, technical and commercial change. This sensitivity analysis enables the user to make a judgement of the risks attached to the project and the profit involved.

The software allows labour and energy rates to be inflated at different annual percentages. Interest charges are adjustable, since it is possible that the imported and

indigenous portions of the overall cost will attract different interest rates. Future costs are collapsed to present values at adjustable discount rates.

SAM gives a technical and economic analysis, shown in Figure 5.5 and Figure 5.6. The technical analysis gives the design specification of the turbine, generator and governor and the measurements for the civil works. It also gives the design flow, the gross and net head and the resulting power output.

The economic analysis gives the costs for the civil works, electrical and mechanical equipment and the cost per kW. This is produced in rupees and pounds sterling. The economic indicators are the Payback period, Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit to Cost ratio (B/C); these are all calculated and displayed (see Chapter 6 for explanation of the economic theory deployed in calculating these indicators). All these methods of appraising the capital investment are important because they give different indications of the profitability of the scheme. The most direct assessment of the merit of an individual project is the payback period, the length of time it takes for the discounted cash flow to return the project account to credit. However, this does not allow comparison of the relative merits of alternative projects. Benefit/cost ratios and internal rates of return allow the comparison of economic performance of alternative projects, but do not take account of the respective sums of money involved. A low capacity site with modest investment could offer the same payback, IRR and B/C as a high capacity site, but the investment in the large site would be considerably greater. The increased revenue over the lifetime of the project would, however, show the larger project to have a much higher NPV.

A report can be produced which gives the technical and economic analyses, in more detail, and also gives the expected cash flow for twenty years.

REPORT SCREEN

Site Details		Design Details			
Site :	<input type="text" value="Test"/>	Gross Head (m)	<input type="text" value="110"/>	Comp Flow (l/s)	<input type="text" value="90"/>
Tea Company :	<input type="text" value="Frogston"/>	Design Head (m)	<input type="text" value="100"/>	Des Flow (l/s)	<input type="text" value="918"/>
Contact :	<input type="text" value="Wallace"/>	Exceedance (%)	<input type="text" value="40"/>	Availability (%)	<input type="text" value="90"/>
Date :	<input type="text" value="4/21/95"/>	Des Power (kW)	<input type="text" value="751"/>		
Assessment by :	<input type="text" value="REW"/>				

Outline Specification		Load Details	
	Lengths (m)	Max Load (kW)	<input type="text" value="150"/>
Diveraion	<input type="text" value="5"/>	Duration (hrs)	<input type="text" value="6"/>
Settling Tank	<input type="text" value="3"/>	Min Load (kW)	<input type="text" value="50"/>
Channel	<input type="text" value="200"/>	Duration (hrs)	<input type="text" value="18"/>
Penstock	<input type="text" value="300"/>		
Line	<input type="text" value="200"/>	Bill Total (Rs)	<input type="text" value="0.00"/>
Road	<input type="text" value="100"/>	Calc Load (kW)	<input type="text" value="0.00"/>
Penstock diam	<input type="text" value="0.64"/>		
Phase Length	<input type="text" value="6000"/>		
Phase Breadth	<input type="text" value="4000"/>		

Selected Equipment	
Turbine	<input type="text" value="T1 2 16.5/1000"/>
Generator	<input type="text" value="1000 kW/1000"/>
Governor	<input type="text" value="PGG 200"/>

Figure 5.5: Typical reporting screen for the technical analysis

REPORT SCREEN

Capital Costs		Commercial Details	
	Rupees	Pounds	
Civil Costs	<input type="text" value="45849617"/>	<input type="text" value="636800"/>	Interest Rate
EM Costs	<input type="text" value="5665978"/>	<input type="text" value="78694"/>	<input type="text" value="10"/>
Total Costs	<input type="text" value="51515595"/>	<input type="text" value="715494"/>	Discount
Cost per kW	<input type="text" value="68621"/>	<input type="text" value="953"/>	<input type="text" value="10"/>
			Purchase Tariff
			<input type="text" value="3.80"/>
			Sell Tariff
			<input type="text" value="2.8"/>
			Inflation (Sales)
			<input type="text" value="5"/>
			Inflation (Labour)
			<input type="text" value="4"/>
			Payback
			<input type="text" value="7"/>
			NPV (over 25 years)
			<input type="text" value="1,336,055"/>
			IRR
			<input type="text" value="23"/>
			Benefit/Cost
			<input type="text" value="2.22"/>
			Exchange Rate
			<input type="text" value="72.00"/>

Annual Costs	
Operating Costs	<input type="text" value="450000"/>
Maint Costs	<input type="text" value="515156"/>
Total costs	<input type="text" value="965156"/>

Figure 5.6: Typical reporting screen for the economic analysis

5.7 Hardware

The ideal equipment to run SAM is on a 486 (or 386) IBM- compatible laptop computer. It can have a monochrome or colour graphics board and must have at least 2 MB of RAM with a hard disk of 1.3 MB of available memory. The choice of a laptop was deliberate because this enables surveys to be carried out on site that was seen as an important benefit of the program.

The software needed to run SAM is

- Kappa PC Runtime version 2.0 or higher
- Microsoft Windows version 3.0 or higher
- MS-DOS Version 3.0 or higher
- Microsoft Excel version 3.0 or higher

5.8 User Interface

The user interface was developed as part of the Kappa shell. This is the part of the program that the end user is working with, so it must be user friendly and suitable for a technician or engineer in the field. Hence the specifications were that the user should:

- Find it clear to use:
- Be able to see how changes in input affect output
- Be able to step through a survey looking at different scenarios for the hydrology, civil works, etc. and see how this effects the output.

This approach is seen in the pictures of the typical screens shown in Section 5.6.

The lay-out was designed so that the final calculated data is displayed on three screens with a two page print out summarising:

- Hydrology
- Technical details
- Cost benefit analysis
- Nett present value

6. MODELS, METHODOLOGY AND DATA COLLECTION

The first field study took place from June 1993 to September 1994 and supplied the information and data that were used to design and write a software program for use in Sri Lanka. The end product has been described in Chapter 5; this chapter will first describe how the variables and information required by the software were collected, then explain the methods and equations that were used and why certain approaches were taken.

The project started by writing a KBS to model the rehabilitation of the hydropower sites in Sri Lanka but, for reasons discussed in Chapter 7, this was subsequently incorporated into a model that could examine green field sites. The standard equations used in hydropower surveys had to be adapted for use by “an intelligent being who may not be an expert in all the technical, economic and financial fields” [Pederson, 1989]. The methodology used in the surveys had to be compatible with the equipment and data that is available in Sri Lanka and there had to be a trade off between high accuracy and results that are acceptable given the local conditions. The technical and economic outcomes produced from the model were analysed and tested in the field, so that the final package can be used to survey any mini hydropower site in Sri Lanka.

As explained in Chapter 5 the information required for the software falls into three categories: hydrological data and information, technical knowledge regarding the hydropower sites and an understanding of the manufacturing capability, market potential and specific financial indicators for the economic database. The structure for obtaining information and understanding for the feasibility study is shown in Figure 6.1.

As seen from Figure 6.1 the amount of information needed to populate the data base, and the experience on which the validity of the software could be judged, required a technical understanding of mini hydropower and understanding of the economic factors involved. To obtain the information also required an understanding of the culture of the country and an ability to communicate with CEB and government officials, managers of the tea plantations, university lecturers, local labourers, craftsmen, suppliers, and NGO's.

This chapter describes the questionnaires that were devised to obtain the site data and the methods of collecting the other relevant data used to populate the database. It then looks at the calculations and analysis used in SAM. It considers how the robustness and reliability of the predictions depends on the data available, since lack of information occasionally limits the calculations that can be performed.

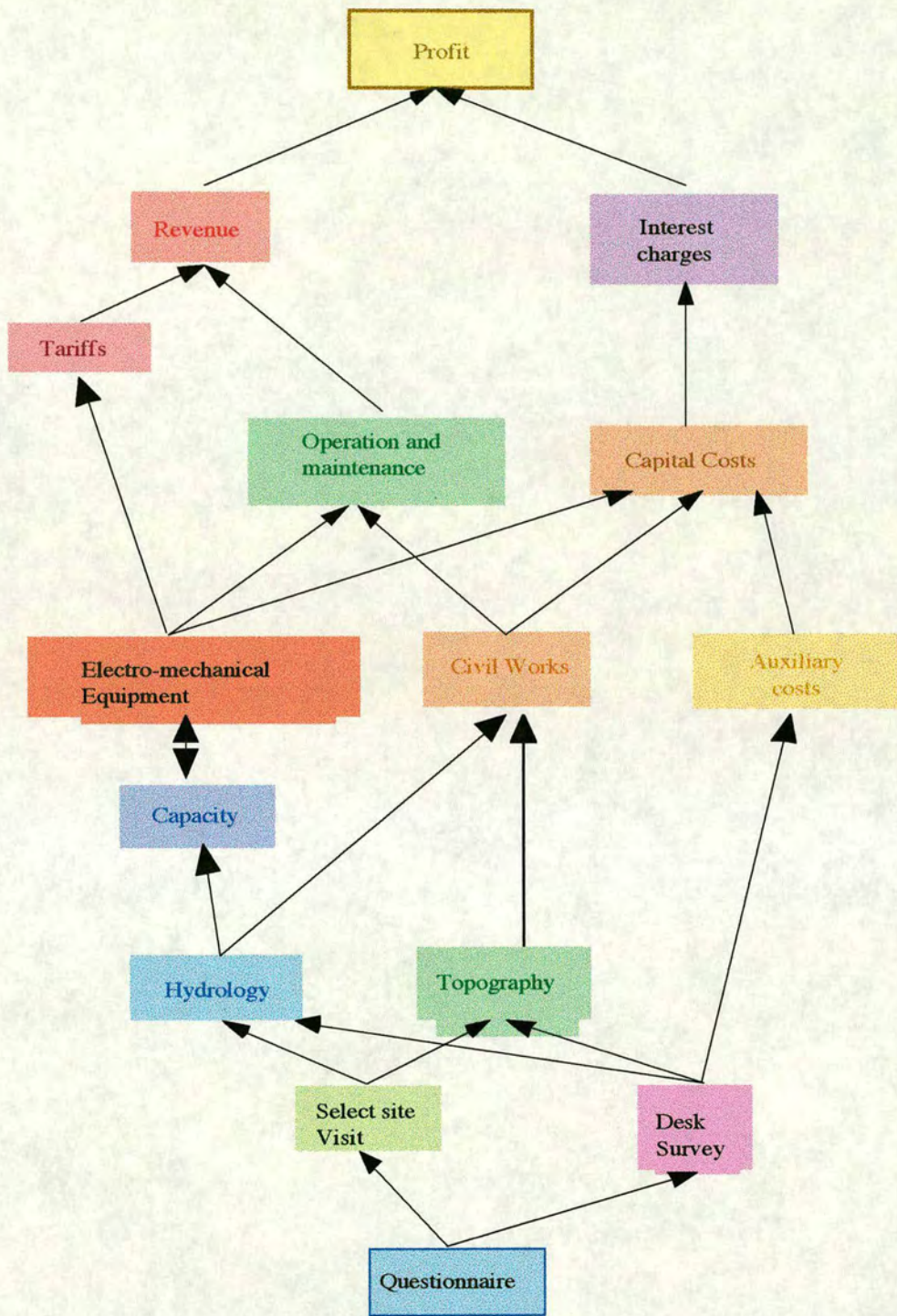


Figure 6.1: Structure for obtaining information for the feasibility study

6.1 Estate Data Collection

An important aim in the software design specification was that it should store data relating to all sites that had existing mini hydropower schemes or had the potential for such schemes. This would allow any interested party to see what had been surveyed and where investment in mini hydropower schemes was feasible.

The data for the decision support software had to be collected by the researcher in the field. Due to the problems with the land infra-structure and also lack of recorded data and statistics in developing countries, the program would not have been viable if designed and built in the UK without a field study. The relevant data had to be collected in Sri Lanka. Most of the data was collected during the author's stay in Sri Lanka from July 1993 to September 1994. Gilbert Gilkes and Gordon provided technical information and also the support of a site engineer, Mr. J. Mattinson, for two weeks in August 1994 to assist with the second evaluation of the machinery on certain sites (described in Chapter 7) and a preliminary trial of the program. A further visit of the author with Mr. J. Mattinson and Dr. A. R. Wallace in July 1995 evaluated the program and checked the technical data on six of the most promising sites.

The first step in populating the data base was to enter all the initial data for the micro hydropower sites that had been installed on the tea estates since 1900 (as described in Chapter 2). This was done by constructing Excel spreadsheets and manually inserting the data from documents and information obtained from the Ceylon Electricity Board and the Intermediate Technology Group in Colombo. The sheets were part of a database that was sub divided into sheets relating to each of the 22 management companies who owned the estates.

The spreadsheet was designed to capture the following information:

- Administrative details of the estates where any mini hydropower schemes existed, including what company owned the estate, the manager of the estate, map reference and nearest railway station.
- Technical information relating to the current state of any existing mini hydropower scheme. This was not a detailed evaluation, but stated what parts of the civil works and the electrical and mechanical equipment still remained, how long the factory had been grid connected and how much power was supplied by MHP.
- Hydrological details of the nearest river, and if rainfall readings were available from the factory..

Then an initial questionnaire was devised and sent to the owners or owner's representatives of the main tea estates. A typical reply to this questionnaire, from the manager of Kotagala Plantations, owned by the George Steuarts management company, is given in Figure 6.2. From the elementary and at times sparse information obtained from the replies, thirty to forty tea plantations were selected for site visits.

The decision on which sub set of sites to visit was made by consulting previous reports, talking to the CEB, IT, and also the management companies that now own the tea estates. Due to economic pressures the tea companies are keen to utilise any hydropower resource and were extremely helpful and supportive.

The criteria applied to distinguish suitable sites were:

- That a map of the area could be procured.

- That the management was interested in the project and prepared to make technical and economic data available.
- That there was sufficient rainfall in the area to run a power system for 7-8 months of the year.
- That the sites should give representative coverage through the tea country, for instance picking ones in the high, mid and low country, factories with a large output of made tea and factories with a smaller output.

QUESTIONNAIRE

**GILBERT, GILKES AND GORDON
ENERGY SYSTEMS GROUP
DTI COLLABORATION**

**MINI HYDRO REHABILITATION ON TEA ESTATES
IN SRI LANKA**

If you think that rehabilitation or installation of a mini hydro power site could improve your cost of production (COP). Please fill in this short questionnaire.

1. NAME OF ESTATE:

8 Estates of Kotagala Plantations Ltd

2. LOCATION OF ESTATE:

In the Kotagala/Patana area (between Hatton and Talawkelle)

3. NAME OF OWNER/OWNER'S REPRESENTATIVE:

Kotagala Plantations Ltd., Ellakande, Horana

4. CONTACT DETAILS FOR OWNER/OWNER'S REPRESENTATIVE:

Kenneth Cosgreve, KPL sub-office, Stonycliff Estate, Kotagala

*Tel: 052-8301 (home)
0512-353 (office)*

5. SIZE OF ESTATE (ACRES):

8 Estates totalling approx. 2250 Hectares (5700 acres)

6. CROP PRODUCED: (i.e Tea, Rubber, Cardamon, Citronella, etc.)

Tea

7. PRESENT SOURCE OF ENERGY: (i.e diesel, hydro, grid, etc)

Grid

8 ESTIMATES FRACTION OF C.O.P.SPENT ON ENERGY

8% (approx)

9. IS THERE A WORKING MINI HYDRO SCHEME ON THE ESTATE?

(YES or NO)

No;

10 IS THERE A DISUSED MINI HYDRO SCHEME ON THE ESTATE?

*Yes- 4 of them have Gilkes machines: Mayfield Estate, Rosita Estate and Craigie Lea.
The others have resevoirs, old water channels etc.*

**11. IN YOUR OPINION COULD A MINI HYDRO SCHEME POTENTIALLY IMPROVE
YOUR C.O.P.? (YES, NO or DON'T KNOW)**

Yes- definitely so

**12. CAN WE CONTACT YOU REGARDING THE REHABILITATION OR
INSTALLATION OF MINI HYDRO?**

Yes, Please do

Figure 6.2: Questionnaire to tea estates

6.1.1 Site survey visits

A comprehensive survey questionnaire was then devised which could be taken to each site. The author used the questionnaire as a template to enable data to be collected on:

- the hydrological factors including rainfall for the last 5 years, where the rainfall measurements were taken from, where the streams and rivers were situated, available head and a general picture of the rainfall patterns obtained by talking to the factory staff;
- the technical information by making an assessment of the present state of the mechanical and electrical equipment and civil works;
- crop production, electricity consumption, factory machine usage and overall costs.

As seen from the example given in Appendix 1, not all the data was collected on one site visit. Some information was put straight into tables and other sources were used to obtain as full a picture as possible, for example grid references for the site of the factory, hydropower plant and intake were found from maps of the area. Factors that influenced the decision to use hydropower, such as power outages affecting production, were also noted as these are important for future implementation of the hydropower sites.

6.1.2 Site surveys

It should be noted that an assessment of an existing site is complex and time-consuming as a thorough assessment of each component is necessary, from the brushes on the generator to the anchor blocks supporting the penstock. The question of how to fabricate worn or lost parts, or to import new ones, must be determined. If an upgrading is considered possible, either from new hydrological studies or optimum

designing of the plant, then the parts of the existing site and equipment that can still be used must also be assessed.

The site visits took considerable organisation and time since the roads are not in a good condition and transport is slow, so two days travelling was needed to reach the tea estates that are situated in the hill country, about 150 kilometres from Colombo. Once on an estate one or two days were spent looking at any machinery and collecting the data concerning rainfall, crop production, electricity consumption, etc. This again could be slow as the tools were generally old and rusty- on one infamous estate three spanners and a labourer's nose were broken- an estate where the author will not be forgotten in a hurry!. The data was usually taken in manual form and transferred to the computer in Colombo. Some of the figures in Chapter 7 show the typical sets of data that were collected from the tea estates. These figures formed the basis for selection of sites for a second site visit with Mr. Mattinson, the senior engineer from Gilbert Gilkes and Gordon. This visit enabled more accurate measurements of the flow of water and a more thorough assessment of the state of the machinery.

6.1.3 Final site surveys

After the program was completed and tested on existing sites in Scotland a final visit to six selected sites was made to check the validity of the output from the program. The project was evaluated by discussing the predictions and recommendations with the managers of the tea factories. However, once the analysis using SAM had been made the final sites were selected on the basis of management interest, probability of finance becoming available and the resolution of any likely problems such as land rights, water for the drinking supply or affect of a hydropower scheme on a tourist attraction such as a waterfall.

6.1.4 Methodology for obtaining data

A synopsis of the methodology for acquiring data to populate SAM and to gain the experience necessary to evaluate mini hydropower projects and so assess the use and place of SAM in these deliberations is shown in Figure 6.3.

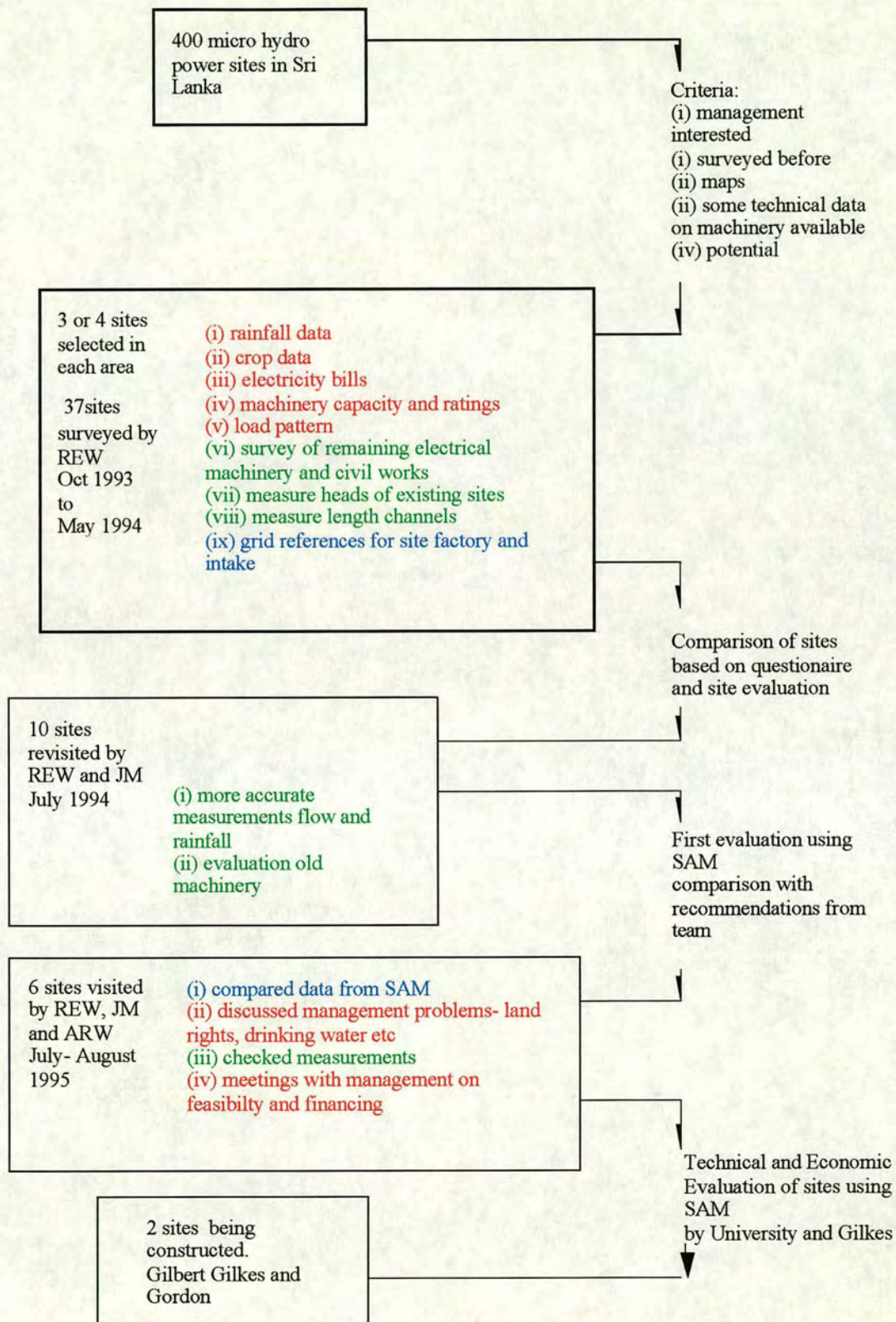


Figure 6.3: Data collection

6.2 Hydrological Data Collection

An accurate assessment of the hydrological characteristics of a catchment area is necessary to calculate the flow in the feeding stream and hence the hydropower potential of a particular site. In the case of plant rehabilitation an estimation of the river's flowrate must be re-determined, as rainfall variations and climatic changes may have affected the flow rate of the stream, from that at the time of the original installation. The design and hence cost of the electrical and mechanical equipment and the civil works will depend on the head and flow of the water at the site. However, the method of determining the hydrological parameters is dependent on the available resources and information, and in Sri Lanka this is limited.

In the hydrological investigation of the catchment areas of the tea estates, the following had to be determined:

- Climate, soil, geological and geographical characteristics of the tea plantations.
- Maps of the areas where the tea estates are situated and corresponding catchment areas.
- The rainfall, runoff, evapotranspiration and flow rate for the gauged rivers in these areas.
- The accuracy and reliability of such data.
- Methods used previously in Sri Lanka to calculate the flow rate of small rivers and streams.

The information was gathered from many sources: Government bodies, CEB, IT, from visiting the estates and reading previous feasibility reports. In particular, hydrological data is collected by the Government departments listed below, but no overall responsibility is taken by a single division:

- Meteorological Office: rainfall data including rainfall intensity
- Irrigation Department: stream flow, evaporation
- Agriculture Department.: evaporation data
- Water Resources Board: hydrogeological data
- Water Supply and Drainage: hydrogeological data.

6.2.1 Geographical data and terrain

Chapter 2 discusses the geographical characteristics of the tea estates. The surveys gathered data regarding the altitude, gradient, estimated level of silt and how prone the land was to landslides and slippage.

6.2.2 Catchment areas

The catchment areas can be measured from ordnance survey maps, with an example given in Figure 6.4. It is worth noting that due to the tight security because of the military conflict in the country it is fairly difficult to get these maps. They are only available from the governmental Surveying Department, and requests for maps must be accompanied by authorisation from official departments

While in Sri Lanka contact was also made with FORLUMP (Forestry and Land Use Mapping Project, funded by the ODA and GTZ) who use the Environmental program ARCVIEW that contains a section called GRID. It has a set of digitised maps of the hill country and can automatically compute the catchment area of a given stream. A further development of this project would be to combine this package with SAM.



Figure 6.4: Example of a catchment area for the Kotagala plantations

6.2.3 Rainfall data

Rainfall data has been collected for over a century and, for certain rivers, flow data is available for the last fifty years. The rainfall data is collected throughout the country, from around forty automatic rain gauges (situated on the major rivers) and at five hundred manual gauges scattered around the island. There has been some query about the precision of certain data from the ordinary gauges, but if the data is collected for a long enough period the accuracy should prove adequate. The rainfall data can be bought from the Meteorological Office and until 1974 it was produced in the Meteorological Office Annual Report. However this report has not been published since 1975.

Most tea factories have a rainfall gauge where rainfall is measured on a daily basis and records are usually available for the last ten years. However, the gauges are not necessarily within the catchment area of the hydropower plant, and there can be some doubt as to the accuracy of this data since the gauges are read manually and problems occur with spillage, readings that are missed due to holidays and illness, and other errors due to human mistakes.

6.2.4 Evaporation data

Other data of possible interest to this survey was evaporation data, available from the thirty-five pan-evaporation stations. Evaporation is estimated because elements such as radiation cannot be measured. The potential evapotranspiration is recorded using 'class A' pans (susceptible to operator errors, dirty water, exposure, etc.). The evaporation is then analysed using Penman's method [Penman 1948]. Statistics concerning the geology, soil characteristics and Base Flow Index [Beran and Gustard 1971] are harder to obtain as few surveys have been carried out, although some information is available from the Agriculture Department and the Land Uses Section in the Irrigation Department. However the amount of information available was not considered sufficient to use it as part of the software calculations.

6.2.5 Runoff

The runoff coefficient is the proportion of the total rainfall in a catchment area that is discharged into the stream of that catchment. It depends upon existing soil moisture content, the permeability of the soil, the evapotranspiration from the surrounding vegetation and the amount of rainfall retained in surface flow. All these parameters are very difficult to estimate.

A survey by Wallingford Hydrology [IOH, 1982] in 1982 estimated the runoff for the island. To date this is the only reliable estimate of runoff in Sri Lanka. The areas where the tea plantations are situated have runoff coefficients of between 0.6 and 0.7 except in the Ratnapura area where the runoff coefficient is around 0.45.

At the time of the survey into the Accelerated Mahaweli Ganga Programme (1987) (see Section 2.6.3) the UNDP attempted to determine the runoff of the Mahaweli Ganga at 11 gauged sites on this river, using 50 year flow data. When interpreting these values it should be noted that there are gaps in some of the data and several of the high flood values were estimated rather than actually metered. However, the UNDP produced monthly rainfall/runoff relationships and runoff coefficients for a 50 year period, 1907-56. They also produced ISO-Yield maps that give the runoff in acre feet/square mile. Local opinion was that they were not very accurate. The author did not have the time or the resources by which to measure runoff, so it was decided that the figures produced by the Institute of Hydrology were the most reliable.

6.2.6 Flow rates

Data concerning stream flow are available for 75 gauging stations (covering 40 of the 103 river basins in Sri Lanka) shown in Figure 2.2. Certain bureaucratic difficulties were encountered in obtaining data for flow rates as well as for evaporation and evapotranspiration that is supposed to be available from the Irrigation Department. Some of the data is published but flow rate data pertaining to particular rivers had to

be purchased and also permission granted from the relevant minister, which took considerable time.

6.3 Economic and Financial Data Collection

6.3.1 Capital and equipment costs

When carrying out a feasibility study for a green field site or refurbishing an existing site the capital costs are probably the largest component costs, and are also the most visible costs. These include the cost of the civil works, electrical and mechanical machinery as well as other auxiliary costs involved with the network. The cost of these items depends on the hydrological and geological conditions at the particular site, the trade-off between the highest quality of materials available and the materials that are acceptable for the project in hand, as well as the specifications for the machinery.

In the U.K. prices for components of mini hydropower schemes are readily available, and the whole system can be sourced from within the U.K. or Europe, but in Sri Lanka there is not the infra-structure to do this. Equipment that has to be imported can be costed fairly easily, but providers of indigenous materials and manufacture have no experience on which to quote. However, because most sources of matching funds specify a local input, such costs are crucial for the database of the model and so figures had to be found. There was a short term and a long term solution to this problem. The first involved an element of judgement and using an average figure from a number of quotations eventually collected by persistent cajoling of suppliers by the researcher. The longer term answer is considered in chapter 8 and depends on employing a local representative, cogniscent with the local conditions and economy who is responsible for keeping the information up to date and eventually building up a reliable market list.

The costings that were incorporated into SAM included:

1. Electrical and Mechanical equipment

Costs for the turbine, generator, governor, switchgear and transformers were collected in Sri Lanka by first drawing up a list of all possible companies. This was done by checking the telephone directory, talking to the CEB and IT and through personal contacts. Once the list was produced the companies were faxed, telephoned and then visited, as it was important to verify that both parties understood the requirements and were capable of producing the equipment. One interesting point to note in the collection of prices in Sri Lanka was that using a male Sri Lankan name in the faxes produced a much quicker and cheaper quote!

Prices were also collected from Europe and India for comparison.

2. Civil Works

Costs for the main components in the civil works, the penstock and power house, were collected in the same manner as for the electrical and mechanical equipment. Arriving at prices for the cement and building materials were harder as there was not a list of certified stockists and most places selling these materials were just stalls. Discussions with CEB and IT arrived at figures that were used in SAM.

6.3.2 Other costs

Labour costs, land costs, operation and maintenance costs and engineering and consultancy costs had to be found. This involved discussions with the CEB, IT, the estate owners and the management companies themselves.

6.3.3 Financial indicators

Exchange rates, inflation rates and tariff structure were collected through the CEB, banks and the management companies. Examples of the tariff structures obtained from the CEB are given in Chapter 7.

6.4 Methodology used in SAM

Once the extent of input data available is known and a representative amount collected and analysed it was possible to produce the equations needed for SAM, as explained in Sections 6.5 to 6.9.

6.5 Hydrological Methodology

Since the data for the flow rate and subsequent calculation of the flow duration curve (FDC) are crucial in the design of a mini hydropower plant, it is important to be aware of the source of the data and have an understanding of the errors that may arise. If flow data for five or more years is available at the site then the peak and minimum flows are easily calculated, as is the mean annual flow duration curve. Anomalous years are easier to identify and the risk of assessing the site for a particularly wet or dry year is reduced.

In the tea estates in Sri Lanka, in common with most mini hydropower sites worldwide, the streams and rivers to be used are mostly ungauged with no flow data available. There are various ways to estimate the flow of an ungauged stream, from using rating curves (but again at least 2 years data must be known), or scaling known gauged rivers [IOH, 1982]. Bearing in mind that SAM is a program for feasibility studies, that more stringent hydrological calculations would be required if the MHP scheme was implemented, and that the input data was limited and also needed to be accessible and easily collected, two methods of estimating flow were included in SAM using rainfall data and gauged river flowrates.

(i) **Rainfall runoff calculations**

Rainfall data is available at most of the tea factories, although these are not necessarily in the stream's catchment area and, as explained earlier, are prone to operator inaccuracies. The collected rainfall data are point observations and hence must be converted into real figures. The most basic method, to achieve this, is to take the arithmetic mean of all gauged stations within the catchment area, although in practice this turns out to agree with the readings from the tea factory. The rainfall readings from the previous 5 or 10 years, if available, are converted into monthly averages. As discussed in Section 5.5.2 and Section 6.2.5 the runoff coefficient can be altered but is set to 0.4 or 0.7 in SAM.

The rainfall is converted into an estimated flowrate in m³/sec per month by using the following equation [Fitz, 1984]

$$\text{Flowrate} = \frac{R * RO * A}{1000 * 31 * 24 * 3600} \quad \frac{m^3}{sec} \quad \text{Equation 6.1}$$

where

R: Rainfall in mm per month

RO: Runoff Coefficient

A: Catchment area in m²

The flowrates are then sorted in ascending order to produce a flow duration curve as shown in Figure 6.5.

(ii) **Ratio of catchment area calculations**

In the Ratio of Catchment Areas method flow data from a gauged site (within whose catchment area the ungauged stream is situated) can be multiplied by the ratio of the catchment area of the ungauged site to the catchment area of the gauged site to obtain

data for the ungauged site. This method is suitable for use in the conditions in Sri Lanka as much of the land in the hill area is topographically similar. However, a problem that arises is that any errors in the measurements from the gauged sites are directly transferred to the estimations for the new site.

The flowrate is estimated by using the flowrates of gauged rivers within whose catchment area the proposed mini hydropower schemes are situated. A list of the gauged rivers that were used is shown in Table 6.1. These rivers are the ones in the tea plantation areas of Sri Lanka. The flowrate of the ungauged stream can then be calculated:

$$\text{Flowrate (UG)} = \frac{\text{Flowrate (G)} * \text{Area (UG)}}{\text{Area (G)}} \quad \text{Equation 6.2}$$

where Flowrate(G) and Flowrate(UG) are the flowrate in m^3/sec of the gauged stream and ungauged stream respectively and Area(G) m^2 and Area(UG) m^2 are the catchment areas of the gauged and ungauged streams respectively. The flowrates are then sorted to produce a flow duration curve as shown in Figure 6.5.

(iii) *Direct entry of flow*

A third method was included in the program as a checking mechanism. If a flow meter was available then it would be useful to do spot checks on the gauged or ungauged stream and the reading could be entered directly.

6.5.1 Comparison of results

In order to estimate the likely errors in the hydrological data the FDC was calculated using both the Standard Rainfall Technique and the Ratio of Areas method for a stream at Mahaweli in the Delta Estate, Figure 6.5. It is seen that the data from the two methods agreed well.

No	Gauged river	Station	Area (m ²)	Runoff Coeff	Map Ref
1	Kotmale Oya	Talawakelle	297	0.5735	065625N 803945E
2	Hulu Ganga	Teldeniya	160	0.4886	071740N 804600E
3	Mahaweli Ganga	Watawela	65	0.6041	065650N 803210E
4	Uma Oya	Welimada	179	0.4294	065415N 805430E
5	Kotmale Oya	Morape	555	0.7071	073040N 803720E
6	Mahaweli Ganga	Bawwagama	169	0.6196	070255N 803155E
7	Kalu Ganga	Wellewela	194	0.6007	073625N 805000E
8	Loggal Oya	Migahakiula	196	0.5066	070930N 810335E
9	Agra Oya	Holbrook	121	0.5548	065250N 80410E
10	Galmal Oya	Moragahamulla	73	0.329	071657N 804826E
11	Maha Oya	Hanguranketa	103	0.3788	071130N 804545E
12	Heen Ganga	Uduwelwela	115	0.5506	072830N 805515E
13	Badulu Oya	Kandaketiya	387	0.3881	071030N 810020E
14	Uma Oya	Talawakanda	52	0.3674	070030N 805825E

Table 6.1 List of gauged rivers used in surveys

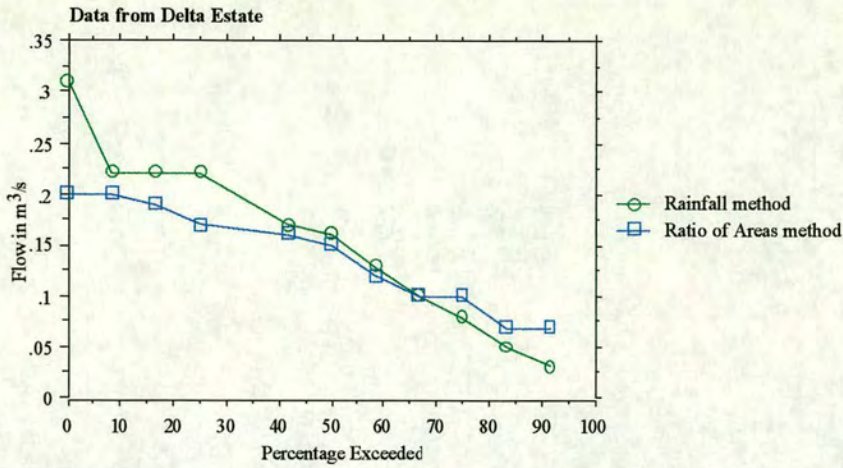
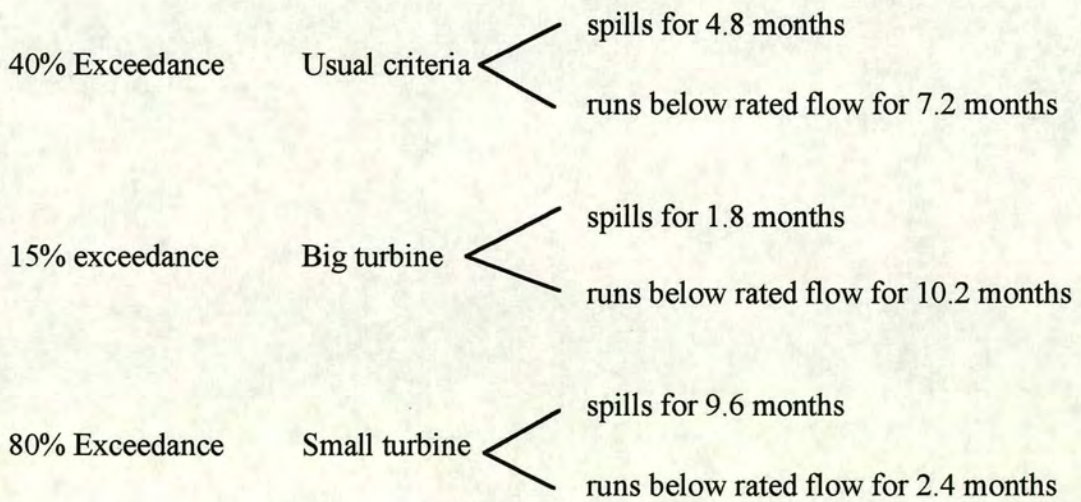


Figure 6.5: FDC comparing Rainfall method and Ratio of Areas method

6.5.2 Design flow

Once the FDC for the stream has been constructed, judgement must be applied to select an acceptable exceedance and flowrate to determine the capacity of the turbine. This is found from the graph and is usually conservatively estimated as that flow rate that is exceeded for 30% to 40% of the time or for about 4 to 5 months of the year.

The design criteria are shown below:



The point on the exceedance curve at which it is decided to select the capacity of the turbine is a judgement for the user. One option would be to size the turbine to pass a flow rate that is exceeded between 70% -80% of the time. This represents spillage at full load generation for 9 months (70-80% of the year) and part load generation for nearly all the remaining time. For tea plantations this would give guaranteed generation for the months during which the electricity is required which coincides with the wet spell. Thus, if the generated electricity is primarily to run the tea factory, then designing a plant based on this flowrate may be the optimum option. It will give a reliable, constant output without needing to buy in power to compensate for shut-down during periods of low flow. However in some cases it may be more economically attractive to design the turbine for a flow exceedance of 10-20%, representing full load generation for 1-2 months of the year, and to sell all electricity generated which is excess to estate requirements to the grid for a few months when the flowrate is very high. These considerations will change the design constraints. The choice between the various scenarios depends on the level of risk and rate of return that the developer is prepared to take. A bigger plant will be more expensive and, if running at part load, must have good governing equipment. However, the return from selling to the grid may make the exercise worthwhile. Alternatively a smaller turbine may be more economic because it is used more heavily. The different options can be explored on the site using SAM.

A compensation flow allowance was necessary, to allow for washing and drinking water, which was nominally 10% of the chosen exceedance flow. The design flow was thus the exceedance flow minus the compensation flow.

6.5.3 Nett head

The nett head was calculated, in metres, as the gross head minus losses of 5%.

6.6 Selection of Electrical and Mechanical Equipment

The electrical power that can be obtained from a given flow rate and head is calculated from:

$$P = \rho * e * Q * g * h \quad \text{Equation 6.3}$$

where

P is the site power in kW ,

e is the overall efficiency of the turbine/generator system,

Q is the design flow rate of the stream in m³/sec

$g = 9.81 \text{ m/sec}^2$ is the gravitational constant

ρ is the density of water in kg/ m³

h is the nett head in m.

Section 6.5 has given the methods used in SAM to find the design flowrate, Q , and the nett head, h . The efficiency of the system was assumed to be 90%.

Having calculated the possible power that could be developed from the stream the next stage is select the turbine, generator, governor and inlet valve.

6.6.1 Turbine design

The high heads and smaller flowrates that are typical in the tea estates mean that the majority of turbines selected for use in Sri Lanka are impulse turbines such as the Pelton or Turgo Impulse. Compared to reaction turbines, impulse turbines are suitable for use in Sri Lanka because they are more tolerant of small particles in the

water, are more easily maintained, are less subject to cavitation, and have flatter efficiency curves if a flow control device such as a spear valve is built in. The major disadvantage with impulse turbines is that they are unsuitable for low head operations but this is not so relevant in the tea country since, because of the terrain, the heads tend to be high.

The results of the research into the turbine manufacturing capability in Sri Lanka is discussed in more detail in Chapter 7, but it is limited to village micro hydropower schemes. Turbines for the tea estates need to be imported and, again for reasons explored in Chapter 7, the turbine specifications used in SAM were based on the turbines that are manufactured by Gilbert Gilkes and Gordon. Figure 6.6 shows the turbine selection graph used by Gilbert Gilkes and Gordon. The design flowrate and nett head are used to read off the selected Pelton (P) or Turgo Impulse (TI) turbine where P or T refers to the type of turbine, 1 or 2 refers to the number of jets, and the 13.5/1000 refers to the diameter of the runner and the specific shaft speed at which it runs. For instance, TI 2 12/1000 refers to a twin jet Turgo Impulse turbine with a 12 mm runner and a specific shaft speed of 1000 rpm.

6.6.2 Generator

The type of generator chosen for a particular scheme depends on the output power and speed of the turbine. As the estates wish to have the option of stand-alone as well as selling electricity to the grid, synchronous generators must be used. For example if a turbine with rated output of 50 kW and a shaft speed of 1500 rpm is selected then a generator with similar rated output and speed is chosen.

As discussed in Chapter 7, there is no capability at present to manufacture generators in Sri Lanka so these would need to be imported. SAM uses data for the Voitti generator with specifications from the Gilkes manufacturing sheets.

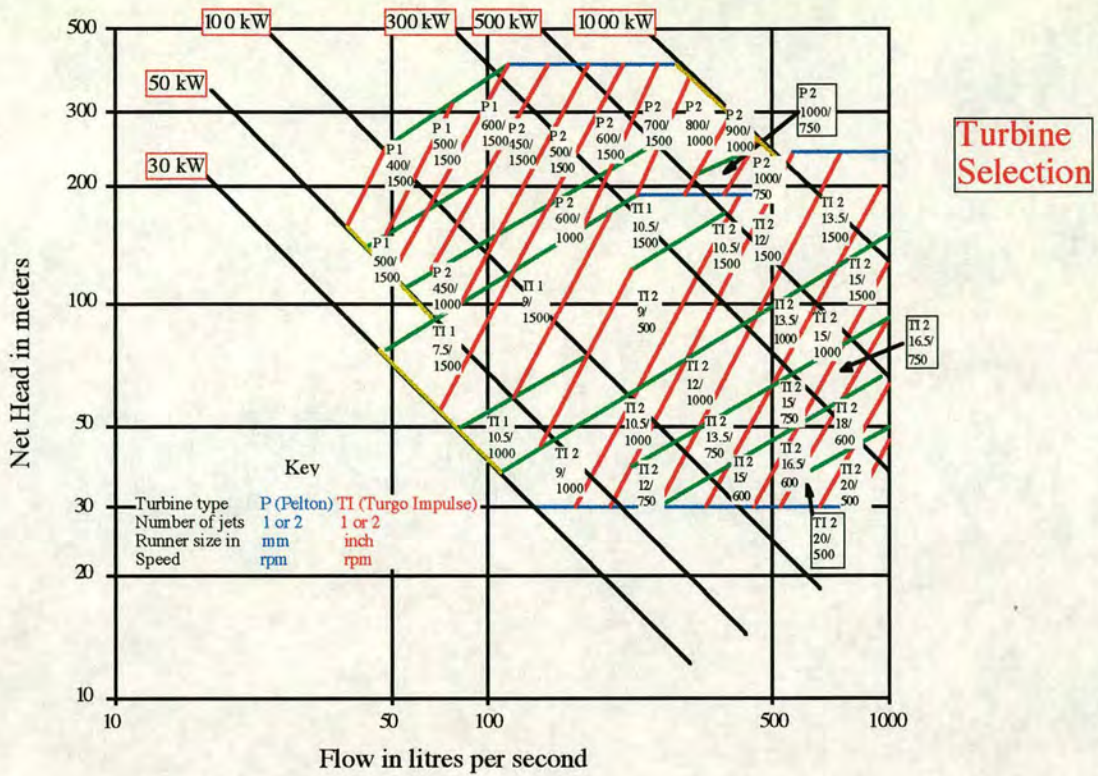


Figure 6.6: Turbine selection graph used by SAM

6.6.3 Governors

In a hydroelectric plant the governor controls the speed of the turbine until it is synchronised. The choice of the governor depends on the turbine capacity, and so is again directly related to the flow and head of the site. In the original installations in Sri Lanka the speed of the turbine was controlled by regulating the flow of the water through the turbine using mechanical/hydraulic governors. Recent schemes, including all the plants installed by Intermediate Technology, use Electronic Load Controllers (ELC) for synchronous generators and Induction Generator Controllers (IGC) for induction machines. These control the speed of the turbine by ensuring that the electrical load is always the same. There is no requirement for adjusting the flow of water into the turbine as a secondary ballast load compensates for any power not needed by the user. These have been successful in the village micro hydropower schemes, but not in the larger plants, as discussed in chapter 4.

ELCs can be assembled from imported components, and IT employ several people capable of doing this. Mechanical governors would need to be imported although there is the expertise to overhaul and repair such equipment. However, the higher cost of a hydraulic governor such as a Woodward governor should be offset against the problems experienced with the ELCs, such as faulty circuit boards and poor repair work. For this reason SAM uses the design specifications for a Woodward Governor. The governor selection graphs are shown in Figure 6.7.

The same technique as used for the turbine selection is used to obtain the equations and specify the generator.

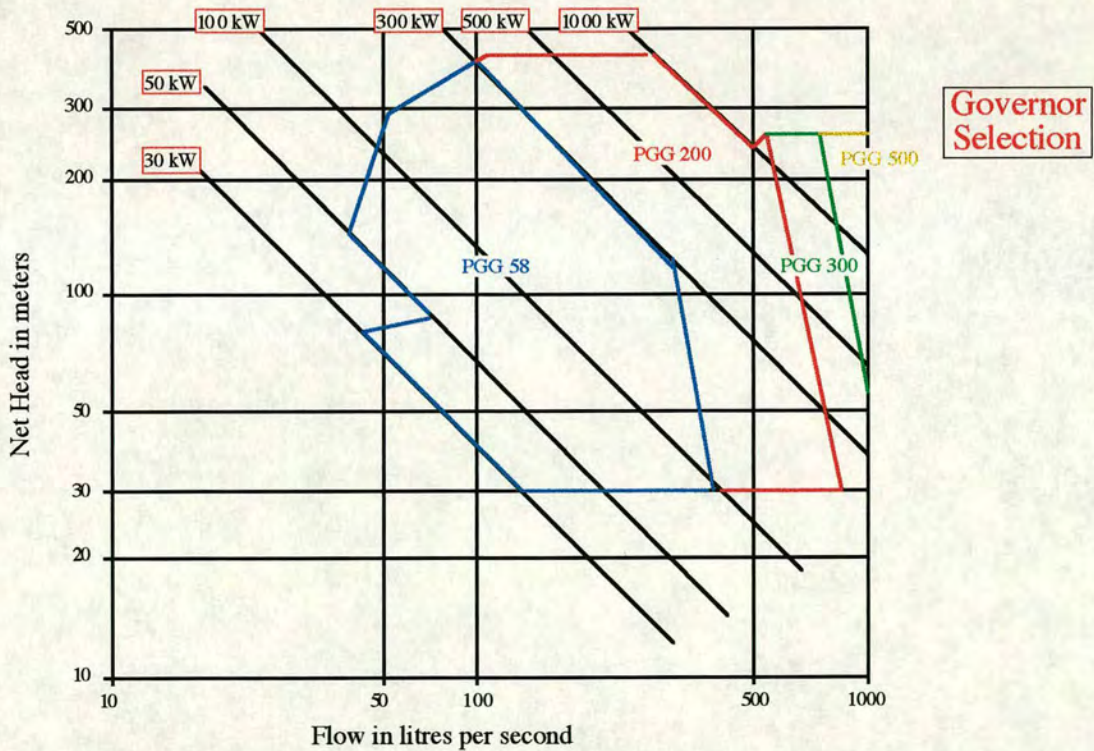


Figure 6.7: Governor selection graph used by SAM

6.6.4 Switchgear

The switchgear in a mini hydropower station protects and controls the electrical system. It is there to isolate the power supply if required and to prevent significant distortions in the frequency and voltage that would damage the equipment. There is controversy in Sri Lanka as to what is strictly necessary to the safety of the plant and equipment, and what is over engineering (Chapter 4). However, in the mini hydropower range the electrical generation and distribution are usually protected with relevant trips in conjunction with either moulded case circuit breakers or contactors

6.7 Civil Works Specification

The civil works in a mini hydropower scheme depend upon the hydrology of the site, the geography and certain factors such as position of plant, condition of roads and the requirements and preferences of the people involved.

6.7.1 Geology and terrain

The land varies considerably across Sri Lanka, and also within the areas where the tea estates are situated. The geology, slope of the land, and the amount of erosion all influence the ease of construction and therefore the cost of the civil works. The difference this can make is incorporated into SAM with a terrain factor, TF, in the calculations for all the civil works and transmission line. The laying of penstocks and the digging of channels is a far more serious task if the slope is at an angle of more than 15° than if the land is flat or gently sloping. The TF varies between 1 and 6. TF1 is used when the land is not particularly steep and it would be relatively easy to carry out the civil works, as shown in Figure 6.8. TF6 is terrain where major excavation work is required and a lot of labour and materials will be needed as illustrated in Figure 6.9. The TF is based on a site visit and allocated solely on the judgement of the assessor.



Figure 6.8: Land with recommended TF 1



Figure 6.9: *Land with recommended TF 6*

6.7.2 Penstock

The length of the penstock plays a major part in determining the feasibility of a mini hydropower project, since it is a significant expense in the civil works of a MHP plant. The length of the penstock would be measured during the site survey, but the required diameter is calculated in SAM. The diameter of the penstock is crucial, as it is this measurement that determines how much water can flow through under a given head and it also influences the cost of the pipe. The equations used to calculate this diameter involve calculating the head loss in a pipe using Darcy's equation. [Daugherty & Co, 1989]:

$$H_f = \frac{4 \cdot f \cdot l \cdot v^2}{d \cdot 2 \cdot g} \quad \text{Equation 6.4}$$

where

H_f is the head loss

v is the velocity of the water in m/sec

f is the friction factor

g is the acceleration due to gravity in m/sec^2

d is the diameter of the pipe and l the length of the pipe in m.

Using the standard equation for flow

$$Q = v \cdot A \quad \text{Equation 6.5}$$

where Q is the flow in m^3/sec and A in m^2 is the area of the pipe

$$A = \frac{\pi \cdot d^2}{4} \quad \text{Equation 6.6}$$

Substituting equations 6.5 and 6.6 in 6.4 gives:

$$d = \left[\frac{0.33 \cdot f \cdot l \cdot Q^2}{H_f} \right]^{0.2} \quad \text{Equation 6.7}$$

It was decided to use a friction factor of 0.005 in SAM. This corresponds to using a Reynolds number of 3200 which was deemed acceptable as the flow should not be too turbulent. The head loss was also set at 5% which is an acceptable loss.

6.7.3 Channels

The width, depth and hence cross sectional area of a channel is determined from the required flow of the water.

6.7.4 Transmission line and connections to the grid.

In the past, hydropower plants used to be situated very close to or in the factory to reduce the cost and electrical losses associated with long transmission lines. However, in order to optimise the hydropower potential on the estates it may be necessary to locate them further from the factory.

The length of the transmission line is determined, by the actual point to point distance, but is influenced by the gradient and roughness of the land where the line can be built, and is reflected in the terrain factor. A detailed analysis would be carried out as the second stage in a feasibility study to determine the optimum cabling, but in the initial stages SAM used specifications and costs for locally manufactured 11 kV transmission lines on wooden poles.

6.7.5 Powerhouse

The size of the powerhouse is inversely proportional to the head available for a certain power output [Fitz 1984]. It depends upon the capacity and therefore size of the turbine and generator to be housed inside it. There is a standard list of sizes [Gilkes 1994] based on the minimum length and breadth needed for the runner diameter.

6.7.6 Roads

Anyone who has driven or been driven in Sri Lanka will know that the condition of the roads is extremely poor even on the major connecting routes between cities and towns. In the tea estates the majority of the roads are dirt tracks without bottoming, tarmac or finishing. It is likely that most of the proposed schemes would need new

roads, and some sections of existing roads would have to be reinforced. However, it is important to determine the level of construction, because standards expected in a Western country may be too expensive for a developing country and not as necessary. For instance, a road leading to the powerhouse would be tarmaced and surfaced in the UK, but a strengthened dirt track in Sri Lanka would be considered adequate. However, the safety of the scheme must comply with rigorous standards wherever the plant is installed, and for this reason SAM uses specifications for a fully load bearing single track metalled road.

6.8 Capital and other Costs in SAM

The types and sensitivities of the capital costs involved in a mini hydropower scheme can be considered in three contexts:

- **Site specific costs:** These are costs that are particular to the site under survey and are dependent on the head and flow rate of the stream available for power generation. These parameters determine the options available for choosing all of the electrical and mechanical equipment apart from the cabling and switchgear. They are also one of the factors affecting the design, and hence cost, of the penstock, channel, the forebay tank, tailrace, and powerhouse all of which are proportional to the head and flowrate.
- **Site variable costs:** These costs relate to particular sites and are calculated from factors such as the length of the components and geography (in particular the terrain factor, see section 6.6.1). These factors affect the cost of the civil works, the roads, the transport and the overhead lines.
- **Site independent costs:** These arise where the incurred costs for a designed output are not related to the specific characteristics of the

site but depend on external factors such as government policy on taxation, consultancy fees and cost of items that are not site specific such as switchgear and cabling.

These cost divisions provide a useful check and guide to cost sensitivities of the scheme when calculating the capital costs. In SAM the capital costs are calculated and displayed in terms of the cost of the electro-mechanical equipment and the civil works. The effect of varying the flow rate, head and terrain factor can be quickly shown, and so the cost sensitivities to these factors assessed.

Some costs within the scheme will depend on the material and labour costs involved, and the factors that should be taken into consideration when calculating these are detailed below. The costing of the civil works and electrical and mechanical equipment for new sites is a relatively straightforward exercise once the design has been specified.

6.8.1 Electrical and mechanical equipment

The costs for the turbine, generator and governor are taken directly from the design specifications and costs given by Gilbert Gilkes and Gordon.

6.8.2 Civil works

Apart from the cost of the penstock, the cost of the civil works depends on the amount and type of material used, labour costs and the terrain factor (discussed in Section 6.7.1).

In any costing for a hydropower project there is a trade off between the overall capital cost and the efficiency and reliability of the scheme. In deciding upon the material and type of channel the severe soil erosion in the estates, the amount of silt in the water and the slope of the terrain must be taken into account.

A substantial number of sites were visited as documented in Chapter 7. The ones that had once had a hydropower plant, but where it was no longer operational, were assessed on the state of the channels. It was found that the state of the civil works mainly depended on the materials that had been used. For example on the Mayfield site where the channels had been lined with rubble and, in some places concrete, they could still be used, whereas on the Drayton estate the channels had been unlined and there were only traces of the channels remaining. For this reason it was decided that costings included in the software should be based on the cost for concrete and steel lined channels, on the grounds that they would cope better with the effects of the silt and last longer. Although the channels are therefore more expensive than if unlined or rough mortar had been used, such channels are narrower for the same flow, so they are easier to build on steep slopes, will cause less damage to the hillside, and lower the possibility of landslides.

6.8.3 The cost of concrete for the civil works

The costs of the concrete for the civil works arise from constructing the channel, the intake, settling tank and powerhouse.

The volume of concrete per metre needed to construct the channel is derived by assuming that the thickness of the walls is one third the height of the channel. The cost of building a channel also involves costs of labour for the excavation and shuttering and the material costs of the steel and concrete.

The volume of concrete needed for the powerhouse walls is calculated in the same way as for the channels. The area of the floor can be calculated and then the volume of concrete needed in the base is found from assuming that the thickness of the concrete is 0.15 times the length of the power house.

The cost of the foundations can be calculated in the same way as for the other civil works in terms of the excavation, shuttering, steel and concrete.

The cost of the concrete is calculated from the price of the concrete multiplied by the concrete volume, but the final cost is also multiplied by a terrain factor.

6.8.4 Penstock

The cost of the penstock is calculated as

$$Cost_{pen} = 2 \cdot \frac{d}{d_{sp}} \cdot C_{sp} \cdot TF \quad \text{in } \text{£/m} \quad \text{Equation 6.8}$$

C_{sp} is the cost of a particular diameter of pipe diameter d_{sp} with a multiplier of 2 to allow for local costs in laying the pipe. The terrain factor TF is another multiplier, but is a site variable cost. In the surveys described in chapter 7 the price of a 0.7 m diameter steel pipe was £82 per metre. It was found that the prices in Sri Lanka were very similar to prices in the UK as all steel has to be imported. PVC pipe is also available in Sri Lanka and is used on the micro hydropower village schemes, but it would not be suitable for the larger plants.

6.8.5 Transmission line and connections to the grid.

SAM calculates costs for the transmission line based on local prices for a 11 kV line multiplied by the terrain factor.

If a grid connection is required it will require auxiliary and control equipment, transformers and transmission lines to the nearest substation. Generally it is the job of the CEB to provide such equipment and normally comes under the terms of the PPA.

6.8.6 Roads

The cost of the new road entered into SAM was calculated per metre for a fully load bearing single track metalled road and multiplied by a terrain factor.

6.8.7 Engineering and consultancy costs

There are a number of companies operating as hydropower engineering consultants in Sri Lanka. There is also a Hydro Forum that co-ordinates and monitors the mini hydropower activity on the island. However the problems of costing engineering consultancy fees relate to the proverbial ‘chicken and egg’ scenario, which is one of the reasons why there has been so little development in the mini hydropower sector in Sri Lanka. The demand for the relevant engineering skills and the resources to cultivate this demand is not at a sufficient level to produce an expert and competent network. Therefore caution should be employed in selecting consultants, with the attendant difficulty of costing their input. For this reason SAM does not include the cost of consultancy fees at this stage in the feasibility survey.

6.8.8 Land and water rights

Land rights are complicated in Sri Lanka and involve bureaucratic legislation. It is forbidden under the ‘Land Reform Act’ for one person to own more than 50 acres of land. In theory the land on the tea estates belongs to the government. However with the government’s need for CEB to have access to more generating capacity, the companies’ wish to minimise costs, and with the environmental advantages of small scale hydropower, it is not expected that there will be any difficulty over land and water rights. However, as described in Chapter 7, there are difficulties if the needs of the hydropower scheme come into conflict with tourist attractions such as waterfalls or the use of drinking water supplies. SAM does not include land costs or water costs at present, as they cannot be easily estimated.

6.8.9 Operation and maintenance costs

The operation and maintenance costs cover the costs incurred to ensure the smooth and continuous operation of a MHP scheme. As with any hydropower plant, operating costs are minimal, since the marginal cost of the primary energy source is virtually zero. Operating and maintenance costs are generally low but are directly

attributable to the project. In Sri Lanka this means regular inspection and upkeep of the waterways; silting in particular is a problem in the tea plantations due to the soil type and general degradation of the land. Extra maintenance is required during the rainy season when the streams and rivers are swollen and will contain more silt and other objects. The channels must be checked during this season to avoid them being filled with more water than they can carry and thus causing them to break and be washed away.

The plant and equipment must also be maintained. A normal expectation is that the plant should be available for 80% of the time taking into account outages, maintenance and repairs. In costing the operations, central administrative overheads are avoided since the plants are normally operated by tea factory staff. Annual operation costs are therefore estimated as 5% of the total capital cost.

6.9 Economic Appraisal in SAM

The economic viability of the plant is tested by the following techniques [Sloman, 1994]:

- Future time to return investment
- Nett Present Value
- Internal Rate of Return
- Cost/Benefit Ratio.

In the economic analysis the future time to return investment is established as the number of years taken for the net revenue to pay back the borrowed capital costs, assuming that the loan is paid off at the fastest possible rate. During the pay-back period all of the difference between revenue from energy sale or avoided costs and the sum of operating costs and interest charges is used to reduce the loan. The payback period becomes

$$\text{Years} = \frac{\text{Scheme capital cost}}{(\text{income} - (\text{operating costs} + \text{interest charges}))} \quad \text{Equation 6.9}$$

The first feature to emerge here is that the income in the first year of operation must exceed the total of operating costs and debt service charges or there is no margin to reduce the debt, and the scheme will never pay back. Further, setting the criterion that the income must exceed the outgoings (which are largely determined by capital costs and interest charges) it is then possible to establish a minimum sale price for the energy generated to make the scheme initially viable.

The procedure for reducing the future value of a project back to a present value is based on the concept of discounting. The nett present value of the project is the sum of the future costs and benefits of the project individually collapsed back to year 0 by applying the discount rate. The discount rate is the rate of return that could be earned by investing the capital cost of the project into a venture of similar risk or into an alternative project. For a project to be economically viable the net present value must be as high as possible. A project with a low NPV is a marginal investment, and with a negative NPV would be loss-making since the overall value of the project would not have risen to recover the invested capital.

Thus the nett present value (NPV) of the investment is found from

$$NPV = \sum_{i=1}^n \frac{X_i}{(1+R)^i} \quad \text{Equation 6.10}$$

where

X_i : earnings in the year i

R : discount rate expressed as a decimal fraction

n : number of years under consideration

and similarly:

$$X_i = B_i - C_i \quad \text{Equation 6.11}$$

where

B_i : Benefits in the year i

C_i : costs for the year i including capital costs and interest charges.

Another approach when estimating whether an investment is worthwhile is to calculate the internal rate of return (IRR), a measure of the economic quality of the investment. This is the discount rate that, applied to the calculation of net present value, would set the NPV to 0 (and the benefit/cost ratio to 1).

$$\sum_{i=1}^n \frac{X_i}{(1 + IRR)^i} = 0 \quad \text{Equation 6.12}$$

This equation represents the maximum discount rate determining the opportunity cost of investing in the project. A low IRR means that the mini hydropower plant would only compete with poor alternative investments, but a high IRR would mean that the other investments would have to be good to compete with investment in the hydropower project.

The benefit to cost ratio is a means of evaluating the present worth of the benefits over the operating life of the plant as the multiple (or fraction) of the income from energy sales to the the sum of operating costs and debt service. Both benefits and costs are discounted to present values.

$$\frac{B}{C} = \frac{\sum_{i=1}^n \frac{B_i}{(1+R)^i}}{\sum_{i=1}^n \frac{C_i}{(1+R)^i}} \quad \text{Equation 6.13}$$

A project with a B/C ratio of 1 will, in present value terms, just pay for the investment in the plant, and be a marginal investment. If the B/C ratio is a fraction the investment is poor, but if it is a number greater than 1, the investment is better. However it must also be judged together with the other methods of assessing the worth of an investment described here.

6.9.1 Interest charges and exchange rates:

The annual interest charge on outstanding capital debt is usually the largest expenditure in the early years of commercially viable projects. Where preferential loan terms may be applied to elements of the capital items in the project it is possible and desirable to compute interest charges based on the split rates applying to different sections of the plant.

Sri Lanka suffers from very high interest rates, especially from lending bodies; the expected average return from such aid agencies is between 25-30%, which renders most projects economically unviable. Sources such as the World Bank lend the money to the projects through the banks of the particular country and not directly to the project, so interest is added through this middle man.

The prevailing commercial conditions are held in the Excel data base and are applied to the assessment of economic viability. These can be changed with changing circumstances, but for 1995 are shown in Table 6.2.

Commercial conditions in 1995:	
High interest rate: 18%	Cost fraction for high interest rate: 15%
Low interest rate: 9.5%	Cost fraction for low interest rate: 85%
Buy in tariff: 3.8 Rs	Sell-out tariff: 2.6 Rs
Discount rate:5%	Exchange: £1.00 = Rs 72
Labour inflation:3%	Energy cost inflation: 5%

Table 6.2: Table of certain economic details in SAM

Labour and energy rates were inflated at different percentages. Interest charges are divisible and adjustable, since it is possible that the imported and indigenous portions of the overall cost will attract different interest rates. Future costs are collapsed to present values at adjustable discount rates.

The foreign exchange rate can have an effect on the overall expenditure especially when it is a politically volatile country that is involved. The exchange rate fluctuates at a high rate, due to political and economic insecurity.

6.9.2 Income

The success of a scheme depends upon its expected projected income over its lifetime. This is decided by the amount of time that the plant runs and the perceived electricity savings made in that time. There are two inputs to be considered, the savings made by avoiding purchasing electricity from the grid and the income from selling electricity to the grid. The other benefits are non tangible and cannot be given an economic value.

Since the power produced by the hydropower plant also varies with seasonal flow, annual revenue is calculated from the hourly factory load pattern and annual flow

pattern, to accumulate avoided purchase costs and sell-out income. Nett income is determined having paid interest charges, returned capital, and funded operation and maintenance.

6.9.3 Tariffs

The tariffs and changing tariff rates have a great effect on the economics of the installation. Chapter 7 discusses the findings for the tariff rates during the time of the field study.

6.9.4 Demand load pattern

Base revenue and the economic viability of the proposed mini hydropower plant are heavily influenced by the energy usage in the tea factory. Where the maximum load, its duration and minimum load are known, an hourly load pattern is assembled. Otherwise, average hourly loads may be calculated from annual electricity bills.

Depending on the daily load pattern and the power being produced by the mini hydropower plant, the factory will either export or import power to or from the grid.

Details for this can be entered into SAM during the feasibility study and used in the sensitivity analysis.

6.10 Conclusions

This Chapter has considered the models and method of information collection for the feasibility study. Once the information has been collected and SAM populated then there are options in assessing the feasibility of the site that are available at many levels. There are options in considering what will happen if the rainfall decreases, in deciding the exceedance levels, in siting the plant, in the economic scenario etc. The technical conclusions from this thesis, discussed in Chapter 8, arise from careful analysis of the results of the site evaluations considering these options.

7. RESULTS

The outcome of the original field trip from September 1993 to September 1994, the subsequent visit in July to August 1995, the work completed in the University of Edinburgh from October 1992 to August 1993 and further work from September 1994 to October 1995 falls into four main categories:

- Population of a data base with the geographical position and owners of the tea plantations, rainfall and flow statistics, local suppliers of equipment and materials, breakdown of the type and rating of equipment used in the tea factories, and analysis of the energy requirements of these plantations.
- Technical assessments of the condition of the remaining electrical and mechanical equipment, civil works, hydrology and geology and energy potential of the mini hydro plants on the tea plantations. This led to an economic evaluation of the rehabilitation involved in these sites and, as the project developed, the assessment of the potential of new green-field sites.
- Evaluation of the decision support software that was written to assist the feasibility studies for the rehabilitation of existing sites and the development of new sites for mini hydro plants.
- Analysis of the infra-structure of government, industry and tea plantations and the commercial policy that determines the energy generation and use on the tea plantations. This led to the evolution of a set of criteria and strategic proposals that should ensure the success of future mini hydro schemes in Sri Lanka.

7.1 Results from Questionnaires and initial surveys

As explained in Chapter 6 the initial surveys were carried out with the aim of rehabilitation rather than building new plants. The four hundred sites where turbines were originally installed were established from Gilkes' list of turbines [Gilkes, 1987] and a list of the estates belonging to each of the twenty-two management companies. Questionnaires were sent to the managers on the estates, and the replies entered into a database from which a list of thirty-five sites was selected. These sites were from three areas, Kandy, Nuwara Eliya and Ratnapura. A typical reply to the initial questionnaire is shown in Appendix 1.

This section will discuss the results of the questionnaire and the data from the thirty-five sites originally surveyed together with information gathered in Colombo from various sources augmented by further site surveys of ten selected sites.

The data collected on the estates included:

- rainfall data for the last 5 years,
- electricity consumption and crop production,
- electricity bills and factory machine usage.

The data collected in Colombo included:

- suppliers of equipment and materials,
- financial information including electricity tariff structure, interest rates, bank loan terms, etc.

Ten of the original thirty-five sites were revisited in July 1994 and more accurate technical measurements were made at this time, so this information was added to that obtained in the original survey to give information on:

- hydrological data,
- machinery ratings and power consumption in tea factories and estates,
- condition and measurements of the civil works,
- economic estimates of the feasibility of refurbishing the plant.

which were incorporated into SAM to give an assessment of the feasibility of rehabilitating the plant.

7.1.1 Rainfall data

Rainfall data, if available at the factories, was collected and plotted to build up a picture of the pattern that could be expected at the site in future years. Figure 7.1 shows the monthly rainfall in mm at Craigie Lee for the last ten years. Craigie Lee is in the wet zone and the effects of the monsoons can be clearly seen. The average amount and variation in rainfall over succeeding years are shown in Figure 7.2. The figures are shown for Craigie Lee estate are typical for this area. Similarly a pattern for rainfall in the Ratnapura areas and Kandy areas was produced. This result was important in the design of SAM as it highlighted the significant fluctuations in the quantity of rainfall that occur throughout the year, and the effect this will have on choosing the appropriate exceedance flowrate from the FDC.

7.1.2 Cost of electricity, machinery capacity and ratings

A comparison of the cost of electricity and the power ratings and usage of machinery used in the production of tea has been given in Section 3.3. In the survey it was found that factories were either using the CTC or Orthodox method of production. From the results of the survey it is apparent that both production methods use approximately the same amount of electricity. One factory at Gordon Estate had just started green tea manufacture, but the results from that survey in terms of machine ratings and power consumed in the process were not available.

Average rainfall at Craigie Lea from 1985-1993

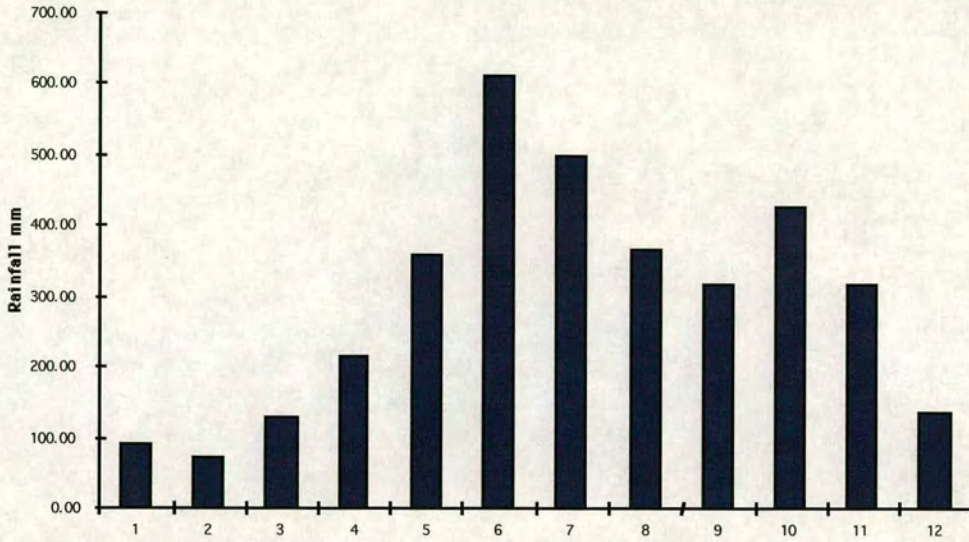


Figure 7.1: Average Rainfall at Craigie Lee from 1985 to 1993

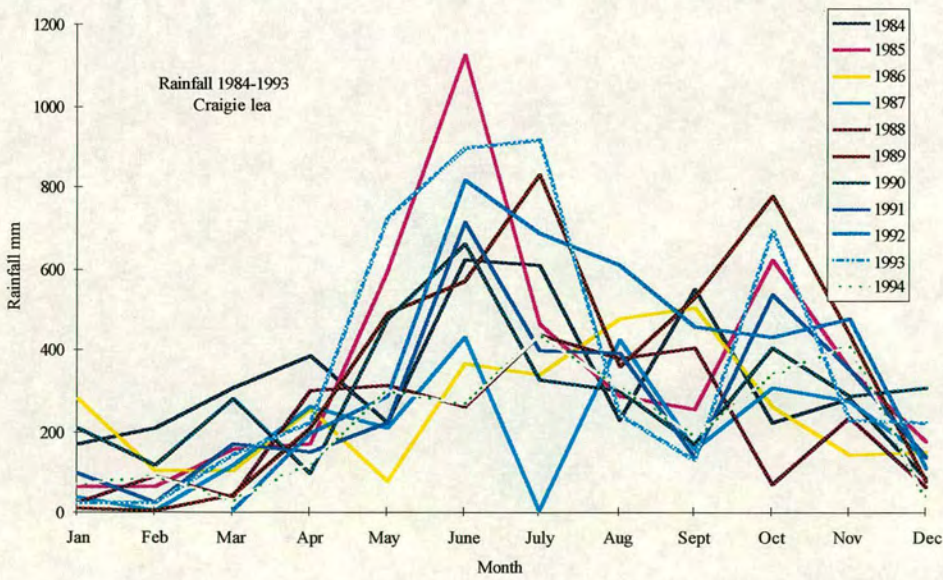


Figure 7.2: Plots of rainfall over last ten years:

Figure 7.3 shows the monthly electricity consumption for the factory at Stonycliff. The red and blue lines correspond to the two different tariff prices; the electricity that was consumed at the 'peak' price and the electricity used at the normal tariff rate. These figures allow the total annual cost of electricity (shown in the yellow line) to be estimated and so can be used when deciding the capacity of the mini hydropower plant and the merits of exporting or importing power. Comparison with the rainfall graph shows that peak electricity consumption occurs in the season of greatest rainfall, which also coincides with the maximum crop.

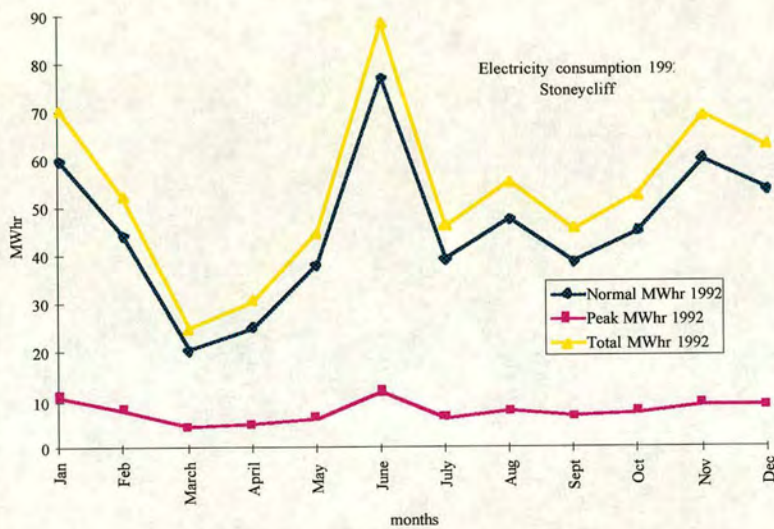


Figure 7.3: Electricity Consumption for Stonycliff, 1993

7.1.3 Crop production

Data of the crop production for each month on the tea plantations was also acquired. Table 7.1 gives an example of a typical black tea factory, Stonycliff; the figures show the normal and peak consumption of electricity in kWh with the corresponding tariffs in rupees, and crop production in kilogrammes. This is also shown graphically in Figure 7.4. Thus these figures can be used to find an average figure for the electricity consumption in kWh per kg of made tea and a corresponding price in rupees for the

electricity cost per kg. It shows a fluctuation between 0.36 Rs/kg to 1.07 Rs/kg depending on the season.

These figures could be used to calculate machinery requirements, and hence estimate the amount of the electricity that would be required on the plantations during the year. This was usually calculated from the estate bills, but the crop production figures provided a useful check. It was also found that there is a correlation between the rainfall and the crop production, and hence electricity consumption. This could be a factor in selecting the exceedance rate and hence the capacity of a mini hydropower plant.

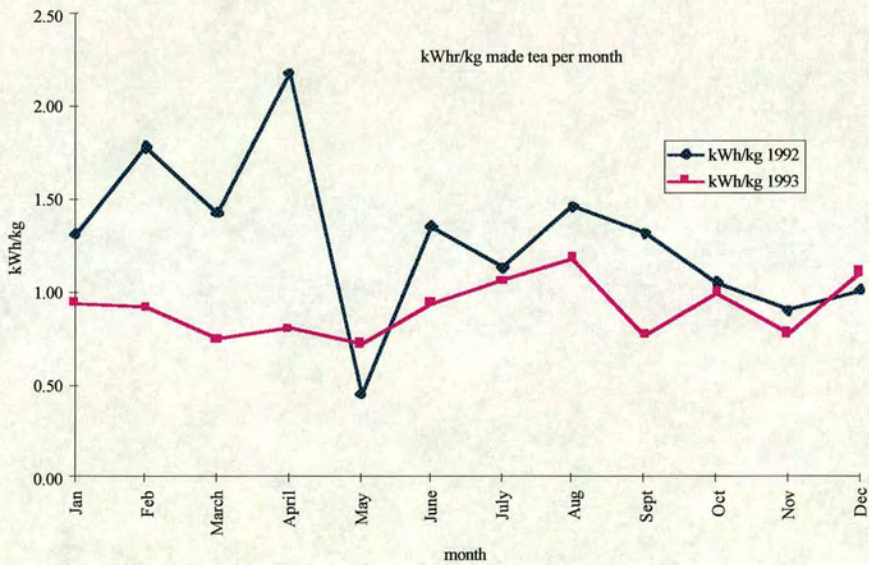


Figure 7.4: Graph of kg/kWh of tea for Stonycliff, 1992-93

Month	Crop (kg)	Normal kWh	Peak kWh	Total kWh	Rs Normal	Rs peak	Rs Total	Rs/kg	kWh/kg
1993									
January	53560	59800	10600	70400	164450	68370	232820	4.35	1.31
February	29257	44180	8260	52440	121495	53277	174772	5.97	1.79
March	17530	20650	4470	25120	56788	28832	85619	4.88	1.43
April	14050	25480	5200	30680	70070	33540	103610	7.37	2.18
May	98367	38260	6620	44880	105215	42699	147914	1.50	0.46
June	65095	76900	11780	88680	211475	75981	287456	4.42	1.36
July	40610	39620	6550	46170	108955	42248	151203	3.72	1.14
August	37822	47610	7940	55550	130928	51213	182141	4.82	1.47
September	34661	38990	6830	45820	107223	44054	151276	4.36	1.32
October	50087	45060	7720	52780	123915	49794	173709	3.47	1.05
November	76493	59960	9440	69400	164890	60888	225778	2.95	0.91
December	61668	53800	9010	62810	147950	58115	206065	3.34	1.02
Total	579200	550310	94420	1223930			2122362	3.66	2.11
Average	48267	45859	7868						

Table 7.1: Crop production and electricity consumption at Stonycliff, 1993

7.1.4 Electricity tariffs

The cost of electricity was found from the CEB, and the tariff that was effective in 1994 is shown below in Table 7.2. These prices had changed by 30% from the previous September as a response by the CEB to the energy situation following the outages and lack of available capacity noted earlier. This volatility in tariffs implies that before a final decision is made to implement a scheme, a decision on the likely changes in the future has to be taken. However, these figures were used to compute the electricity costs used in the economic assessments of SAM.

It can be seen that the tariff has been designed to keep down peak domestic use and encourage off peak use. Tea factories use electricity at peak times and hence are penalised for this pattern of use. The CEB is also encouraging local generation by recently publishing attractive buy-in tariffs: 2.6 Rs/kWh at sites of capacity less than 1 MW and 3 Rs/kWh at sites over 1 MW. This will influence decisions on the economic viability of a plant and its capacity.

7.1.5 Suppliers of equipment and materials

As explained in section 6.3, one of the problems with setting up manufacture of mini hydropower equipment in Sri Lanka is the difficulty of finding companies and individuals capable of manufacturing or assembling the electrical and mechanical equipment or supplying the materials for the civil works. Using the methods of data collection described in Chapter 6, a summary of the manufacturing capabilities for Sri Lanka was constructed and is given in Table 7.3

C. E. B TARIFF	Effective from	01-01-1994	
DOMESTIC MONTHLY	First 60 units 61-180 units Above 180 units Fixed Charge up to 60 units/month over 60 units/month	@ Rs 1.70 per unit @ Rs 4.40 per unit @ Rs 5.25 per unit Rs 8.50 Rs 17.00	
RELIGIOUS & CHARITABLE INSTITUTIONS	First 150 units Above 150 units Fixed charge for a month	@ Rs 1.35 per unit @ Rs 5.00 per unit Rs 17.00	
OTHER CATEGORIES: Monthly	General Purpose	Industrial	Industrial (Time of Day)
Supply at 400/230V Contract demand less than 50 kVA			
Unit Charge (Rs/unit)	5.30 +	4.00 +	3.00 (off peak) + 8.35 (peak 6 p.m. to 9 p.m.) +
Fixed Charge (Up to 10 kVA) Rs	43.00	43.00	43.00
Fixed Charge (Above 10 kVA) Rs	205.00	205.00	205.00
Supply at 400/230V Contract demand 50 kVA and above			
Demand Charge (Rs/Unit)	256.00 +	222.00 +	102.00 +
Unit Charge (Rs/unit)	5.20 +	3.80 +	3.00 (off peak) +8.35 (peak 6 p.m. to 9 p.m.)+
Fixed Charge Rs	408.00	408.00	408.00
HT Supply at 11 kV, 33 kV and 132 kV			
Demand Charge (Rs/kVA)	239.00 +	196.00 +	94.00 +
Unit Charge (Rs/unit)	5.00 +	3.65 +	3.40 (off peak) + 8.00 (peak 6 p.m. to 9 p.m.)+
Fixed Charge Rs	408.00	408.00	408.00

Table 7.2: CEB Tariffs, 1994

EQUIPMENT	LOCAL SOURCE	COMMENT	IMPORTERS
Turbines	Browns NERD Small workshops	Quality doubtful	Gilkes, Biwater, etc.
Generators	None		UK, India, China or Japan
Drive systems	Small workshops	Assembled locally	Components imported
Switchgear/control suites	Small workshops	Assembled locally	Components imported
Transmission poles and cables	Small workshops	Constructed locally	
Transformers	Small workshops	Re-winding etc. local	Imported
Civil works	local materials and contractors	Possibility of using estate workers	
Penstocks	PVC manufactured locally	Assembled locally	Steel imported
Valves			China and Europe

Table 7.3: Manufacturing capability in Sri Lanka

The prices for materials used in the civil works are shown in Table 7.4, and a wage scale for local labour, craftsmen and engineers is given Table 7.5. Data for all these tables was found from personal contact with the small factories and businesses involved.

Material	Price (Rs)	Material	Price (Rs)
Sluice gate (2m by 2m)	5,750	Cement (100kg)	400
Intake Gate (2m by 2m)	5,750	Bricks (1000)	1,050
		Rubble (m ³)	212
Corrugated G.I. sheet (m ²).	235	Sand (m ³)	212
Ridging Tiles pair	140	Gravel (m ³)	125
Timber Beams (m ³)	18,368	Steel mild (1000kg)	26,000
Timber Planks 25mm (m ²)	700	Steel mild flat (1000kg)	28,800

Table 7.4: Illustrative table of prices for materials and parts

Skill	Rate per hour (Rs)
Labourer	150
Mason	200
Carpenter	250
Engineer	800

Table 7.5: Rough guide to the cost of labour in Sri Lanka

These figures were all used to populate SAM and are used in the evaluation of many sites using the software.

7.2 Results of Technical Assessments

Between September 1993 to September 1994 over twenty field trips were undertaken to the plantations in order to see and understand the extent of the work needed to rehabilitate the sites, and to adapt the software algorithms to the demands of the tea estates. A variety of sites were chosen to encompass the main options in

rehabilitation: sites with disused equipment both with and without civil works, sites with only civil works remaining, sites with and without working equipment, sites with rehabilitated machinery already installed, and sites with no previous plant but with mini hydropower potential. Information on these sites was entered into a database and a judgement was made on whether upgrading was feasible. A description of the technical assessment of the electro-mechanical equipment and civil works for a selection of sites is shown in Table 7.6 This shows the variety of problems that typically have to be addressed if a rehabilitation scheme of the size envisaged in the initial proposals was to take place.

	N Meddecombra	Dunstan	Delaveria	Maldukelle	Oonagata
Hydro logical	only 25% used	25% used	good head, steady flow		
Working equipment	2 Francis turbines	rehabilitated Ossberger crossflow			Armstrong
Disused equipment			Gilkes 5672	Gilkes Turgo 3512 and CCC Pelton machine	
Civil works	aqueducts rusty	prone to earth slips	remnants	disrepair	disrepair
Present Output	100kW	274kW potential 150kW usual run			
Problems		maintenance		rainfall data	
Verdict	new power station	upgrade	management not interested	upgrade	transfer turbine to Maldukelle ?

Table 7.6 Summary of initial technical assessment of a selection of sites

7.2.1 Specific sites selected for further investigation and assessment using FOREMP

Some of the sites worth further investigation were deemed to be:

- Maldukelle and Oonagala
- Glentilt
- Rosita, Mayfield, StonyCliff and Craigie Lea

The final four were attractive as they are operated by the same management company, are within easy travelling distance of each other and required the same sort of rehabilitation work, mainly to the civil structures.

During the field surveys it became obvious that rehabilitation was not an economic option. The author visited the majority of suppliers in Sri Lanka and made a comprehensive list of the equipment that was available for MHP rehabilitation. It became clear that most of the equipment would have to be imported. For example it was difficult to find a spare drive belt and there was not the expertise to make parts or to fix minorly deficient equipment. Gilkes had believed in the viability of the initial proposal because they supplied most of the original turbines and thought that many of these could be restored. However, although Gilkes still have all the runner and turbine designs on file, they would have to make new castings and they do not have the spare parts to hand. The cost of importing these parts was found to be too expensive when the cost of the rehabilitation was calculated against the economic benefits to the tea plantations.

7.3 Results from Surveyed Sites

A synopsis of the reports from the main sites is given in the author's report [Wilkinson, 1994]. However the results from three sites are discussed in this section to show the methodology used and findings obtained from a site visit, and the results

from both an expert appraisal and the use of SAM. The Maldukelle and Oonagala sites were chosen as an example since they were selected in the original site survey [Wilkinson 1993] as being worthy of further investigation. Maldukelle was deemed feasible for development but Oonagala was not. The other site described in this section is Hapugastenne since this is the site that matches the criteria for mini hydropower development that are recommended as a result of the research for this thesis.

7.3.1 Case study for the sites at Maldukelle and Oonagala

Agents: Aitken Spence & Co. Ltd, Uda Pusselawa Plantations

Surveyed March 1994 and July 1995

Oonagala and Maldukelle are two factories within the same catchment area. They each have existing mini hydropower plants. Oonagala draws water from a reservoir in its own catchment and is the higher of the two plants. Residual flow in the river feeding this reservoir carries on below Oonagala and the discharge water from the factory rejoins the river lower down. The river continues for a short distance and water is again drawn off into two reservoirs that feed the Maldukelle factory. Discharge from this factory into the original river joins the Hulu Ganga River, about 500m past the site.

CEB has previously surveyed these sites for refurbishment of the civil works and replacement of the electromechanical plant. In addition there was a survey of the refurbishment of both of these sites by a local engineering firm, Engineering Projects 2000 (Pvt) Ltd.

Maldukelle

Hydrological considerations

The rainfall data was only collected at the factory so the data does not cover the entire catchment area. The flow available was estimated using the ratio of areas technique, comparing the 6 km² catchment of Maldukelle with the area of the Teldeniya catchment, and applying this to the runoff in the gauging stations in the Teldeniya system. A design flow of 140 litres/sec was calculated based on 40% exceedance and allowing 10% compensation flow. This flow would develop 200 kW in the factory and 260 kW if the plant was sited lower down (this is discussed later as option 2).

Condition of plant

The existing Gilkes machine, a 20 HP Turgo (serial number 3512), was in a state of disrepair with heavily corroded buckets and totally worn bearings. The governor had also disappeared. The CCC (Colombo Commercial Company) Pelton machine was in a better condition and both the turbine and governor had been recently tested although there were problems with the manual governor. However it was decided that both machines were beyond repair.

Civil works

The Maldukelle site draws its water from two reservoirs below Oonagala. The first reservoir is used for bathing, and feeds the second that contains the dam and the intake. This was found to need dredging, leaked at several points and required to be grouted. The weir needed attention, the sluice gates overhauling, the outlet and scour sluice valves replacing and the channels and tanks cleaning and relining. There is an existing channel from the lower reservoir to the penstock inlet that is 400 metres in length. The channel, made of lined rubble, leaked badly and would need to be completely replaced before it could be used. A picture of the civil works at the site is

shown in Figure 7.5. It was noted that if the intake was repositioned lower down near the road (marked on map) the channel length would be shortened to 250 metres. There were two pipes, both with some leaks although the 8 inch (31.5 cm) pipe leading to the Turgo was in a worse condition than the 10 inch (39.4 cm) CCC pipe. The penstock was buried and many sections leaked badly. It was felt that it might be possible to use some of the existing sections of pipe, but the assessment costed the complete replacement of the penstock at a length of 1180 metres.

Terrain Factor

There is a road into the factory and an existing CEB supply. The terrain across which the channel and penstock would have to be taken was assessed terrain factor 3.

Technical Recommendations

There were three options considered in the development of this site. The first (option 1) was to locate the plant in the factory - giving an available head of 200 metres. The second (option 2) was to place the powerhouse about 100 metres below the factory, on the Hulu Ganga road. This would have required about 500 metres of additional penstock and a new power house, but increased the head to 260 metres. The third (option 3) was to channel more water into the reservoirs from two feeder streams approximately 1000 metres away (currently feeding water tanks to the village). Another survey would be needed to establish if this was feasible. Only the first two options were assessed.

The decision support software selected a 200 kW or 260 kW, twin jet pelton turbine and four-pole synchronous generator. The load in the factory was assessed as 150 kW for 8 hours and with a 40 kW minimum load for the rest of the day.

Economic Analysis

When the commercial conditions were investigated the economic performance of the option 1 site was marginal, and the site went into operating profit only in year 16. The reason for this was that the inflation rate applied to electricity costs was 5% per annum (which was judged to be a reasonable figure) and the labour inflation rate was 2%. With a 0% discount rate the revenue exceeded the expenditure in the early life of the project and eventually accumulated enough funds to pay off capital and interest. Reducing the terrain factor to 2 gave a nine year payback. These payback times could be reduced by considering more closely the costs of modifying the turbine room in the factory rather than allowing full power house costs. The CEB had also surveyed Maldukelle and, inserting their repair costs directly into the calculation, produced a payback of eight years, but it should be noted that the interest rates applied at this time differ from those used in the CEB assessment.

Option	(1)	(2)
Gross head (m)	200	260
Flow (litres/sec)	140	140
Capacity (kW)	198	258
Penstock (m)	1180	1680
Road (m)	0	0
Line (m)	0	500
Civil costs £ (£/kW)	299,995 (1,515)	422,500 (1,638)
E&M costs £ (£/kW)	17,6328 (891)	188,619 (731)
Total costs £ (£/kW)	476,323 (2,406)	611,120 (2,369)
Payback (yrs)	16	17
Benefit/cost	1.93	1.92
NPV over 25 years (£)	1,160,727	1,460,988
IRR (%)	7	7
Feasible	YES	YES

Table 7.7: Summary assessment from SAM for Maldukelle

Assessment from SAM

The assessment for Madulkelle is shown in Figure 7.6 and summarised in Table 7.7, considered two options. Option 2 differed from Option 1 in the increase of the gross head, a larger penstock, construction of a power house, site road and transmission line for a 260 kW plant. This increased the capacity of the plant that was available to be utilised but affected the NPV and slightly increased the payback period.

Outcome

If this site is to be developed economically the capital costs must be reduced significantly (for Option 1 at the factory) to ensure that the revenue exceeds the expenditure during the payback period of the plant. Option 2 achieves the same effect by increasing the plant size and associated revenue from sales.



Figure 7.5: Photo from Maldukelle estate

Gillies and Edinburgh University Pre-Feasibility Report		Sri Lanka Tea Estates Mini Hydro Project			Date	10-Jul
		Site(s)	Madukelle	Tea Company	Aitken, Spe	Assessment by
		Contact			Ruwan Fernando	
Site Details	Map Reference	Hydrology			Design details	
Diversion	8043N724E	% exceeded	Flow (l/sec)			
Settling tank	8043N7237E	0	501.38			
Power House	8044N723E	8.33	345			
Grid	8044N723E	16.66	344.25			
Road	8044N723E	25	247.5			
Map scale	636000	33.33	217.5			
Catchment area	6	41.66	154.5			
		50	153.75			
Leading dimensions		58.33	145.5			
	(m)	66.66	130.13			
Intake	10	75	123	Load details		
Settling tank	2	83.33	86.63	Maximum (kW)	150.00	
Channel	250	91.66	72	Duration (hrs)	8	
Penstock	1180	100	0	Minimum (kW)	40	
Line	0			Duration (kW)	16	
Road	0			Bills total (Rs)	0	
Penstock dia (m)	0.33	Capital Costs		Rupees	Pounds	Calc load (kW)
Phouse len	4.5	Civil costs	23399594	299995	Commercial details	
Phouse breadth	3.2	Electromech costs	13753620	176328	Interest rate (%)	10.35
Turbine	P2 500/1500	Total costs	37153214	476323	Discount rate (%)	0
Generator	300 kW/1500	Cost/kW	187388	2402	P tariff (Rs/kWh)	3.80
Governor	PGG 58	Annual costs			S tariff (Rs/kWh)	2.6
Terrain factor	3	Operating costs	156000	2000	Inflation on S (%)	5
		Maintenance costs	185766	2382	Inflation O&M (%)	2
		Total - year 0	341766	4382	Payback yrs	16
		Min En Cost	4.65	5.96	NPV over 25	1,160,727
		Feasible	YES	Exch (Rs/5)	78.00	IRR
						7%
						Benefit/cost
						1.93

Figure 7.6: Data from output screen for the assessment of Maldukelle

Oonagala

Hydrological considerations

Oonagala uses the same stream as for Maldukelle.

Condition of plant

This was a disused factory with no grid connection and only dc transmission lines. The factory machinery was belt driven and there remained an old Pelton turbine and dc generator, as shown in Figure 7.7, that supplied electricity to the bungalows.

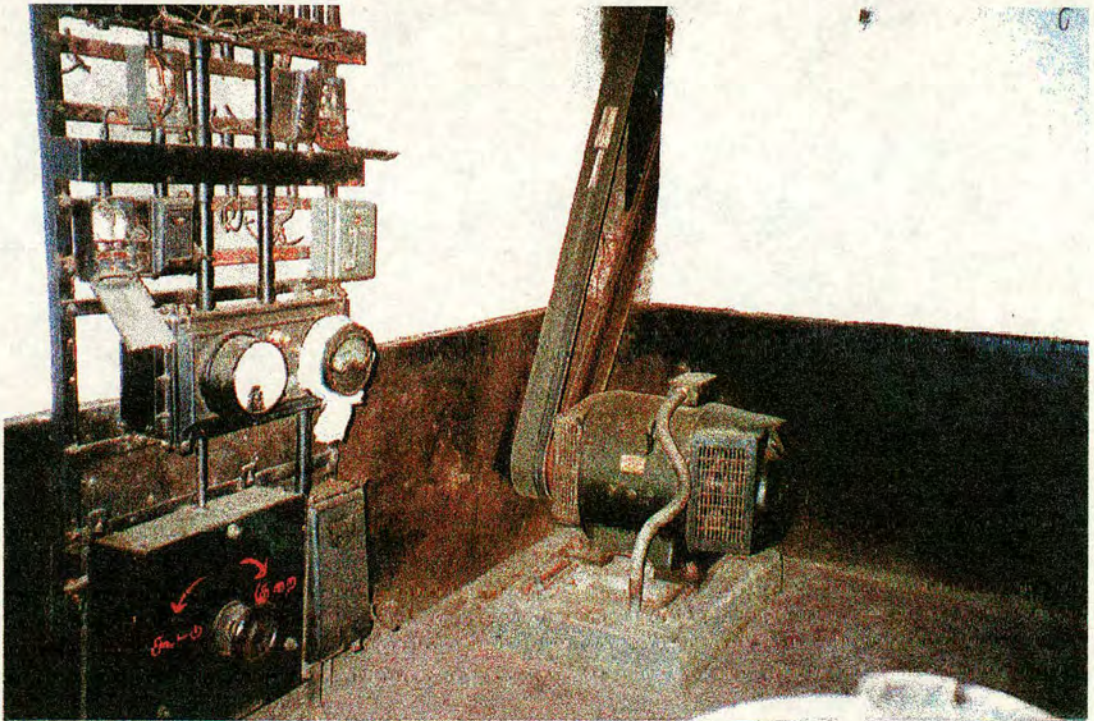


Figure 7.7: Photo of Oonagala plant

Civil works

The penstock, channels, spillways and tanks needed some repairs. It was found, from the site inspection, that the reservoir needed cleaning and de-silting and the dam improved to avoid seepage. The banks are mainly earth although some sections near the weir have been reinforced with concrete. The weir is 20.5 metres in width and needed to be resealed and the crest relined. A 900 metre channel of stone, pointed with concrete, leads to the penstock intake and there were some leaks in the stone sections. The portal valve and wash-out valves of the weir, the steel aqueducts and sections of pipe in the channel, the trash screen and 200 metres long penstock all needed replacing. The intake tank at the entrance to the penstock needed re-lining and a new overflow was required.

Electro-mechanical equipment and site connection

The existing electromechanical equipment would need to be replaced and, since the factory at Oonagala was virtually abandoned, the power developed transmitted to Maldukelle. Synchronising facilities would be necessary unless the power just supplied an isolated section of the Maldukelle factory load or the workers' houses. The factory load (for both factory and houses) was estimated to be 250 kW for a single shift, during which time either option would require a net import of power from the grid. For the remainder of the day most of the generated capacity would be exported, and for that reason the sites were costed as grid-connected. The length of the overhead line that would be required was taken as distance between the factories, measured as approximately one kilometre.

While the roads to and between the factories existed, their condition was so poor that an allowance of 500 metres of new road was made for their improvement. A terrain factor of 3 was considered appropriate.

Options

Two options were considered. The first was to situate the plant in the existing factory, giving a head of around 70 metres. The second extended the penstock by about 150 metres that increased the gross head by 35 metres.

Option	(1)	(2)
Gross head (m)	70	105
Flow (litres/sec)	98	98
Capacity (kW)	49	73
Penstock (m)	200	300
Road (m)	500	500
Line (m)	1,000	1,000
Civil costs £ (£/kW)	138,661 (2,830)	205,060 (2,809)
E&M costs £ (£/kW)	152,989 (3,122)	156,583 (2,145)
Total costs £ (£/kW)	291,650 (5,952)	361,463 (4,954)
Payback (yrs)	>25	>25
Benefit/cost	0.12	0.15
NPV over 25 years	-ve	-ve
IRR	n/a	n/a
Feasible	NO	NO

Table 7.8: Summary assessment from SAM for Oonagala

Assessment from SAM

Considering the flow figures suggested alternative plant capacities of 60 kW and 85 kW. When the ratio of areas method was used from the nearest gauged river (the Hulu Ganga) with a 30% exceedance an output power of 49 kW was achieved for the 70 metre head and an output of 73 kW for the 105 metre head.

The assessment of the two options, from SAM, summarised in Table 7.8, shows that even increasing the head to provide a capacity of 73 kW does not offset the interest charges and operating costs against the electricity costs. Even though a split-interest loan was incorporated, the projects could not be made to pay back investment if UK equipment in the 100 kW power range was used. The determining factor in this estimate was that the existing turbine room was unsuitable for new equipment so new civil works would have to be undertaken. Therefore, in the power range considered, this site was assessed as uneconomical for grid connected UK equipment and would be better suited to development using locally manufactured equipment, to supply the factory at Maldukelle and domestic load.

7.3.2 Case study for the site at Hapugastenne

Agents: James Finlay and Co (Colombo) Ltd

Surveyed July 1995

There are two factories virtually within line of sight of each other. The upper is a tea factory and the lower a rubber factory. Both are in production.

Hydrological considerations

The water runs from a 23 km² catchment into the Rat Ganga where it is diverted by a weir towards the tea factory. Float measurements and repeat measurements with the calibrated flowmeter gave a channel velocity of 1 metre/sec or a flow of 280 litres/sec. There is no opportunity to increase the flow because along most of the 2300 metre length the channel was full to the edges with spilling in parts, as shown in Figure 7.8

Civil works

The weir was in good condition and could be moved to take more water from the river since, at the time of inspection, only 20% was being diverted towards the hydropower plants in the factories. However, the river bed where a new weir would be constructed is boulder-strewn; access to the weir is limited and it is about a twenty minute walk from the nearest point that can be reached in a jeep. Most of this walk is along the channel that measures 0.35 metres deep by 0.79 metres wide, reducing in width at parts along its length and with many sections that are aqueducts across valleys. The channel materials vary from concrete lining to tin sheet to earth at various places. The existing penstock intake and settling tank was found to have a spillway and scour outlet - there was some sand deposit in the channel. All elevations were measured and all distances were estimated at site. The altitude of the weir at 549 metres was taken as the baseline, the elevation of the existing penstock intake was 478m, and from this intake the 500 metre, 12 inch (47.3 cm) diameter penstock drops sharply to the factory at an elevation of 347 metres. The penstock is brought down the right-hand side of a valley, looking downwards, where the land is unstable and slippage has introduced deflections into the penstock. There were numerous leaks at leaded joints. The gross head on the Boving turbine was found to be 131m and the maximum available flow 280 litres/sec. If the channel was relined to avoid losses and the penstock was replaced to the existing settling tank, the power available in the tea factory would be approximately 260 kW.

The water from the tea factory is partly discharged into another penstock, which feeds the rubber factory and from there into a succession of falls down into a valley containing the Denawak Ganga, joining it at an elevation of 85 metres. The penstock between the two factories was dewatered and there were many perforated sections in the lower parts near the rubber factory. The elevation of the rubber factory is 292 metres, and restoring the penstock from the tea factory would give a gross head of 55 metres and, for a flow of 280 litres/sec, produce a maximum capacity of 110 kW.



Figure 7.8: Photos of Hapugastenne estate

Condition of plant

The penstock leads the water into the tea factory where there is an existing Boving single jet Pelton turbine, belt connected to an alternator. The Pelton turbine was from the era when two-legged buckets were bolted to a plate hub. The buckets were of the 'Doble' design without good elliptical forming and had no notches but, since the factory had extensive experience of casting, grinding and fitting their own buckets, these were in working order. The generator was dc excited with pilot exciter, slip-rings and brushes and again, due to meticulous maintenance, the rings and brushgear were in good condition. A GP Electronics load controller was used to dump excess power into a ballast load. Although the load controller exhibited fairly poor stability at times when the load was low, the plant was in service and produced about 30 kW that was used to supply an isolated section of the factory load.

The discharge flow from the turbine was measured in the tailrace by a calibrated flowmeter and found to be 160 litres/sec. In addition to the leaks in the channel, there were a number of points at which water for washing was taken out, and the factory also used the high pressure water for some processes. This accounted for the differences between this and the higher upstream flow.

Within the rubber factory there is a 50 HP Gilkes turgo turbine that is in good condition, although the runner had been replaced with a locally sourced single piece casting. The machine drove a belt system that either supplied line drives or a generator, which appeared to be in reasonable condition. A single cylinder heavy oil engine was also available to drive the shaft system or generator. The generator was used to supply an isolated section of the factory load and was not grid connected. A 440 V switchboard brought the grid supplies into the plant and was also in fairly good condition.

Infrastructure

This factory had the resources to tackle most fabrication, machining or electrical work required to keep the equipment in working order. For example, at the time of the inspection, they were in the process of rewinding one phase of a three phase transformer that had been damaged by a lightning strike - including replacing the 33 kV insulation. There also was skilled labour available for stonework and masonry. There was a lot of enthusiasm and help at this estate for the project.

Recommendations

Four options were considered at the site visit in July 1995, and these were all restricted by the flow that the existing channel was capable of delivering. Rainfall figures were not available, so initial estimates of power were based on flow measurements made at this time. A fifth option was considered on return to the UK and used the rainfall figures supplied by Mr. Wanigatunga (manager of Hapugastenne

estate) which showed that over the applicable catchment area of 5 km² the flow rose to 861 litres/second, for a 40% exceedance and 10% compensation flow. Therefore Option 5 used the typical exceedance curve rather than the flattened curve of a limited flow.

All the options recognised the relatively difficult terrain and a terrain factor of 4 or 5 was used. Also it was recognised that the channel and penstocks are extremely long and whether it would be worth upgrading the waterways to develop more power must be a major factor in the assessment.

The options were to:

- 1) Restore the Turgo in the rubber factory and install new civil and electrical/mechanical equipment.
- 2) Swap generators at the factories.
- 3) Construct a new intake at an elevation of 518 metres with an additional 1500 metres of penstock led down the left hand side of the valley to a new plant near the rubber factory that would give a head of 225metres
- 4) Construct a new intake at an elevation of 225 metres with an additional 2300 metres of penstock led down the left hand side of the valley, past the rubber factory and on below to the river at an elevation of 85 metres. This would give a gross head of 433 metres. In the current SAM assessment the head is limited to 400 metres to allow the decision support software to select a turbine. This limitation is discussed in Chapter 8 and its relaxation is a possible future enhancement of the model.
- 5) Construct a new channel and penstock to make full use of the available rainfall, leading the water to a site at the rubber factory.

Option 1 was rejected for two reasons. It would require most of the investment needed for option 3 and the available power would be limited by the capacity of the existing machine. Furthermore if a new machine was installed the old machine could be moved to the Kiriwendala site to be used for village electrification. Option 2 was not pursued as the factory could address this themselves if they wished and the increase in available power would be marginal. Options 3 and 4 were reported to James Finlay at a meeting in Colombo in July 1995 on an early assessment of the economics of these sites. Initially Option 3 was only marginally feasible due to the relatively low power and the length of penstock crossing fairly difficult land. However Options 3-4 were reassessed on return to the UK and, together with Option 5, are summarised in Table 7.9.

Option	(3)	(4)	(5)
Penstock intake elevation (m)	517	517	517
Power house elevation (m)	292	85	292
Gross head (m)	225	400*	225
Flow (litres/sec)	160	160	860
Capacity (kW)	260	462	1380
Penstock (m)	1500	2300	1500
Road (m)	200	200	200
Line (m)	200	800	200
Capacity (kW)	262	462	1380
Civil costs in £ (£/kW)	295,963	410,022 (887)	845,690 (613)
E&M costs in £ (£/kW)	208,745 (803)	193,486 (419)	196,695 (142)
Total costs in £ (£/kW)	504,709	603,508	1,042,384
Payback (yrs)	10	7	4
Benefit/cost	3.48	5.79	9.98
NPV over 25 years (£)	2,510,233	4,931,137	14,020,646
IRR (%)	13	20	31
Feasible	YES	YES	YES

Table 7.9: Summary assessment from SAM for Hapugastenne

In option 5 the channel was replaced to remove the restriction on flow applied by the dimensions of the old channel. The site chosen was at the elevation of the rubber plant (option 3). This produced a plant of capacity 1380 kW. Extending the penstock to the lower site at the river would produce a capacity around 2500 kW. The reason that the electromechanical costs/kW of the 1380 kW site are so low is that the decision support software could not at the time select generators of greater capacity than 1000 kW. Manually inserting the cost of a 1000 kW, 1500 rev/min generator increased the total cost to £1,080,084 and extended the payback to 5 years.

7.4 Use of SAM

Selected results from SAM have been shown for the sites described in Section 7.3. The ease with which a sensitivity analysis can be undertaken, different options investigated and the clarity of the display demonstrated the use and effectiveness of this software in the field.

The accessibility and user-friendly nature of SAM were also demonstrated in a meeting with Lahiru Perera, of Intermediate Technology, in July 1995. He initially had no intention of buying a Gilkes turbine for a development project. However, an interactive discussion on the site where the output from SAM was compared with the original data from his preferred machine changed his mind. The ability to slightly change the specifications and show the sensitivity of the models allowed him to compare the performance and costs of the two turbines under consideration, and reach a decision that was based on good analysis and detailed comparisons, far beyond that possible in the time scale without the decision based software.

7.4.1 Evaluation of the effect of changing the capacity of a plant

As a result of economies of scale, refurbishment of existing mini hydropower plants or installation of new plants is likely to be more cost effective for plants of larger capacity. The installation of a plant which was based on the available hydrological

potential, rather than just meeting factory load, was attractive to the CEB and the new tea companies. The management of the tea estates saw restoration or replacement of mini hydropower plants as offering:

- secure power sources for tea production processes that potentially would reduce crop-loss costs;
- considerable reduction in annual electricity purchase costs;
- the opportunity to export excess capacity which would earn revenue

The capacity of the plant was modelled by SAM. An example in Figure 7.9 shows what happens when the capacity of a plant was reduced by diminishing the annual rainfall and hence flow. SAM selected and costed successively smaller plant, but the costs of the civil works are not linearly related to the flow and this led to an increase in the overall cost/kW as the plant capacity fell. This is consistent with results from mini hydropower plant surveys world-wide.

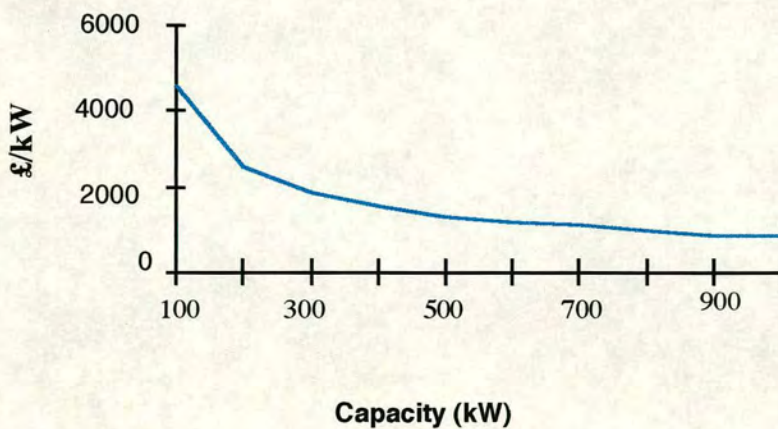


Figure 7.9: Costs versus capacity of a plant using results from SAM

SAM was also used to model the relationship showing the minimum capacity at which a plant became commercially viable and the relationship between the payback periods and the capacity. All these graphs demonstrate that mini hydropower schemes, connected to the grid are more attractive than small schemes providing power only for the tea plantations. Figure 7.10 gives an example of this, showing that where commercial and geographical conditions are fixed, there is a minimum capacity of plant that will be economically viable.

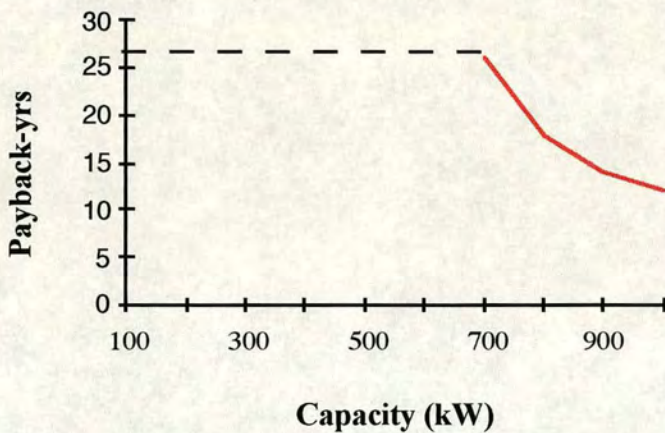


Figure 7.10: Payback versus capacity using results from SAM

7.4.2 Conclusions: decisions after site surveys and use of SAM

Examples of the results of the field studies have been discussed in sections 7.5 and the findings were presented in the reports [Wilkinson, 1994]. A synopsis of the results for the sites at Oonagala, Maldukelle, Obadaya Oya, Mount Vernon and Hapugastenne is shown in Table 7.10

	Oonagala (2)	Maldukelle (1)	Maldukelle (2)	Obadaya Oya	Mt Vernon (1)	Mt Vernon (2)	Mt Vernon (3)	Hapugastenne (1)
Head (m)	105	200	2260	152	94.5	146.5	167.7	225
Flow (litres/sec)	98	140	140	370	700	700	700	860
Civil costs £M	0.21	0.3	0.4	0.22	0.34	0.5	0.78	0.85
E&M costs £M	0.16	0.18	0.19	0.2	0.24	0.25	0.28	0.2
Total costs/£kW	4,954	2,406	2,369	1,045	1242	1020	1264	755
Capacity kW	73	198	258	400	472	732	839	1380
Payback (yrs)	>25	16	17	10	14	7	17	4
benefit/cost	0.15	1.93	1.92	3.8	1.29	5.92	1.17	9.98
NPV over 25years		£1.1M	£1.5M	£2.3M	£0.3M	£6M	£0.3M	£14M
IRR	n/a	7	7	14	14	21	12	31

Table 7.10: Comparison of the economic analysis for selected sites

It is seen that the relative payback times, IRR and NPV show that the Hapugastenne site offered the best option for development. However it also shows the need for the economic analysis which considers all these factors. The IRR for Obadaya Oya and Mount Vernon (1) are the same, the capacities of the plants are similar but the NPV and benefit cost analysis show that for these two schemes Obadaya is superior. However option (2) for Mount Vernon would give a better economic return on all counts. The comparison of the economic returns for Mount Vernon (2) and Hapugastene compared with the other results showed the economic benefits of increased capacity.

7.5 Issues of Infrastructure

The preceding sections have discussed the technical and economic results of this work. However, one of the most important factors in a project in a developing country is to build up support and trust in the local community. This has been discussed in Chapter 4 where it was shown that the failure of many previous schemes was due, in part, to a lack of knowledge of the local culture and a misunderstanding of the local environment. For example, the costings of equipment from local suppliers could not have been done in the U.K. nor on a single short visit to Sri Lanka; it relied on an appreciation of the local environment that could only be built up over time.

How this factor was addressed, the criteria that were developed to identify the knowledge and understanding required, and the methods used to obtain the relevant information together with examples of visits, seminars, etc. are described in the next two sections.

7.5.1 Approach and criteria

Early work in Sri Lanka to ensure the commercial success of the projects emerging from the study indicated that it was necessary to find out:

- Who is important in the relevant sector in government, civil service and industry and obtain introductions to them (e.g. Ministers, head of CEB, Directors of the tea plantations, Hydro Systems and the Project manager for Intermediate Technology).
- Where influence lies in supporting new projects in the area of hydropower (e.g. votes, energy policy)
- What factors generate support (e.g. loan funds, grants from ODA)
- Where relevant data and information are to be found (e.g. CEB, ITDG)

7.5.2 Methodology

The methodology for organising a technical-economic research project in a developing country is based on the setting up and maintaining personal contacts. Data cannot be obtained from readily available published sources but must be obtained, checked and verified through diverse means including word-of-mouth. Thus the methodology in dealing with such an infrastructure differs from that encountered in other technical projects that are based on experiments carried out in western universities.

The following paragraphs describe the method that was employed and, while the examples are based on the work in Sri Lanka, the general approach would be useful in any similar exercise. The implementation of this method is central to any project undertaken by a researcher in a developing country.

- **Initial meetings:** on arriving in Colombo the author, Dr. A. R. Wallace and Mr. D. A. Williams from Gilbert Gilkes and Gordon had a series of initial meetings to set up the first contacts for the feasibility study and to arrange a seminar at which the project was launched. The initial contacts, their organisation and function in this research are shown in Table 7.11.

Organisation	Title	Name	Remit
Open University of Sri Lanka	Vice Chancellor	Prof. D. Wijeysekera	Arrange a base
British High Commission	First Secretary (Commercial/Economic)	Mr Ian Dallas	Analysis of current energy policy and political situation.
Ceylon Electricity Board	Assistant General Manager Generation Planner	Mr S. Fernando Dr T Siyambalapitiya	Structure CEB and current situation re feasibility studies and grid connections. Comparison with UK
Ceylon Electricity Board	General Manager Planning	Mr D Wijeratne	Electrical and safety aspects of mini hydropower. Support available from CEB
Secretariat for Infra-structure, Development and Investment		Mr Bennett Parton Mr Paul Lynch	Involved with environmental assessment, training work force, development safety procedures
Intermediate Technology	Country Manager	Mr Lahiru Perera	Description IT projects. Arranged REW to join CEB/IT mini hydropower study group
Hydro Systems (Ceylon)	Director Consultant Engineer	Mr S. De Silva Mr R. Wijeyeratne	
Ministry for Energy Conservation	Minister Secretary	Mr S. Rajakaruna Mr W Rajakaruna	International business links
Park Lloyds	Agent	Mr U Boralessa	Introductions

Table 7.11: Initial meetings to introduce the project

- **Introductions:** During the following twelve months contacts were made in the CEB, ITG, management companies, technical firms, government bodies, NGOs, academia, British Council, consultancy firms and the local Institute of Engineers (IEE).
- **Meetings:** After contact had been made meetings were set up regularly to keep abreast of the latest political, economic and technical developments. The author was dependent on personal contacts rather than merely accessing data from published sources.
- **Feedback:** It was necessary to give feedback to the contacts to keep them informed on the progress of the project. Because of the necessity to obtain local information, often not available in any other form, the researcher, as organiser of a project, had to maintain a two-way system of sharing information.

An example of feedback is the talks given by the author to the CEB, ITDG and IEE groups and the meetings with the Hydro Forum, summarised in Table 7.12. These built up a two-way communication system. The author explained her activities and what she was trying to achieve. This enabled people in different organisations to understand the relevance of her work to them, so they could offer advice and help.

- **Key players:** It is important to recognise and identify the key people in the country. For example, during the field survey it was found that a key player in the hydropower market in Sri Lanka is Mr. Lahiru Perera, of the Intermediate Technology Group. He is involved with proposals for around ten sites in the 1000 kW power range and is well respected by CEB. He is likely to proceed with these as a private developer

Date	Group	Title of Talk
23/9/93	Launch	Demonstration of software
1/12/93-5/12/93	25th Anniversary Exhibition	Poster on project
4/5/94	CEB	Seminar to 50 people on project
10/5/94	ITDG	Seminar to MHP Group
17/5/94	IEE	Audience of engineers
20/8/94	Hydro Forum	Feedback meeting

Table 7.12: Showing date, venue and title of talks

- Local agent:** at the beginning of the project Gilbert, Gilkes and Gordon employed Mr. Borralessa from Park Lloyds International as their agent. During the initial visit he efficiently organised all details of the visit, including transport, meetings, the trip to the tea estates and the launch seminar. However, he had no technical expertise and was unable to assist with relevant information during the field surveys. A second agent, Mark Marine Services Ltd. has been employed since.
- Maintaining contact:** At the end of the field study a method of maintaining contact with the most important sources through email and letters over a protracted period is necessary if valuable information is not to be lost. Recent experience by Gilkes suggests that a project falters locally (and the prospects of business diminish) when UK staff return home. At meetings during the final visit it was observed that there is an inherent danger in operating a great distance from the Sri Lankan market. The presence of Biwater in Sri Lanka, as discussed in Chapter 4, gives them a greater advantage as the local investors are aware of their presence and international investors have

increased faith in Biwater's knowledge and experience of the country. Between September 1994 and July 1995 the Biwater project, as discussed in Chapter 4, had progressed to the stage where seven sites were under detailed feasibility study and there was considerable local interest in taking equity in these schemes.

7.6 Other Factors Affecting Decisions:

Discussions with the CEB during the field study raised the following issues that, although the survey only addresses the cost of connection to the grid, and assumed that equipment such as transformers etc. would be part of the PPA, are still relevant to the issue of mini and micro hydropower in Sri Lanka.

7.6.1 Safety regulations.

A similar statutory requirement to the UK Electricity Council requirement, G59, existed in Sri Lanka, but the grid voltage and frequency could not be maintained within the limits prescribed by G59. An example of the ubiquitous electrical safety standards is shown in Figure . In the increasingly stretched Sri Lankan system the protection equipment in many tea estates automatically disconnects the supply due to fluctuations in the grid supply (giving indications of under voltage or under frequency) rather than as a result of overload from connected equipment.

Particularly in outlying rural areas there is no ethos of safety. In many cases CEB engineers have set out to make safe an area of the grid, to find that a remote generator had not been tripped and continued to operate allowing areas of the grid to remain live and potentially harmful. While in principle G59 should legislate against this, it was clear that the only practice that would ensure safety of staff would be to operate a system that forbade access after a trip (padlock out system) on all mini hydropower plants and only allow authorised representatives access.

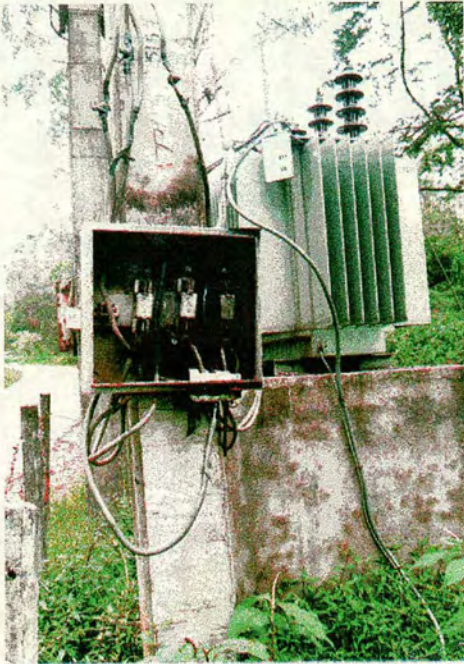


Figure 7.11: An example of electrical safety standards in Sri Lanka

7.6.2 Connection to the grid

CEB staff are reluctant to allow grid connection of induction generators at the end of long transmission lines. Any additional demand for magnetising current, which the CEB system must provide, can cause problems of voltage regulation in their system. There is also the danger of self-excitation in the event of grid failure. They are also concerned at the indiscriminate installation of load controllers and phase angle controlled devices at plant that connected to their system. They prefer that new installations include synchronous generators with electronic AVRs and water turbines controlled by a recognised and standard governor system. The CEB liked the idea that use of SAM would tend to standardise control equipment and that experience would be developed in the operation and maintenance of a limited number of standard devices.

Experience has shown that the governors and control systems for mini hydropower plants have to be simple, maintainable and affordable. Mini hydropower generators

must be doubly excited and capable of supplying reactive power to stabilise the voltage of the grid at remote points. Frequency stability can be improved by the presence of properly governed turbines with adjustable governing systems.

7.6.3 Management response to proposals

The response of the managers of various tea companies to the proposals was mixed but some interesting points arose which showed the importance of understanding the culture and the infrastructure. These comments were made at meetings during the final field visit in 1995.

Investment in larger sites and comparison with returns from tourism

In a meeting with a management company, Aitken Spence, in Colombo in July it was explained that some investment companies take the point of view that “bigger is better” and so avoid mini hydro plant investment. Again others prefer not to develop hydropower-plants when the greater short-term economic benefits may be obtained from tourism and hotel building. Aitken Spence themselves had moved into the travel/tour and hotel business, but saw mini hydropower as the most serious of several diversifications in their investment plans. They felt they would have little difficulty in raising funds for the correct mini hydropower project, but were only interested in larger scale plants, in excess of 300 kW. The assessment using SAM had indicated that Maldukelle was a 200 or 400 kW site with marginal economic feasibility based on the local costs for new civil works. To reduce the payback on this site to eight years required the insertion of CEB refurbishment costs. To proceed with this option the local costs would need to be reduced significantly, but Aitken Spence did not seem to be interested in schemes of this size. They were basing their economic expectations for mini hydropower schemes on the profitability of the tourist industry (i.e. expecting the same payback and IRR), which was wholly unrealistic and a very unfair comparison. The capital investment for tourism is much lower and the operating costs (at local labour rates) are very low. The revenue from

the throughput of tourists is based on international hotel, food, beverage, and entertainment prices that were around ten times the local rate so the profit margin on the 'fuel costs' is very good. It was felt that if the tea companies persisted in comparing mini hydropower with tourism as an investment they would not invest in any schemes on a strictly economic basis.

Turn-key projects compared to local involvement

Whereas Lahiru Perera was adamant that schemes should be locally resourced and built as far as possible, some of the owners of the tea plantations were only prepared to consider turn-key projects and were wary of the management framework and infrastructure necessary for other approaches. Again a synopsis of a discussion with another management company, George Steuarts, in Colombo in July 1995 clarifies this position. They felt that of all the sites surveyed in this project, the Mount Vernon scheme was the most attractive in every respect. Hydrologically it was good, topographically it was excellent, and there was a rising demand from the factory load that could be met with export to the grid. George Steuarts stated that they had the interest and enthusiasm to proceed, but were wary of embarking on such a project other than on a turn-key basis. However, even on such a basis they felt that "prior to committing more time and effort to this very attractive project the requisite management framework would have to be put into place". It therefore did not go ahead at this time.

Pilot Scheme

The most successful proposal to arise from this project was that at Hapugastenne. The potential of the site together with the support of the management were the factors that led to the proposed development of this site. A resume of discussions with the management highlight the criteria for success.

- Interested management: James Finlay were very keen on establishing a 'Pilot Project' or 'Demonstration Scheme' which could be used to illustrate the technical and commercial success of mini hydropower installations in their tea estates
- Technically good site: they had a significant number of potential sites for power schemes on their estates in the Hapugastenne area, although some schemes might only be in the 100-200 kW capacity range. Two sites at Hapugastenne and Alupola were on a high priority for upgrading. Both had three options and, based on the assessments carried out at the time of the visit, all six options were economically feasible with four of the six returning capital in ten years or less.
- Good information and data: one of the configurations of the equipment at each site was economically attractive. There were other sites, which might be much larger, but they had not been conceived or surveyed in detail. Some of the smaller sites might suffer economically if they were developed on their own using imported equipment
- Support local community: James Finlays regarded supplying the two factories as a first priority, rather than only being interested in commercial operation to sell to the CEB. It was felt that they had a positive and realistic view of mini hydropower development and were not basing their continued interest on the availability of UK funds, or difficult partnerships of contractors.
- Finance in place: they did not see that project management was a problem and were prepared to operate the entire local content of any projects themselves. They recognised that the next level of study

implied a commitment of time and funds and were prepared to assist with local arrangements and expenses.

The criteria developed as a result of these surveys and discussions has been incorporated into general recommended criteria for the success of mini hydropower schemes in Sri Lanka, which is discussed in Chapter 4 and summarised in Chapter 8.

The decision support software is particularly useful in sensitivity analyses when one variable at a time is adjusted while the others are held at constant values. Small projects are more vulnerable to increasing interest and inflation rates since capital costs and loan repayments do not reduce linearly with plant capacity - so the effects of increasing loan interest rates on the payback period of the project can be examined. The economic viability of the plant is influenced by the tariffs of avoided purchase costs and export sales earnings. In a large plant exporting power most of the day for many months of the year, the sell-out tariff has a greater effect on viability. As plant capacity reduces to and below factory load levels the avoided cost tariff and factory load profiles have a greater effect. The relationship between the capacity of the plant and diminishing the annual rainfall and hence flow can be explored. This is important in plant design because although the program will select successively smaller plant, the overall costs are not linearly related to this because of the inelasticity of the costs of the civil works. Again the overall charge for units of electricity produced can be compared with the plant capacity, and an estimate found of the level that prohibits investment without subsidy in the form of inflated tariffs can be found.

The strength of this program lies in the ease with which all these factors can be examined.

8. CONCLUSIONS

This thesis considers the following issues:

- Why is there interest in mini hydropower development in Sri Lanka?
- Why have many feasibility surveys into mini hydropower on the tea estates failed in the past?
- Why is the option of new hydropower schemes on the tea estates seen as more attractive than rehabilitating old plants?
- Is there a role for software that performs feasibility studies in Sri Lanka? What are the criteria and methodology needed for such software?
- Could the program be used in other countries?
- What are the criteria for successful mini hydropower development in Sri Lanka?
- What is the way forward for future mini hydropower development in Sri Lanka?

This thesis has shown that the potential for mini hydropower plant in Sri Lanka is at least as significant as suggested at the conception of this project. The abundance of hydrological potential, the maturity and reliability of the technology, and the heritage in the installation of mini-hydro plant advances mini-hydro as a suitable rural power source was seen and proved in the surveys.

There is a large demand for the power that could be produced, specifically on the tea and rubber estates with disused waterways and plant. Originally many of these plants were sited in the factory to provide mechanical power and, if positioned

elsewhere, could make optimum use of the available head and water flow. The CEB are encouraging investment to assist with the problems that they face in providing reliable supplies to the rural areas. Foreign investors, some of the tea companies and private Sri Lankan companies are prepared to invest in mini-hydro plant. Every participant in the development process would benefit by the establishment of a reliable, sound mini-hydro installation programme.

8.1 Interest in Mini Hydropower

There are several factors that contribute to making Sri Lanka appear the ideal place for a thriving and profitable mini hydropower industry, such as the hydrological conditions of abundant rainfall in particular regions in Sri Lanka and the topography of the land in the hilly and mountainous regions. There is also a history of hydraulic use, from the early civilisation to the later installations of micro hydropower plants in the tea estates at the beginning of the century.

There is a requirement for electric power from small stand-alone systems, due to a weak grid that does not reach all parts of the country and a shortage of generating capacity. Unlike most other developing countries the demand for such power is not just domestic but is primarily needed in the tea estates. Discussions with the new tea management companies confirmed that they must reduce the cost of production of tea to remain competitive in the Asian tea market. The assessment of the tea production process verified that demand for electricity is rising on all of the estates, and is typically 150 kW in order to meet the factory load and domestic demand. Electrical energy costs are a substantial part of the cost of the packaged tea and the manufacturing equipment requires substantial three phase supplies. There is also a need for electricity for lighting and water heating in the villages of the estate workers. Mini hydropower plants earn 'revenue' from avoided purchase costs supplying this local demand, and accrues export sales earnings from the export of additional energy to the grid. While this thesis has focused on mini hydropower in the tea estates it

also discusses the need for rural electrification in a country where only 25% of all households have access to electricity supplies.

Despite the above factors it was found that the progress in setting up a mini-hydro programme has been slow, with fragmented, sporadic activity and many aborted international initiatives. The political and commercial climate does not encourage investment in the area and recent experience of UK and Chinese micro-hydro practice has led to scepticism about the viability of such schemes. In the past fifteen years there has been an unfortunate and expensive history of poorly constructed and finished projects. Efficiency is poor and reliability is low.

8.2 Previous Surveys

As shown in Chapter 4, the previous surveys were examined in detail, and comments and opinions on their worth were solicited from ITDG, CEB and estate owners while in Sri Lanka. This examination strengthened and confirmed the criteria listed in Section 8.6.

8.3 Rehabilitation versus New Sites

In the 1980s there was interest in reviving the old plants due to grid shortages and the need for a constant electricity supply during the batch process of making tea. Since then there have been about 50 rehabilitation projects installed in the 50-150 kW range, all of which are stand alone plants used to supply the electricity needs of the adjacent factory. The rehabilitation process has been fraught with problems including: badly designed and installed electrical/mechanical equipment that was quickly found to become unreliable and difficult to maintain; optimistic hydrological assessment based on imprecise data; high foreign consultancy costs; lack of investment capital; inadequate technical back-up; low plant factor, usually less than 50%; and insufficient use of local components and materials.

One conclusion of this research was to show that the original remit to look at the rehabilitation of mini hydropower schemes is not economically viable, and also is not what the owners of the tea estates required. They were more interested in the option of developing new sites which would give them the opportunity to take advantage of the offer from CEB to purchase surplus electricity. This would enable them to undertake new surveys and install slightly larger plants with new equipment thus overcoming some of the problems associated with the rehabilitation scheme.

8.4 The Role of SAM

One of the reasons that previous studies failed was that the amount of information, concerning rainfall, location, equipment details and other data, although available, was not easily accessible. An appreciation of the manufacturing capability and available expertise in Sri Lanka was also needed and this was achieved by developing the Decision Support Software in KAPPA which incorporates a database and also allows sites to be assessed and prioritised. The software program SAM was written to design and cost a proposed mini hydropower plant, combining necessary expertise with optimum time spent on the proposed site. It enables the user to make pre-feasibility studies; a hydrology analysis to determine available flow and head, a technical appraisal of old and new equipment, and an economic assessment based on UK, Sri Lankan and parametric costing.

SAM was designed so that particular parameters can be changed during a site survey to see the effect on the economic analysis. It can be used to prioritise sites according to their economic feasibility. It provides options for sites according to the use, for instance, if the selected capacity of the plant is for a 40% exceedance flow or a 70% exceedance flow. The software is applicable to Sri Lanka where there is a need for consistent, reliable feasibility studies, and where the stored data, which is difficult to obtain in other forms, is accessible to the user.

As shown in Chapter 7, the program has been used successfully by Gilbert Gilkes and Gordon as a commercial tool in Sri Lanka. There is a great interest and commitment to hydropower now in Sri Lanka, so the market and potential for such a program are there. The number of studies carried out in previous years have generated a lot of paper and SAM has been shown to be more efficient as well as cutting down time used in repeating calculations and assessing different options.

In particular the advantage of SAM was demonstrated when it was used to assess some of the sites of ITDG for which an independent feasibility study had already been carried out. The assessors were surprised that the difference in capital costs between the imported equipment recommended by SAM and locally manufactured plant was rather less than they had expected. They also realised that the significantly higher efficiencies of the options found using SAM capitalised very heavily over the early life of the project. It is the ability to carry out a full analysis on site and also put in different options and compare the sensitivities of the schemes that is the strength of this software.

However, as the analysis of previous surveys has shown, the transfer of technical knowledge even with economic assistance is insufficient to ensure the success of a scheme. Modern technology can enhance the data maintenance and design specifications for a mini hydropower development but the complex elements of knowledge discussed so far in this thesis must be synthesised with the engineering expertise necessary to produce the calculations, simulations and data needed to design a mini hydropower plant which meets the needs of a given situation in a given country. This experience has helped to define some of the criteria for successful mini hydropower development, detailed in Section 8.6, which had to be implemented before the program could be used and validated.

8.5 Applicability of the software

The calculations in SAM are based on the standard equations used for mini hydropower analysis. However the information that is available in Sri Lanka was taken into account in deciding the specific methods used, for example there are a number of techniques which can calculate the flow of a stream but the choice is limited by the available data.

The technical part of the programme is generic, and has also been used successfully to advise on a system for a pig farm in South Africa, and to recommend a system for use in Knoydart on the West coast of Scotland. However the economic analysis with its dependency on political priorities and decisions is unique to each country. The costings are based on local figures for the price of manufactured goods, raw materials, labour or imports in Sri Lanka. There is no universal scaling factor that can be used for these items. The model also depends on the rate of inflation, the interest rate scenario and tax schemes, so is sensitive to the political system. Therefore to use this program for other countries the economic data, and in particular the local costs, would have to be changed. To obtain relevant data requires knowledge of the local manufacturing conditions and understanding of the local political and economic culture.

The above considerations limit the commercial importance of such decision support systems to cases where the market is large enough to justify the cost of acquiring the relevant data and inputting it into the system. As was discussed in Chapter 6 the data must be collected in a field study and cannot be acquired from a desk study in the UK.

8.6 Criteria for a Successful Mini Hydropower Development Programme in Sri Lanka

Section 4.5 has given reasons why MHP surveys and installations carried out in the last two decades have not been successful despite the available resources and inherent benefits that MHP would provide. After a detailed field survey and extensive evaluation of the MHP proposals that have taken place over the last twenty years the following set of criteria has been developed by the author. This study has proved that it is necessary to fulfil these criteria in order to produce a rational and successful approach to building MHP plants in Sri Lanka:

- **Good technical site.** The sensitivity analysis and economic appraisal documented in Chapter 7 show that, the first requirement, for a successful scheme is a good technical site with high head, large catchment area and consistent pattern of rainfall so that sufficient water is available to run a power system for several months of the year.
- **Good information and data.** The information required for the project falls into three categories: hydrological data and information; technical knowledge regarding the electromechanical equipment and civil works at hydro sites; and an understanding of the manufacturing capability of the country, market potential, taxation policy and funding options to provide an economic database. Lack of information in any of these areas means that the scheme cannot be properly assessed. Lessons should be learnt from previous surveys and projects. The knowledge gained from examining previous studies should be used to prevent similar economic and technical mistakes from occurring; for example the information contained in and lessons learnt from the Consult and ODA surveys must be used. Account has to be taken of the

availability of information and data; complex equations cannot be solved and software solutions evaluated if the data needed for these programs is not available. The problems are unique to each country, and in Sri Lanka are particularly acute when assessing the flowrate and making hydrological calculations..

- **Interested management.** There has to be an interested management; for example when the estates were under national control, there was not the incentive to invest in them and so hydropower schemes did not progress.
- **The Establishment and maintenance of a network of good contacts with an interest in mini hydropower.** There has to be support from local government officials, tea plantation personnel, engineering companies, NGOs, and agents in order to establish and maintain a viable communications network of personal and professional contacts. To obtain data for a feasibility study it is important to commission a thorough field study in the country. Data has to be obtained from the factories, from measurements on site, from Government bodies, manufacturers, NGOs, Universities and specialist groups. Sri Lanka is a developing country, so significant information that is collated and published in the Western world is not available. Little information is documented in papers, books or trade journals but must be obtained through personal contact. Procurement of the relevant factual material is often only possible through personal contacts. It is necessary to spend enough time in the country to build and sustain a communications network of informed contacts at all levels of industry and government. In addition local contacts on the sites should be made and maintained, so that a communication network is in place to avoid repeating work and wasting time finding

data that may already be publicly available. A considerable amount of time is lost and data repeated with surveys being done on the same sites. It takes time to reach the tea estates or rural villages, because of the terrain and poor condition of the roads, and many site visits to collect and check data are inefficient and time consuming. Therefore it is important to have good contacts.

- **Work locally and maintain a reputation for quality.** It is important for a mini hydropower developer, or consultancy firm, that is not based within the country to maintain and build up its profile and reputation. In Sri Lanka the number of people involved with the hydropower engineering industry is so small that good credentials, especially foreign, are difficult to establish and easily lost. For example Gilkes has the reputation, from a long heritage, of providing reliable and competent machinery, whereas the Chinese are unlikely to find support for building any further plant
- **Application of technology and use of appropriate expertise.** In Sri Lanka there are few experts in all aspects of a mini hydropower survey. A balance between the equipment imported and the necessity to build up a base of qualified technicians must be addressed. Once a hydropower engineering industry is established with a number of reliable and successful plants in operation, there will be a market for companies which maintain and service turbines and generators. Then there will be the expertise and knowledge to judge whether the schemes and equipment are appropriate in the local situation. Also they can address the problems of the compromise between price and quality, which is a difficult balance especially when funding is restricted. The equipment must be technically safe and reliable but it should not be over-engineered or use expensive alternatives.

- **Finance.** There must be adequate finance in place. There is little state investment in power generating capacity, but the CEB and the Sri Lankan government are trying to stimulate private sector investment. No management companies are able to fully finance mini-hydro power development and only a few are able to part-subscribe. Management companies are therefore mainly interested in collaborating with foreign companies who are willing to take equity or build mini-hydro plant on a BOO/BOT basis. Interest rates in Sri Lanka are much higher than in the countries supplying the plant, and split-source finance is an enabling economic mechanism for most mini-hydro plants. Irrespective of the desirability of local manufacture of plant, larger sites are likely to be developed with imported plant financed (at least in part) from outside Sri Lanka. The capital costs of mini-hydro schemes (and interest charges) are relatively high and, coupled with the complexity of the financing process, provision of suitable funds may often be the most difficult task in developing a mini-hydro site.

8.7 Future Developments

The circumstances for mini hydro power site development can be ideal; the hydrological conditions perfect and an end-use available for the electricity generated.....but without the infrastructure, the scheme will not be successfully implemented. This has been the case in several of the surveys for mini hydropower plants in Sri Lanka.

The technical limitations for hydropower engineering that exist in Sri Lanka have been discussed. There is the basis for an industry but it is in its early stages. The disorganisation and lack of coherent guidelines for the technical installation of a MHP plant are very apparent. In addition to the above general criteria, there are measures which the government should undertake to underpin the framework for MHP

development. A competent technical department responsible for the development, installation and monitoring of mini hydropower projects is needed. This should include appraisal of the projects economic viability, technical safety and standard. The legislation for the use of the land and water, the drawing up of the PPA's and the structure by which private generators can sell electricity to the CEB should also be put in place.

Having promoted investment in grid-connected hydro plant CEB are compelled to accept the power produced by these plants in the mini and small hydropower power range provided that it complies with minimum supply quality and safety standards. Even in industrialised countries with very much more robust grid systems there are comprehensive specifications for control, synchronising and protection systems. [The UK Electricity Association 1991], [The UK Electricity Association 1989] There is a clear need for the implementation of such standards to prevent unauthorised or improper connection, but they cannot simply be prescribed in Sri Lanka because at the prospective connection points the voltage and frequency of the grid can vary outwith normal limits. At the moment there are a number of plants nearing completion without the establishment of commercial purchase agreements or appropriate technical acceptance standards. Strictly they may not be connected to the grid and may not begin to earn export revenue. Serious investment in larger plant may have to wait until the technical and commercial framework is agreed and proven.

There are numerous good mini-hydro sites which are distributed geographically and in wide ownership, but there is no coherent development framework indigenous to Sri Lanka. There is a forum for mini-hydro power development consisting of companies, organisations and individuals which is active but development is sporadic. Since the rights to develop the sites are now vested with at least twenty two individual companies it is unlikely that there will be a single, co-ordinated development programme. Formation of an association of independent power producers could co-

ordinate, harmonise and streamline practice, but in the short term investment will proceed on a site by site basis.

Therefore although the majority of the current mini-hydro development in Sri Lanka have arisen from the market changes which have attracted tea management companies and private investors, there is no central organisation, or pivotal body, responsible for advancing mini-hydro power. This is seen to restrict the systematic development of mini hydropower potential, although the commercial climate for investment in mini-hydro plant is advanced, all participants and beneficiaries are in place, but the lack of a coherent programme or methodology is limiting progress. If a suitable technical and administrative framework covering the development, installation, technical safety and standards, monitoring, PPA's and legal requirements for mini hydropower can be established in Sri Lanka, investment may proceed with mini hydropower schemes, installed to meet agro-industrial load and reinforce the rural grid.

Future research should monitor the development of these sites, the implementation of safety standards and power purchase agreements and if the criteria given above are necessary and sufficient for a successful scheme.

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APPENDIX 1

Results from Questionnaire at Kotagala Plantations

Hydrology

Map reference:

Terrain: steep, hilly, very moist (rarely dries up)

Stream catchment:

area :

name: Haluganga (tributary)

characteristic:

moderately silty

Are any flowrates available?no

Maximum flowrate:

Minimum flowrate:

Average flowrate:

Annual rainfall figures (last 15 years):

Monthly rainfall figures (last 3 years):see table-note that rain gauge is in factory

Irrigation paths:

Site head: 36.6 m

% of stream utilised:all

ROR or storage:storage

Any nearby streams that could be utilised in catchment area:no

name:

flow details:

Equipment Information

Turbine 1

Serial number of turbine (if available):3512

Year installed:1928

Turbine type:10.5" T.I.

Rated output:21.4

rpm:

Voltage:

Current:

Head:36.6

Condition:bad state of disrepair, bearings completely worn, casing o.k,

runner severely corroded

Turbine 2

Serial number of turbine (if available):CCC

Year installed:1930

Turbine type:Pelton.

Rated output:50 HP

rpm:

Voltage:

Current:

Head:

Condition:see report. Moderate rehabilitation needed, valves need repairs.

Economic/Demand Assessment

Monthly values of electricity consumption for past three years:see table	Generator disappeared, was single phase ac
Factory motor capacities for each process:Total-220HP	Year installed:
Hours per day that each machine is used: see table	ac or dc:
Domestic lighting consumption:2*10A	Rated voltage:
Is domestic grid or hydro?hydro	Rated current:
Monthly production of green leaf/ made tea for past three years:see table	Rated output:
Method used in production:CTC	Excitation details:
Gross turnover:Rs 50,000 (next year est:Rs 750,000)	Type:
Electricity Charges (Peak, kVA, Tariff):	Voltage:
Fixed charge: Rs 313	Current:
Off Peak: Rs 2.75	Output:
Peak Rs 6.45	Condition:
Fuel surcharge; 20%	Standby (i.e. diesel) generators: no
Maximum demand: Rs 78	Capacity:
% of hydro used per months in daily and hourly terms:	How often, and for how long, are they used for? (in hourly and daily terms per month)
How much on average, annually, is lost due to power cuts?	Governor 1:disappeared
Crop wastage (kg):	Governor 2:Year installed:1928
Lost revenue (Rs):Rs 20,000 (last year Rs 1m)	Type:Manual
What months, and for how long, do such cuts occur?	Manufacturer:
Equipment Information contd.:	Condition:still there but needs rehabilitation
Weir/Dam	Belt type:vee, new one needed
Dimensions:	Flywheel:no

Type:

Material:concrete

Condition: several leaks and desilting needed

Intake

Location:

Type:

Construction:

Settling tanks/Forebay tank

Number:1

Dimensions:

Type:

Material:concrete

Condition:cleaned, minor repairs needed.

Channel:

Dimensions:1200ft length

Type:

Material:lined rubble

Condition: leaking, moderate rehabilitation

Spillways

Number:

Dimensions:

Type:

Material:

Condition:

If plant is disused:

Has the turbine, generator or governor been run or tested since the plant stopped operating?
yes,figures unavailable- will ask Project 2000

If so, what was the result, in terms of starting problems, output power, efficiency, head, flow,power factor, speed, temperature, and headloss at different loads?

Penstock 1- to Gilkes machine

Length: 830 ft

Diameter:10"

Material:iron

Headlosses:

Condition (including supports and anchor blocks):several leaks, needs moderate repairs

Penstock 2 to CCC

Length: 3768 ft

Diameter:8"

Material:iron

Headlosses:

Condition (including supports and anchor blocks):bad condition, substantial repairs needed

Powerhouse: turbines in factory

Dimensions:

Base:

Condition:

Does it have a crane?

Switchboard: new switchboard necessary

Trash racks

Dimensions:

Type:

Material:

Condition:

Rating

Main switch

circuit breaker

What kind of switch is it?

Transmission

Grid connection date:

Length of transmission lines:

Rating:

Reservoir

Number:2

Dimensions:

Condition: (1)- nearest factory

No leaks, rusty sluice gate

(2) Leaks, minor rehabilitation needed

Civil Works: figures unavailable

3 sections;

1st part: 30 000 cft reservoir (850m3)

60 ft dam

intake at 3910 ft

canal, tank

9" penstock

feeds Oonagala factory

2nd Part:

22 ft dam

canal with aqueducts

276 000 cft reservoir

dam: 40&190 ft

6" penstock

3rd section:

8000 cft reservoir

30 ft dam

canal, 4 tanks

APPENDIX 2

Contacts and visits to the tea Estates in Sri Lanka

1. Aitken Spence Plantation Management's (Pvt) Ltd Sites Pusselawa Plantations

- 1.1 Delmar
- 1.2. Concordia
- 1.3. Oonagala
- 1.4. Madulkelle
- 1.5. Obadaya Oya
- 1.6 Gordon

2. George Steuarts Management Services (Pvt) Ltd, Kotagala Plantations Sites

- 2.1. Mount Vernon
- 2.2. Craigie Lea
- 2.3. Rosita
- 2.4. Mayfield
- 2.5. Drayton
- 2.6. Stonycliff

3. Hayleys Plantation Services Ltd (Talawakelle) Sites

- 3.1. Wattedode
- 3.2. Holyrood

4. James Finlay and Co (Colombo) Ltd Sites

- 4.1. Hapugastenne
- 4.2. Alupola
- 4.3. Wewellewatha
- 4.4. Kirriwendala

5. Hydro Systems (Ceylon) Ltd Sites

- 5.1. Cecilton
- 5.2. Moratenne
- 5.3. Kalupahana Factory
- 5.4. Ediropola Tea Factory
- 5.5. Ediropola Rubber Factory
- 5.6. Kiripowura Factory

6. Carsons Agro Services Ltd, Elpitiya Plantations

- 6.1 North Meddecombra
- 6.2 Dunsinane
- 6.3 Sheen
- 6.4 Udaveria

7. Uva-Western Plantation (Pvt) Ltd, Maskeliya Plantations

- 7.1 Glentilt

APPENDIX 3

List of Organisations and companies

The following is a list of the organisations visited in Sri Lanka and the UK, which provided information for this research. A contact name is given if there was one main contact, otherwise the name and address of the organisation or company is given

Sri Lanka

Tea Research Institute

Tallawakele

Park Lloyds International

7A Maitland Cres

Colombo 7

British High Commission

Galle Road

Colombo

University of Moratuwa

Department of Civil Engineering

Moratuwa

Colombo

Open University of Sri Lanka

Department of Electrical Engineering

Nugegoda

Institute of Engineers

120/15 Wijerama Mawatha

Colombo 7

Land Use Policy Planning Unit

Mr. Tikeri Banda (Land Use Planning Officer)

Kachcheri

Nuwara Eliya

Survey Department

Mr. J. Jayasinghe

150 Kirula Road

Colombo 5

SIDI

Ministry of Planning and Implementation

87 Horton Place

Colombo 7

Marga Institute

Niranjali Dias

61 Isipathana Mawatha

Colombo 5

Ceylon Electricity Board

Energy Unit

Sir C.A. Gardiner Mawatha

Colombo 2

Rubber Research Institute

Dr. Tillerkeratne

Agalawatte

ITDG

Mr. Lahiru Perera

No.5 Lionel Edirisinghe Mawatha

Kirulapone

Colombo 5

GTZ

Nigel Legg

Kandy

Irrigation Department

Mr. Dharmasena

Hydrology Division

Ministry of Power and Energy

Mr. W Rajakaruna

50 Sir C.A Gardiner Mawatha

Colombo

Janatha Estates Development Board

55/57 Vauxhall Lane

Colombo 2

Hydro Systems (Ceylon) Ltd

Siri De Silva

143 St Michaels Road

Colombo 3

James Finlay Plantation Management

Hapugastenne Plantations

Finlay House

186 Vauxhall Street

Colombo 2

National Engineering Research and Development Centre of Sri Lanka

Ekala

Jaela

Browns Engineering Ltd

Stuart Gibson

33 Katukurunduwatte Road

Ratmalana

Biwater International

Maurice Mackay

3 R.A De Mel Mawatha

Colombo 5

Mahaweli Authority

Dam Site

Polgolla

International Irrigation Management Institute

Dr. Wijayaratna

107 Havelock Road

Colombo 5

Central Engineering Consultancy Bureau

415 Bauddhaloka Mawatha

Colombo 7

Hayleys Plantations Services Ltd

25 Foster Lane

Colombo 10

Aitken Spence Plantations

Rohan Fernando

316 Bloemendhal Road

Colombo 13

George Steuarts Management Services

Kotagala Plantations

Ellakande Estate

Horana

Department of Engineering

Peradeniya University

Kandy

UK

Mr. David Williams

Gilbert Gilkes and Gordon

Kendal

Cumbria LA9 7BZ

Department of Trade and Industry

Graham Atkinson

Ashdown House

123 Victoria Street

London SW1E 6RB

Intermediate Technology

The Schumacher Centre for Technology & Development

Bourton Hall

Bourton-on-Dunsmore

Warwickshire

CV23 9QZ

APPENDIX 4

Selected published papers based on work in this thesis

1. "Rural Electrification and mini hydro power in India and Sri Lanka", Conference paper, IEEE Conference on demand side management, Malaysia, 1995
2. "A knowledge based system for mini hydro assessment in Sri Lanka", Conference paper, 6th Hydropower Conference, Barcelona, 1995

RURAL ELECTRIFICATION AND MINI-HYDRO POWER IN INDIA AND SRI LANKA

Dr A.R. Wallace, Ms Rona Wilkinson

Department of Electrical Engineering, University of Edinburgh, UK.

Dr Alison Doig,

Centre for Environmental Strategy, University of Surrey, UK

Abstract

The first mini-hydro plants in India were built to provide electrical power to areas where there was little prospect of supply from the (then remote) electricity grid. At the same time planters developing the tea estates in Sri Lanka installed several hundred mini-hydro plants to supply mechanical and electrical power to the tea factories. Both countries are extending and reinforcing grid electricity supplies in rural areas. The abundance of hydrological potential, the maturity and reliability of the technology, and the heritage that each country has in the installation of mini-hydro plant advances mini-hydro as a suitable rural power source. There are similarities between the countries in terms of geography, hydrology and the demand for energy in the rural areas, but many differences between the countries mean that the development of the mini-hydro resource is likely to proceed in different ways, if it is to fulfil differing technical, economic and developmental expectations. This paper considers the electricity supply systems in each country, and reviews the potential in each for mini and micro-hydro. The differing end-uses of the electrical energy are examined and the ramifications of plant design, manufacture, installation and utilisation considered. Similarities and differences are discussed and conclusions drawn about the best way to proceed with mini-hydro power in the respective rural electrification programmes.

1. Bulk energy supply in India

The total installed generating capacity in India at the start of the Eighth Five Year Plan (1992) is shown and itemised by fuel source in figure 1 below. [1]

Country	India	Sri Lanka
Installed capacity (MW)	69,810	1,385
thermal (including gas based)	48,825	250
hydro	19,168	1,135
nuclear	1,785	
wind	32	
Population (million)	950	19
Installed capacity (kW/pc)	0.073	0.073
Gross annual energy production (kWh/pc)	297	230
Annual energy usage (kWh/pc)	229	153
Average annual growth in demand (%)	10	10

Figure 1 - Electricity Supply Statistics

The complex power sector comprises of State Electricity Boards, multi-state organisations for projects such as inter-state hydro projects, central government organisations and companies, Government of India Departments such as the Department of Atomic Energy and now an increasing private sector involvement. The Indian power system incurs high losses averaging 23% of the power transmitted, with some rural networks losing over 40% of transmitted power. The large line losses are attributed to the relatively low level of investment in the transmission and distribution system plus the over extension of the largely radial rural and urban network. It is hoped that renewal and upgrading will reduce the losses to 15% by the end of the century.

1.1. Policy changes and privatisation

Until recently the electricity supply system in India has been tightly controlled and regulated by the public sector, with less than 1,000MW of licensed capacity or embedded industrial power plant. [2] Similarly, there have been strict limitations on foreign investment in the country. However, due to a shortage of public financing, India has now been forced to open the power sector to private investment and is now encouraging foreign investment of up to 100% equity in power generation projects. The changes in power policy have consequently opened new opportunities for private, NGO and community development of mini-hydro power plants.

1.2. Rural electrification and mini-hydro power in India

Rural Electrification in India was almost non-existent at the time of independence in 1947, but has grown to the extent that, by 1990, 81% of villages were supplied with electricity. Coverage of rural electrification in India is most commonly defined in terms of the percentage of villages with electricity. It is generally the very large, poorer, states such as Uttar Pradesh, Orissa and Bihar, which are well below the Indian average extent of rural electrification. In addition, most of the remote North Eastern states have very minimal rural electrification, excluding Assam, which is the most modernised and developed state in that region. The definition of an electrified village in India is a village with "one service connection provided within its revenue boundary" [3]. Not even one household need be connected for a village to be counted as electrified. The percentage of rural households with electricity supplies is quoted as only 27%. [1] Of the budget allocated for Electricity Sector Development in the Eighth Plan period, only 5% has been allocated to the development and upkeep of rural electrification.

The extent to which the rural areas in India are already electrified means that, where possible, grid-connection is likely to displace the installation of isolated generation systems, which are seen as more suited to the geographically remote areas, where the extension of grid supplies is difficult and expensive. The Rural Electrification Corporations, at both central and state level, were set up in 1969 to plan and finance the development of rural electrification by the State Electricity Boards around the country. In nearly all cases rural electrification is far from viable in financial terms, which puts huge strain on the State Electricity Board resources, so that they are often reluctant to

undertake rural electrification projects. Reasons for the poor return from investment in rural electrification include: the low load density and large investment required in line extension; the low rural tariff; and the low load factor in rural areas.

One option being employed during the Eighth Plan is the use of decentralised, non-conventional generation methods. It is envisaged that 10,000 of the planned 50,000 villages to be connected are to be electrified by non-conventional means. [1] The Eighth Plan proposals for new and renewable sources of energy (NRSEs) give priority to the development of indigenous technologies and their commercial exploitation and promotion.

1.3. Potential for development of mini-hydro power in India

The small hydro power potential in India is frequently conservatively estimated at 5000MW, of which 40% is located in the Himalayan hills and the other 60% is to be found on the Southern plains. The majority of India's 75MW installed capacity is in the Himalayan region, with some of the North Eastern states generating most of their power at small hydro plants. Although the majority of new sites under construction are also in the hills, there is development in many other states at canal drops on the irrigation network, with 350 MW of potential in Karnataka alone. [4]

1.3.1. Low Head Sites - Canal Drops

The Rural Electrification Corporation identified over 1000 possible low- and ultra-low head sites in the mid-1980s. Although at canal sites the civil works are usually available with only limited modifications required, there have been problems encountered with power house construction. One disadvantage of power generation at irrigation canal sites is that the canals are frequently only used for eight or nine months in the year. Also flow is highly dependent on the amount of rainfall during the monsoon, which can be unreliable. This seasonality limits the production of power and requires prior operation planning and load management. At grid connected projects this is less of a problem, though there is a loss in revenue when the canals are out of service.

1.3.2. Medium and High Head Sites - Hill sites

The Government of India has given priority to remote hill sites, especially in those regions into which the grid is unlikely to extend and diesel generators are presently the only source of power. In addition it plans to develop mini-hydro plants for grid reinforcement in Himalayan states in locations where the grid supply is weakest. At higher head sites there are different problems associated with civil works due to the nature of the geology and climate in the Himalayan region. The long power channels and penstocks are prone to frequent damage due to flooding and landslides, particularly during the monsoon period, and silt erosion is common. Problems with extreme temperature and remoteness of some hill sites frequently hinders site construction and implementation. Installation and maintenance costs are frequently increased as a result and local construction and technical skills may be limited. In the Himalayas the lean flow period of a high hill site is not in the dry pre-monsoon period, during which time snow and glacier melt is available, but in the winter months when the streams freeze over. The resulting reduction in generating capacity

during winter frequently coincides with the population leaving the higher regions, and so has less impact than may be expected. These are not strictly technical issues but are the main obstacles limiting widespread development of mini-hydro sites. Projects in remote hill areas are to be promoted by the Global Environment Facility (GEF) in collaboration with the DNES through a three year programme entitled "Optimising Development of Small Hydel Resources of Hilly Regions". [5] The programme is expected to concentrate on the development of schemes up to 200kW in capacity, though it is officially to incorporate sites up to 3MW. The funding provided by the GEF should enable the development of an effective programme in the Himalayan states. However there is precedent that most of the funds could be allocated to the creation of institutional and bureaucratic structures, rather than to rural mini-hydro development.

1.4. Indigenous technology and manufacturing capabilities

India has become almost self-sufficient in producing equipment for mini hydro power generation, through import substitution and technology transfer contracts with overseas manufacturers. There are nine manufacturers of mini-hydro turbines in India, all of whom have had collaboration with European manufacturing companies. Each of the turbine manufacturers produce equipment both for the domestic and the overseas market. Seven of these Indian turbine manufacturers also produce generators and four can develop mini-hydro projects on a turnkey basis. Three other manufacturers produce generators suitable for hydro applications. The Government crossflow turbine research and pilot schemes have had varied success. The turbine, designed and tested at the Indian Institute for Science in Bangalore, has been developed as a low cost, simply fabricated alternative to the costly conventional, high precision turbines produced by conventional manufacturing companies. At many isolated sites electronic load controllers are installed rather than conventional speed governors to reduce cost and complexity.

1.5. Power utilisation

Two problems commonly experienced in terms of power utilisation at mini-hydro plants are under-utilisation during the day and over-utilisation in the evenings. Overloading during the evenings occurs due to poor load management with over-extension of the distribution system to more domestic users than the generating plant can adequately supply. Reasons for under-utilisation during the day are directly related to the lack of wider use of electricity, other than for lighting purposes, so that there is very low daytime load. In order to diversify the daytime load it is important to link power projects with other development initiatives. For example, reduction of fuelwood use could be achieved by the promotion of cooking with off-peak power and the adoption of low cost low wattage cookers. Also there are opportunities for controlled expansion of the tourist industry, as has happened in Nepal, where some of the tourist villages in the hills are supplied with electricity by micro-hydro power plants. Conversion from diesel driven motors used for milling and small diesel generators to water power could reduce dependence on costly import and transportation of fuel. It is evident that the most successful mini-hydro sites in India are those which have developed day time loads for commercial use.

1.6. Finance and administration of Mini-Hydro Power in India

The principal financial organisation for supporting the development of NRSEs is the Indian Renewable Energy Development Agency (IREDA), established in 1987 as a "specialised, autonomous public undertaking at the central level to translate the policies of the government of India into reality". [6] As NRSEs are generally viewed as a risky investment by the commercial banks and the private sector, IREDA has been set up as the enabling financial mechanism to promote NRSEs in India. The agency has two main functions: - to finance NRSE projects; and - to encourage state agencies, commercial companies and other financial institutions to popularise and commercialise NRSEs and to establish an industrial infrastructure for NRSE technologies.

The mini-hydro programmes in the Indian Himalayas have consistently lacked clear objectives for power development, with the role of the hydro plants never properly defined within the wider energy sector. Frequently, at the project proposal stage, benefits of projects have been exaggerated and the costs involved have been understated in order to gain project approval. This has led to arbitrary site selection and poor planning of load development and power utilisation.

Development projects are constrained by the frequently extensive and inflexible Indian bureaucracy and hierarchical administrative systems. The level of bureaucracy is illustrated by the example of one hill district where the responsibility for mini-hydro projects of the State Electricity Board is dispersed between the offices for electro-mechanical equipment, civil works, transmission and distribution and administration, which are located in different towns across the district. This has resulted in fragmented record keeping and poorly co-ordinated implementation and running of the projects, including delays in carrying out repair work. Similar disorganisation can be found at central and state government level also. Inflexibility has resulted in over-specification of project designs, administration and staffing requirements. This in turn has increased overall project costs and reduced economic viability. The creation of the central body for mini-hydro development is a first step towards improving this at the state level, by designating one office in charge of mini hydro development. A restriction of the Indian bureaucratic system is the sectoral nature of departments and the internal barriers for interaction and co-operation. There will need to be effective co-ordination of development sectors if mini-hydro projects, and similarly other NRSE projects, are to be viewed as a tool for development and environmental purposes, and not just as part of rural electrification programmes.

2. Bulk energy supply in Sri Lanka

The total installed generating capacity in Sri Lanka in 1993 is shown and itemised by fuel source in figure 1 above. [7] Since Sri Lanka gained independence in 1948 the transmission and generation system (and 80% of the distribution network) has been owned and operated by the Ceylon Electricity Board (CEB). The remainder is owned by the Lanka Electricity Company (LECO), which is jointly owned by the CEB and the Urban Development Authority. Losses in the Sri Lankan power system average between 20-30% of the gross transmitted power but reduction of losses to around 10% is a priority. [8] In the short term there is a projected load growth exceeding

10% due to the increase in the tourism industry. Coupled with retiral of ageing plant reducing system capacity, the resulting loss of load probability will soon exceed 20%. [7]

2.1. Policy changes and privatisation

The most significant change in the attitude towards mini-hydro development came about in 1992 as the government devolved management of the tea estates to 22 private companies, ultimately on a 30 year lease. The management companies face considerable economic hardship as the market value of the quality tea grown in Sri Lanka has fallen below production costs. Most of the management companies own micro-hydro plant in varying states of repair and have, on their estates, the majority of the hydrological potential for mini-hydro power. Coincident with the change in management and the opportunity to diversify into power generation CEB offered a buying in price of 2.6 Rs/kWh for privately produced power. This has caused considerable foreign and Sri Lankan interest in developing and owning mini-hydro plants on an equity basis. [9]

2.2. Rural electrification mini-hydro power in Sri Lanka

In Sri Lanka there are two requirements for renewable energy generation. The existing grid system requires to be further reinforced with additional generating capacity, particularly in rural-industrial areas such as the tea estates, and there are many more-isolated areas which will require isolated generation systems, since they are too remote from existing or projected grid supplies. There are around 25,000 rural villages in Sri Lanka, housing about 70% of the population. Rural electrification proceeded initially under the auspices of the local authorities but in 1969 became the responsibility of the CEB, financed by annual government grants. In 1977 the Asian Development Bank and CEB collaborated to implement a structured approach to village electrification, with the result that now over 12,000 villages are electrified. Not all houses in these villages can afford a connection and only about 20% of rural households have electricity. [10] This is due to: high capital costs of supply; the dispersed nature of the households; low financial returns on investment and high maintenance costs; low load factors, typically 7%.

2.3. Potential for development of mini-hydro power in Sri Lanka

Sri Lanka has the potential and resources to provide another 510 MW of power mainly through upgrading or installing new mini hydro plants in the tea rubber and coconut plantations.

2.3.1. Rehabilitation and up-grading of plant in the tea estates

At the turn of the century many British tea companies installed UK mini-hydro plant, with the main purpose of supplying factory mechanical shaft power and dc electricity for domestic use. In the 1950s several large power stations were built and the CEB grid expanded, resulting in a surplus of grid-electricity. Following nationalisation of the tea industry the estates were encouraged to take electricity from the grid. As this coincided with a general shift away from mechanical power to ac-supplied motors, most factories took advantage of the connection charge subsidies offered and established grid supplies. It became less necessary to maintain the mini-hydro plants and almost all fell into disrepair. At rated capacity there is about 15 MW of power available from these plants but

by upgrading most could be increased in output by about 50%. [11] In the 1980s there was interest in reviving the old plants due to grid shortages and the need for a constant electricity supply during the batch process of making tea. Since then there have been about 50 rehabilitation projects installed in the 50-150kW range, all of which are stand-alone plants used to supply the electricity needs of the factories. There are few rehabilitated and new schemes nearing completion with capacity 100kW-1MW. The rehabilitation process has been fraught with problems including: badly designed and installed electrical/mechanical equipment that was found quickly to become unreliable and difficult to maintain; pessimistic hydrological assessment based on imprecise data; high foreign consultancy costs; lack of investment capital; inadequate technical back-up and low plant factor, usually less than 50%; insufficient use of local components and materials.

2.3.2. *Village electrification*

Around eighteen villages are supplied from vertical shaft multi-jet Pelton turbine generators in Sri Lanka, implemented at 'marginalised' communities where there was little chance of grid connection within the next five years. These schemes have been installed with maximum village participation, by the formation of an Electricity Consumers Society responsible for construction of civil works, administration and operation of the schemes. Up to 50% of the funds for these schemes have come from the communities themselves. A sale tariff system is implemented based on economic viability, welfare considerations, end usage, and capital costs. [12]

2.4. Indigenous technology and manufacturing capabilities

Since most of the sites are in the hill areas with high heads the micro-hydro turbines currently installed in Sri Lanka are mainly Pelton, turgo impulse or Francis machines which have been imported from Europe and China. The manufacturing capability for small hydro power equipment in Sri Lanka is limited, but the relative simplicity of multi-jet vertical shaft Pelton turbines and crossflow machines allows local manufacture up to about 100kW. The plants offer reduced capital costs and efficiency, but this must be evaluated carefully if the plant is to be installed on a commercial basis. Generators need to be imported and the components for the switchgear are also imported but assembled locally. Sri Lanka has the engineering capability in small consultancy firms, manufacturers of electrical and mechanical equipment and civil contractors to rehabilitate schemes under 100 kW. Larger mini- and small-hydro plants for grid-connected export which must be economically attractive to investors will have to include imported plant of high efficiency, conventional design and proven reliability.

Having promoted investment in grid-connected hydro plant CEB are compelled to accept power produced by plants in the mini- and small-hydro power range which comply with minimum supply quality and safety standards. Even in industrialised countries with very much more robust grid systems there are comprehensive specifications for control, synchronising and protection systems. [13][14] There is a clear need for the implementation of such standards to prevent unauthorised connection, but they cannot simply be prescribed in Sri Lanka because at the prospective connection points the voltage and frequency of the grid can vary outwith normal limits. At the moment there are a number of plants nearing completion without the establishment of commercial purchase

agreements or appropriate technical acceptance standards. Strictly they may not be connected to the grid and may not begin to earn export revenue. Serious investment in larger plant may have to wait until the technical and commercial framework is agreed and proven.

2.5. Power utilisation

The new tea management companies must reduce the cost of production of tea to remain competitive in the Asian tea market. Electrical energy is a substantial part of the cost of the packaged tea with, on average, 0.7kWh/kg required for drying. Once dried, the tea passes through many cutting and rolling machines which require substantial three phase supplies. Demand on all of the estates is rising and may be around 150kW. While this varies with shift working the night-time troughs in demand are filled to a certain extent by lighting supplies to the estate workers villages. Mini-hydro plant earns 'revenue' from avoided purchase costs supplying this local demand and accrues export sales earnings from export of additional energy to the grid. While interest in mini-hydro has mainly centred on the tea estate areas, it has been found that village-level electrification schemes in the rice and coconut areas are also viable due to the productive end uses for the electricity.

2.6. Finance and administration of mini-hydro power in Sri Lanka

There is little state investment in power generating capacity, but CEB and the Sri Lankan government are trying to stimulate private sector investment. No management companies are able to fully finance mini-hydro power development and only a few are able to part-subscribe. Management companies are therefore mainly interested in collaborating with foreign companies who are willing to take equity or build mini-hydro plant on a BOO/BOT basis. Interest rates in Sri Lanka are much higher than in the countries supplying the plant, and split-source finance is an enabling economic mechanism for most mini-hydro plants. Irrespective of the desirability of local manufacture of plant, larger sites are likely to be developed with imported plant financed (at least in part) from outside Sri Lanka. The capital costs of mini-hydro schemes (and interest charges) are relatively high, and coupled with the complexity of the financing process, provision of suitable funds may often be the most difficult task in developing a mini-hydro site.

Since the newly-privatised management companies in the tea estates can no longer seek national empathy or international subsidy in the production of uncompetitive tea, they are now considering diversifying into other more lucrative businesses, such as tourism, travel and private power production. There are numerous good mini-hydro sites which are distributed geographically and in wide ownership, but there is no coherent development framework indigenous to Sri Lanka. There is a forum for mini-hydro power development consisting of companies, organisations and individuals which is active, but development is sporadic. Since the right to develop the sites are now vested with at least twenty two individual companies it is unlikely that there will be a single, co-ordinated development programme. Formation of an association of independent power producers could co-ordinate, harmonise and streamline practice, but in the short term investment will proceed on a site by site basis.

3. Discussion and Conclusions

The similarities and differences between the Indian and Sri Lankan MHP programmes emerge as:

<u>Similarities</u>	<u>India</u>	<u>Sri Lanka</u>
Climate/topography		Tropical/hill country
Demand for energy		Urban/rural
MHP heritage		Existing plant and large potential.
Existing rural supplies	Incomplete/over-extended	
Commercial change		Recent opportunity for private investment

<u>Differences</u>	<u>India</u>	<u>Sri Lanka</u>
Constructors	Government	Tea Estates/NGOs/Private developers
Admin framework	Extensive	Yet to be instated
Role of NGOs	None	Active
Marketplace	Rural economy	Highly commercial
Funding sources	Government/GEF	Private
Manuf. industry	Indigenous	Imported equipment
Purpose	Rural electrification	Grid sale/agro-industry/rural electrification
Loading pattern	Low load factor	Full/good/low load factor

There are many natural and historical similarities between the mini-hydro programmes in India and Sri Lanka, and they both have increasing urban and rural demand for electrical energy, but the grid systems do not yet serve fully the rural areas. There are areas in each country where the grid supplies exist in rural areas but the uptake of rural domestic supplies is limited by the cost of connection, unless subsidised. Availability of rural industrial load and community involvement in the installation and operation of plants has assisted in the establishment of micro-hydro plants in both countries. There is potential to develop mini-hydro plants at a large number of sites in both countries and increasing opportunity for private development. Both countries have access to support from bodies such as the Global Environment Facility, to proceed with infrastructural development in the rural areas, using micro-hydro as a power source.

The majority of the current mini-hydro development in Sri Lanka arises from the market changes which have attracted tea management companies and private investors, whereas in India the interest is still largely confined to that of government or central authorities. India has an extensive administrative system for mini-hydro development which proliferates responsibility. Sri Lanka as yet has no central organisation, or pivotal body, responsible for advancing mini-hydro power. In either case this is seen to restrict the systematic development of mini-hydro potential. The commercial climate for investment in mini-hydro plant is more advanced in Sri Lanka than in India and all participants and beneficiaries are in place, but the lack of a coherent programme or methodology is limiting progress. Non government organisations are more active in promoting micro-hydro systems for rural electrification in Sri Lanka than in India.

India has indigenous manufacturers whose products could be used to develop commercial scale mini-hydro sites, but the manufacturing base in Sri Lanka is currently limited to micro-hydro plant for village level electrification. The perceived application of the technologies is, unfortunately, the converse. In the rural areas of India, installation of hydro power is likely to remain part of village electrification programmes requiring mainly micro-hydro plant. If a suitable technical and administrative framework can be established in Sri Lanka, investment may proceed in mini-hydro schemes, installed to meet agro-industrial load and reinforce the rural grid.

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A Knowledge-Based System for Mini-Hydro Assessment in Sri Lanka

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1. INTRODUCTION

There is a large number of mini-hydro plants in the tea estates of Sri Lanka, many of which operate poorly or are disused. If restored or replaced these plants could contribute to the increasing rural, industrial and national demand for energy. Commercialisation of the management of the tea estates has renewed interest in mini-hydro power generation and brought about the need to survey many potential sites, either for refurbishment or replacement of the existing power plants. Rapid and consistent assessment of the viability of investment in a large number of generically similar projects is best carried out on a knowledge-based system.

This paper reviews the role for hydro power in Sri Lanka and briefly considers the history of mini-hydro plants in the tea estates. Recent changes in the tea industry and how they might affect the development of new and existing mini-hydro plants are discussed. The paper describes some of the principles embodied in a KBS that the authors have developed for site assessment of mini-hydro plants in Sri Lanka. The breadth of information and depth of detail required to assess the economic viability of refurbishment or replacement is described in a succession of flow diagrams and screen captures. The extensive local information and expertise embodied in the KBS is described where appropriate.

2. MINI-HYDRO IN THE TEA ESTATES

Sri Lanka is trying to reach the status of Newly Industrialised Country (NIC), in the same category as Thailand and North Korea, before the year 2000. One of the criteria set by the World Bank for NIC status is that the country must have an electricity demand growth rate greater than 10% per annum and an energy consumption per capita greater than 600kWh/annum [Siyambalapitya, 1994¹]. At the moment Sri Lanka does have a demand growth rate of 10.8%, but only generating capacity for 153 kWh/annum per capita. It should also be noted that only 30% of all households in Sri Lanka are electrified.

Sri Lanka has a tropical climate, dominated by two monsoons. Most of the rain falls in the mountainous regions, where for many years the water has been used for agricultural purposes and as a source of energy for electricity generation using mini-hydro plants. Hydro-power plays an important part in the electricity production of Sri Lanka. Large-hydro plants accounted for 90% of the 1017MW generating capacity in 1991, and are still used to meet the base load of the country, as shown in table 1, [Siyambalapitya and Samarasinghe, 1993²]. Reductions in capacity of existing large-hydro plant and seasonal droughts have limited the available generating capacity in recent years, and reduced the plant margin. Load-shedding is commonplace at times of high demand; the loss of load probability has been projected to exceed 10% in the near future. For reasons of national status and rural development the Sri Lankan government proposes to further increase the generating capacity.

Most of the large-hydro power sites have now been developed and other bulk sources of energy are being considered, such as the installation of coal-fired plant built under Build-Own-Operate-Transfer agreements and fuelled from imported low-sulphur coal. The location of Ceylon Electricity Board (CEB) generating capacity and geographical layout of their transmission system means that rural areas such as the tea estates are served by weak sections of the grid with relatively low fault level which would benefit from reinforcement. Voltage and frequency stability could be improved, reliability could be increased, and local load shedding would

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therefore be less prevalent. CEB committed to provide grid-connections to all estates by the end of 1995, and is keen to encourage any private investment in mini-hydro plant in the tea estates.

Installed Capacity	1289	MW
Hydro	1017	MW
Thermal	272	MW
Maximum Demand	685	MW
Units generated	3376	GWh
Hydro	3116	GWh
Thermal	260	GWh
Annual demand growth	10.8%	
Electricity consumption per capita	153	kWh/year
Households Electrified	30%	

Table 1: Energy Statistics for Sri Lanka, 1991

2.1. History of Mini-hydro in Tea Estates

At the turn of the century small-scale hydro played an important role in supplying mechanical and electrical power to the main industries at the time, notably tea and rubber processing. In the development of the tea industry during the period 1890-1950, many British tea companies installed UK mini-hydro plant, with the main purpose of supplying mechanical shaft power to operate the factory machines and dc electricity for domestic use. At that time Gilbert Gilkes and Gordon alone supplied over 400 turbines to the tea estates. In the 1950s several large power stations were built and the CEB grid expanded, resulting in a surplus of grid-electricity. Following nationalisation of the tea industry the estates were encouraged to take electricity from the grid. As this coincided with a general shift away from mechanical power to ac-supplied motors, most factories took advantage of the connection charge subsidies offered and established grid supplies. It became less necessary to maintain the mini-hydro plants and almost all fell into disrepair. In the 1970s only 5% of the original hydro plants in the tea estates were still operating, [Hislop, 1988³]. By the 1980s the major sources of grid-supplied electricity had become large-hydro plants at the Victoria, Kotmale, and Randendigala dams. Due to a combination of silt build-up which prevented some of these generating plants from operating at maximum capacity, and repeated monsoon failures, for five months of the year there were regular, widespread power cuts affecting the whole country which could last up to several hours every day. The whole country was affected by these power shortages, but as the tea estates were a considerable distance from the urban load centres such as Colombo, they were often the first to experience supply outages. The tea manufacturing industry required a more reliable source of electrical energy to wither and process the crop, and the financial losses incurred as a result of these supply failures led to a revival of interest in the rehabilitation of the disused hydro-plants. It is estimated that there are still around a thousand tea, rubber and coconut plantations in Sri Lanka, all of which have a high energy demand for primary commodity processing. These estates are largely located in the central hill region of Sri Lanka as shown in figure 2 below [Humbel, 1991⁴].



Figure 2 - Map of Sri Lanka

2.2. Changes in the Tea Estates and Industry

As mentioned above, in the 1980s, the two formerly state-owned tea companies in Sri Lanka (State Plantations Board and Janatha Estates Development Board) became keen to restore and upgrade the mini-hydro generating plant on the estates. Although a number were restored, interest waned and there were many more sites which did not proceed beyond the feasibility study stage, for a number of reasons. These included:

- pessimistic hydrological assessment based on imprecise data;
- scheme designs and costings making insufficient use of local components and materials;
- lack of investment capital;
- installation of new equipment that was found quickly to become unreliable and difficult to maintain.

The tea estates were originally cultivated, planted, operated and privately managed by British Colonists. After Sri Lanka gained independence, the estates remained in private ownership until 1950 when they gradually came under government control. A powerful trade union formed in the then huge labour force, resulting in the allocation of available subsidies to wages and the provision of local services for estate workers. This reduced investment in fertiliser, new bushes and factory machinery. In the late '80s, very few estates made a profit and the tea industry as a whole faced a falling world-wide buying price. Sri Lanka's tea is of high quality but gives low yield compared to India and Kenya, [The Economist, 1993 ⁵]. These factors combined with the result that the cost of production exceeded the auction price over several years, [Central Bank of Sri Lanka, 1993 ⁶]. After some years of support, the World Bank threatened to withhold future aid to the tea industry if it did not restructure into a more commercial operation. In 1992 the process of commercialisation began with the government devolving management of the tea estates to 22 private companies on a 5 year lease, extended to 30 years at the end of 1994. The World Bank continues to forecast falling tea prices and the new management companies are considering other methods of saving costs or generating income, including refurbishment or replacement of the mini-hydro plants for power generation for factory supplies and export to the grid.

2.3. Demand for Energy in Tea Estates

The new management companies must reduce the cost of production of tea to remain competitive in the Asian tea market. Electrical energy is a substantial part of the cost of the packaged tea with, on average, 0.7kWh/kg required for drying. Withering and drying is a carefully controlled process; a 15 minute loss of electricity supply results in a lowering of the quality of the tea and a break of more than 3 or 4 hours results in the leaves being processed at the time being ruined. Once dried, the tea passes through many cutting and rolling machines which require substantial three phase electricity supplies. Electrical demand on all of the estates is rising and the average demand at the sites is now estimated to be around 150kW. The existing and former mini-hydro plants are generally medium head run-of-river type, with minimum storage, whose average output power is around 75kW. Demand has outstripped the capacity of the hydro plants, even if they were all in good working condition. The estates have become heavily dependent on the availability of grid supplies and increased demand has reduced stability and reliability. In addition, wide frequency and voltage variation caused by poorly regulated water turbines and generators being synchronised to weak and unreliable grid supplies results in frequent failure of induction motor drives in the factories. Downtime, repair and replacement further increases the costs of tea production.

As a result of economies of scale, refurbishment of existing mini-hydro plants or installation of new plants is likely to be more cost effective for plants of larger capacity. The installation of a plant which is based on the available hydrological potential, rather than just meeting factory load, is attractive to the CEB and the new tea companies. The management of the tea estates now see restoration or replacement of mini-hydro plants as offering:

- secure power sources for tea production processes which potentially will reduce crop-loss costs;
- considerable reductions in annual electricity purchase costs;
- and the opportunity to export excess power which will earn revenue.

CEB are encouraging local generation by recently publishing attractive buy-in tariffs of 2.8Rs/kWh at sites of capacity less than 1MW and 3Rs/kWh at sites over 1MW, where at the time of writing the rate of exchange is £1:Rs72.

2.4. Development of Existing and New Mini Hydro

The overall potential for development of mini-hydro power in Sri Lanka has been estimated as 510MW, at sites of average capacity 250kW, [CEB, 1989 ⁷]. Of nearly 500 tea estates formerly operated by the two tea boards in Sri Lanka, around 10% have operational mini-hydro plants providing electrical power to the factories. Just as many estates have mini-hydro plants where the machinery and/or the civil works has fallen into disrepair, [Perera, 1992 ⁸]. Many estates have undeveloped hydrological potential and there are management companies who are fortunate to have more than one possible site. At an estate with an existing site the choice may be between refurbishment or installing all new equipment somewhere else on the estate. Access to development funds is critical because few of the management companies have capital to invest directly in mini-hydro plant. Irrespective of the ultimate source of funds, it is necessary to demonstrate technical and economic viability of proposed investments by carrying out feasibility studies.

To carry out a comprehensive feasibility study requires a considerable amount of knowledge and experience. The base information on which the assessment is made must contain manufacturing detail of the mini-hydro plant, other overseas costs and rates, and a great deal of Sri Lanka costs and rates. The site-specific information required ranges from hydrology and topography, through the condition of operational or disused generating plant and civil works, to the current or projected loads in the tea factories and end uses for the power generated. Once this information is obtained the experience and knowledge of the assessor is used to:

- conceive the scheme;
- design, select and cost the plant;
- compute revenue;

- evaluate technically and economically a number of alternatives, even at one site.

The process has to be rapid, repeatable, and consistent and must produce acceptably accurate results, when used by different assessors. The authors have developed a knowledge-based system (KBS), which supports the assessment of feasibility. The KBS was required to:

- Survey and report the condition of operational/disused schemes with a view to assessing the cost and economic merit of their refurbishment.
- Investigate and report on the feasibility of installing new schemes whose capacity was maximised to supply present estate demands, provide electrical power for local consumption on the estate, and export excess capacity to the grid;

It was essential to maximise the indigenous content of work by using local rates for labour and materials for site work, and prices for plant manufactured or retailed in Sri Lanka.

3. KNOWLEDGE-BASED SYSTEM

The KBS was developed on a 486 Personal Computer (PC), to operate in a Windows™ environment, to be robust and portable as a 'run-time' version on a notebook PC. It is constituted of three interlocking knowledge structures:

- the *knowledge base* containing all of the information pre-loaded into the system;
- the *inference engine* controlling the assessment and decision process;
- the *site object records* classifying and storing all survey detail and process output.

The knowledge base and inference engine were constructed to accumulate

- the experience and technique of survey engineers
- technical detail of plants previously supplied
- technical detail and costs of replacement machinery and components
- historical hydrological data for the catchment areas containing the tea estates
- selection and performance detail and costs of turbines, generators, governors, and valves
- design and specification detail for new civil works, switchgear, and transmission equipment
- local costs and rates for bulk commodities and services
- local costs for proprietary and retail hardware
- commercial detail of the purchase/sale of energy, and inflation and interest effects

The extent of manufacturing detail and engineering experience and knowledge which had to be embodied in the KBS demanded the use of an *object oriented* programming structure which allowed software objects to be created to represent parts, and features, of the mini-hydro schemes with pre-defined characteristics and behaviour. The KBS software was written in the KAPPA™ development system in the KAL™ programming language.

Specific items of equipment, civil works, or features of the schemes are represented as *classes* in the object structure. Parts of the equipment or finer detail are represented as *sub-classes*. Each subclass in the object structure has another dimension attached to it known as the *slot structure* consisting of a set of *data slots*. Each slot is programmed with permitted types and values so that it may hold only data which is of the correct type, relevant to the class concerned. Information can only be entered or calculated in the process of a survey as a property of one of the objects in the object structure. The assessor is therefore constrained to enter data of the correct type, within the value range for the particular slot.

In the process of carrying out a survey the assessor has to input base information to ensure that consideration is given to its currency and validity. If necessary this information can be adjusted to consider sensitivity to changing technical detail or economic conditions. This information is always taken through the KAPPA interface during the survey. Most of the Sri Lankan detail, local rates and prices could be subject to annual or monthly revision so a large section of the knowledge base has to be accessible and easily updated. The EXCEL™ spreadsheet is used for

this purpose. Dynamic Data Exchange (DDE) is used to pass information between KAPPA and EXCEL, with numerical processing and cost computation being carried out in EXCEL. Logical assessments and decision processing take place in KAPPA. Raw survey and feasibility study information may be stored in .KAL files for retrieval into KAPPA. Final reporting takes place through EXCEL, from which re-accessible .XLS files may be printed.

All of the KBS is accessed through a custom-designed WINDOWS™-based interface with drop-down menus and sub-menus. Most programme control and data entry is by mouse-selection. Keyboard input is heavily type-trapped for spurious input and value-trapped for out-of-range errors. The remainder of section 3 describes the breadth of the KBS by identifying the higher level options - as appear in the menu bars. The depth of the KBS is illustrated in the case of a refurbishment survey, by successive movement to lower level of detail.

3.1. Entry to the KBS

Having entered a pre-configured password, the assessor must enter "Assessor Details" followed by "Client Details", by filling data entry windows. On completion the assessor chooses between "Refurbishment Survey" at an existing site, or "New Site" as appropriate. The symbol shows graphically which alternative is selected to illustrate the vertical hierarchy of the KBS. In this paper this is illustrated by the example where the assessor is recording the condition of the deflector mechanism on a Pelton or Turgo-Impulse turbine.

3.2. Refurbishment Survey

Having selected "Refurbishment Survey" a new menu bar allows the assessor to select the features of the mini-hydro scheme shown in figure 3. Each of the options has up to six lower menu-bar selections, proceeding into greater detail and further down into the hierarchy of the KBS software. Figures 4, 5 and 6 show the selection of "Turbine" from the "Electromechanical Equipment" menu-bar, "Stationary Assembly" from "Turbine", and then "Deflector Assembly". Having reached the area of the KBS which describes the deflector assembly all of the wearing, sealing, or enclosing components are listed. The condition of each of these components is shown as a data entry window, wherein the condition, as found on site, can be selected by mouse operation, as shown in figure 7. Extent of wear, or leakage are selected from discrete levels. Where the condition may be described numerically or as a percentage, this input is made via Windows slider-bars.

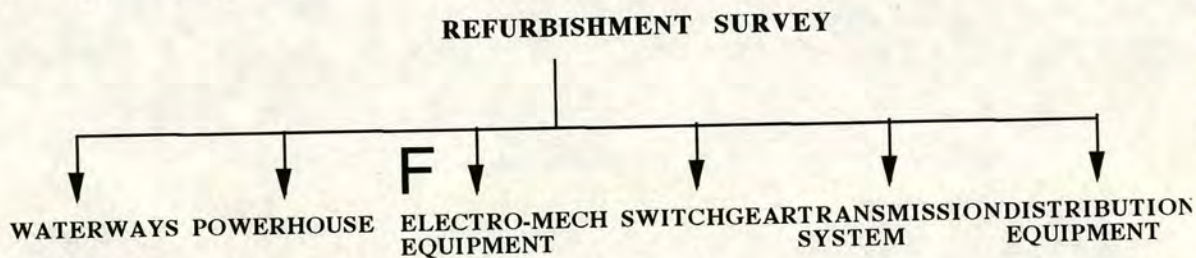


Figure 3: Refurbishment survey

In the example above, "Electro-mechanical Equipment" is a class in the Object Structure, which has a slot "Condition". The sub-classes "Turbine", "Stationary Assembly", "Deflector Assembly" and "Bearings" are subsidiary classes to "Electro-mechanical Equipment" and each above in the hierarchy, but they all inherit the slot "Condition". The selection made in figure 7 would be from the allowable values shown, and would be ascribed to the condition of the bearings on the deflector rod.

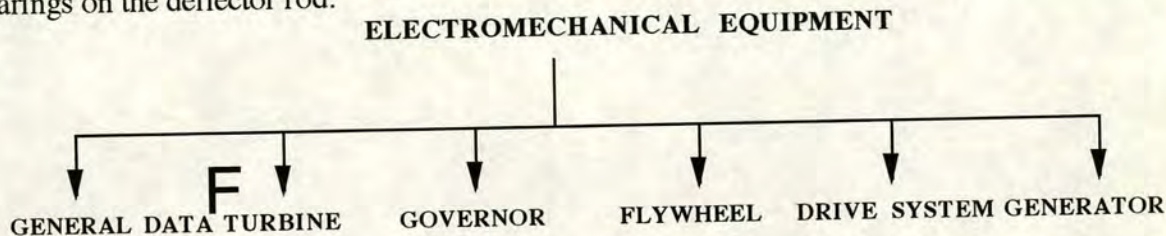


Figure 4: Electro-mechanical equipment

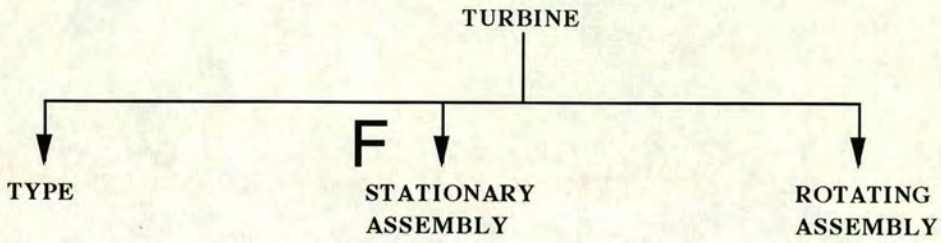


Figure 5: Turbine

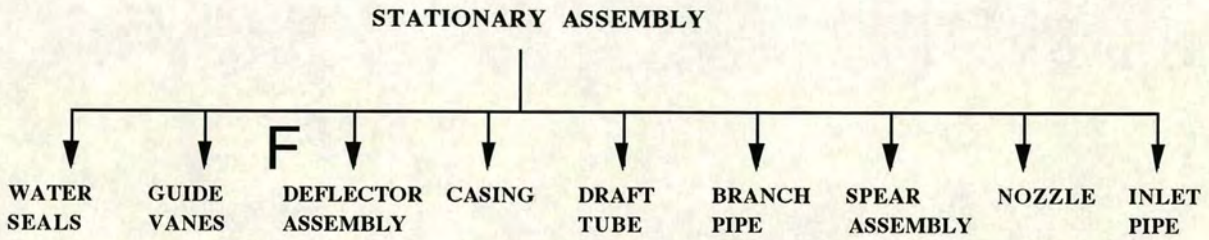


Figure 6: Stationary assembly

Data Entry Form		
Next Page		
Turbine: Data Entry Form 2 for Stationary Assembly.		
Deflector Bearings: General Condition <input type="radio"/> GW0 <input type="radio"/> Worn <input type="radio"/> Seized <input type="radio"/> Missing <input checked="" type="radio"/> Not_Assigned	Deflector Seal: General Condition <input type="radio"/> GW0 <input type="radio"/> Leaking <input type="radio"/> Missing <input checked="" type="radio"/> Not_Assigned	Casing: Chamber Facings <input type="radio"/> GW0 <input type="radio"/> Worn
Deflector Levers: General Condition <input type="radio"/> Fractured <input type="radio"/> Bent <input type="radio"/> Eroded <input type="radio"/> Missing <input type="radio"/> GW0 <input checked="" type="radio"/> Not_Assigned	Deflector Shaft: General Condition <input type="radio"/> GW0 <input type="radio"/> Bent <input type="radio"/> Fractured <input type="radio"/> Worn <input type="radio"/> Missing <input checked="" type="radio"/> Not_Assigned	Casing: Condition of Case Drain <input type="radio"/> Clear <input type="radio"/> Blocked
Deflector Plate: General Condition <input type="radio"/> GW0 <input type="radio"/> Worn <input type="radio"/> Loose <input type="radio"/> Missing <input checked="" type="radio"/> Not_Assigned	Casing: General Condition <input type="radio"/> Watertight <input type="radio"/> Leaking <input type="radio"/> Corroded_Internal <input type="radio"/> Corroded_external	Casing: Condition of Vane Bushes <input type="radio"/> GW0 <input type="radio"/> Worn

Figure 7: Deflector assembly

The costs of repair of this component are calculated as a percentage of replacement cost and allocated to another slot "Cost of Repair" also recognising the viability of repair. Overall repair costs are calculated by summing the costs of each sub-component to the slot of the main-component one level above in the hierarchy. The above example is for one sub-component of the deflector mechanism, but there are paths offering equally detailed scrutiny of other assemblies and components, amounting to around 2000 objects.

3.3. New Site

If the assessor wishes to consider an entirely new site, this would be selected from the options at the entry menu bar, producing the "New Site" menu shown in figure 8. Numerous details of the site are inserted by the assessor, upon which the feasibility design can proceed, such as:

- intake channel length;
- penstock length;
- distance from the road;
- distance to the grid.

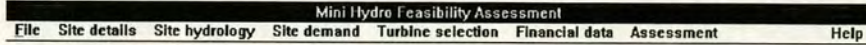


Figure 8 - New Site - Menu Bar

3.4. Hydrology

Site hydrology must be assessed before further design or costing can take place. Gross head is entered, based either on route survey or from site maps. The KBS incorporates three methods to establish the flow rate. The first takes direct input of flow if this is known. The central hill region contains 90% of the river basins and watersheds in Sri Lanka, but ground water is limited, as most of the rainfall escapes as surface water. Annual rainfall is high averaging 2,500-4000mm but most areas experience a dry period between mid January to mid-March. Rainfall data has been collected for over a century from around 40 automatic rain gauges (situated on the major rivers) and 500 manual gauges scattered around the island. Stream flow data is available for the last 50 years, [Dharmasena and Machanayke, 1994⁹]. The second and third alternative methods of flow estimation make use of either the rainfall figures or run-offs measured at gauging stations, as shown in figure 9.

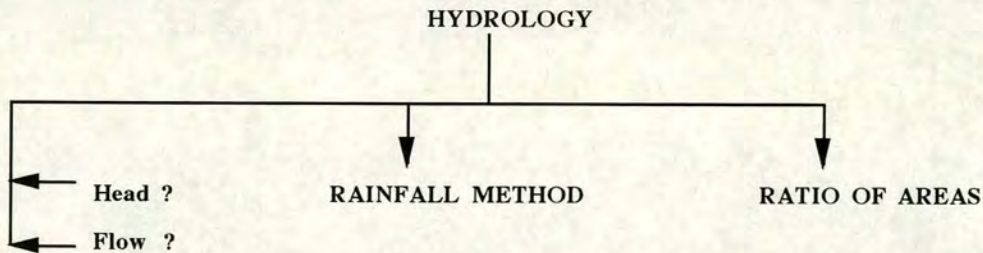


Figure 9 - Hydrology

The "Rainfall Method" is standard, using rainfall data, surface area and an accepted run-off coefficient between 0.4 and 0.7, [IOH, 1982¹⁰]. If the rainfall figures are not available the "Ratio of Areas" technique is selected. Most of the mini-hydro sites in the tea plantations are at

ungauged tributaries in the upper catchment areas of the river basins, of which the Mahaweli Ganga basin is the largest. The average of 50 years of flow data at each of fourteen gauging stations in the tea plantation areas have been installed in the KBS. The assessor selects which gauging station lies in the same catchment as the site being surveyed, and provides the area of the catchment for the proposed scheme. The run-off from which the scheme can draw is estimated from the gauged site and the ratio of catchment areas. In each of the two methods, the monthly flows are converted into exceedance curves, from which the gross flow can be selected, based on an adjustable exceedance. The KBS also subtracts an adjustable compensation flow.

3.5. Energy Survey

Base revenue and economic viability of the proposed mini-hydro plant is heavily influenced by the energy usage in the tea factory. If the maximum load, its duration and minimum load are known, an hourly load pattern is assembled. Otherwise, average hourly loads may be calculated from annual electricity bills.

3.6. Turbine Selection

The head and design flow are used to establish the site design point, which the KBS sets on the application diagram to select from a small number of standardised single- and twin-jet Pelton and Turgo-Impulse units a turbine which will rotate at 4, 6, or 8 pole speeds in the head and power range of 25-300m and 50kW-5MW. The governor, inlet valve and generator are also selected. On selection the KBS allocates a cost to each of the components. The design flow is used to establish the dimensions of the inlet channel, settling tank and penstock.

3.7. Financial Analysis

Parametric and empirical cost modelling is used to estimate the cost of the civil works. Tendered local costs are allocated to the control and switchgear, and transmission lines. The KBS determines the scheme capital costs, and operating and maintenance costs.

Annual revenue is calculated from the hourly factory load pattern and annual flow pattern, to calculate and accumulate avoided purchase costs and sell-out income. Nett income is determined having serviced interest charges, returned capital, and funded operation and maintenance. Labour and energy rates may be inflated at different percentages. Interest charges are divisible and adjustable. Future costs are collapsed to present values at adjustable discount rates. Economic viability is tested by the following techniques:

- Future time to return investment;
- Internal Rate of Return
- Nett Present Value;
- Cost/Benefit Ratio.

A succession of report screens convey the technical and economic merit of the current scheme to the assessor, two of which are shown below in figure 10 - containing dummy data.

REPORT SCREEN

Site Details		Design Details	
Site :	Test	Gross Head (m)	110
Tea Company :	Frogston	Comp Flow (l/s)	90
Contact :	Wallace	Design Head (m)	100
Date :	4/21/95	Des Flow (l/s)	918
Assessment by :	REW	Exceedance (%)	40
		Availability (%)	90
		Des Power (kW)	751

Outline Specification		Load Details	
	Lengths (m)	Max Load (kW)	150
Diversion	5	Bills Total (Rs)	
Settling Tank	3	Duration (hrs)	6
Channel	200	Calc Load (kW)	0.00
Penstock	300	Min Load (kW)	50
Line	200	Duration (hrs)	18
Road	100		
Penstock diam	0.64		
Phase Length	6000		
Phase Breadth	4000		

Selected Equipment	
Turbine	TI 2 16.5/1000
Generator	1000 kW/1000
Governor	PGG 200

[Next Screen](#)

REPORT SCREEN

Capital Costs			Commercial Details	
	Rupees	Pounds		
Civil Costs	45849617	636800	Interest Rate	10
EM Costs	5665970	78694	Discount	10
Total Costs	51515595	715494	Purchase Tariff	3.80
Cost per kW	68621	953	Sell Tariff	2.8
			Inflation (Sales)	5
			Inflation (Labour)	4
			Payback	7
			NPV (over 25 years)	1,336,055
			IRR	23
			Benefit/Cost	2.22
			Exchange Rate	72.00

Annual Costs		
	Rupees	Pounds
Operating Costs	450000	6250
Maint Costs	515156	7155
Total costs	965156	13405

[Return to Main Screen](#)

Figure 10 - Typical Reporting Screens

The KBS allows the assessor to rapidly perform feasibility studies of different schemes which may be ranked in order of viability for allocation of funds. Economically marginal schemes may be investigated to establish the sensitive factors and the effects of changes which could improve financial viability may be tested. The assessor is able to re-configure individual schemes and assess the impact on economic viability. It is also possible to assess how robust an acceptable scheme is to hydrological, technical and commercial change.

4. CONCLUSIONS

There is a considerable potential for mini-hydro power in the tea estates in the Central Highlands of Sri Lanka, but the economic conditions prevailing require that the feasibility of any prospective site is tested efficiently and consistently for comparison with other sites which may be competing for limited investment funds.

The large number of existing sites which operate poorly or have fallen into disrepair cannot be neglected, since many might be improved or returned to service in a cost efficient way. Repair or replacement costs have to be readily assessed for components that are feasible to replace.

The extent and nature of the hydrological, technical, commercial and economic information which is required to carry out flexible and repeatable feasibility assessments can only be mounted on a personal computer in a structured, knowledge-based system. Object oriented software has provided an environment within which such a structure has been assembled, and populated with the necessary detail, knowledge and experience.

It is essential that scheme costs are minimised and therefore that the local content is maximised. Selection of standardised electromechanical equipment enables the reduction of capital costs. The KBS holds local rates for civil works and all available components or services available in Sri Lanka.

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