MICADO: A System of Decision Support Software for Micro Hydro Power in Nepal
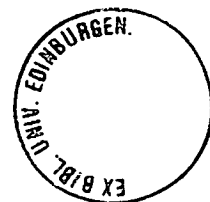
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Abstract

Micro hydro power schemes are characterised by a power output of less than 100kW. They have been identified as a means of providing mechanical and electrical power for isolated communities in developing countries, with a view to increasing the rate of development in such communities. Nepal is one of poorest countries of the world, and apart from hydro power, has little in the way of natural resources which it can use as a basis for development. It is essential, therefore, that this hydro resource is exploited efficiently. Large scale hydro power schemes benefit the country as a whole, but bring few benefits to the rural poor. Micro hydro power schemes supplying mechanical and electrical power can, however, have an immediate impact at this level.

Small scale engineering projects in developing countries are constrained by factors which are not present in the developed world, such as lack of infrastructure, transport problems, communications problems, and meagre materials and skills resources. Experiential knowledge is therefore as important as professional knowledge in the design and installation of micro hydro power schemes. When personnel leave the organisations which are involved in micro hydro power their skills are lost to the field. Expert systems and Decision Support Software (DSS) provide a method for capturing their experiential knowledge.

The MICADO system of DSS is a software tool created to support engineers designing micro hydro power schemes and others who may be assessing the viability of such schemes. The software is intended for use in Nepal, but the evaluation routines can be applied to micro hydro power schemes elsewhere in the world. MICADO was programmed to specifications given by its user group in Nepal, and was constrained to run on hardware which was already available to them. It is configured on the commercially available CRYSTAL expert system builder, and runs on IBM PCs and compatibles. It draws on a knowledge resource of workers in the field of micro hydro power in developing countries, technical and semi-technical literature, and experts in the fields of the specialisms included in the system. The software has been tested and released to the user group.

The thesis discusses whether Artificial Intelligence is an Appropriate Technology for Development.

Declaration of Originality

The work described in this thesis and the thesis itself are original and are the work of the author alone.

Teresa Anderson

Acknowledgements

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To David and Leila

"....and they shall beat their swords into ploughshares

and their spears into pruning hooks...."

Chapter 1

Micro Hydro Power and Development in Nepal

This chapter introduces micro hydro power and its perceived and actual role in the development process in third world nations. The state of development in Nepal is outlined, including the way in which micro hydro is uniquely suited to the energy demand profile and energy resource of the country. The problems which generally impede the design, installation and operation of micro hydro schemes in Nepal are explained.

1.1 : Introduction

Micro hydro power schemes are very small scale hydro power schemes which are conventionally characterised as having a power output of 100kW or less [Monition et al]. Where they produce electricity they can be stand-alone or grid-connected, as with any other generating plant. Some schemes are used as a source of mechanical power alone, say, for driving mills. In developing countries micro hydro power has been hailed as an answer to the energy problems of rural areas, as it harnesses an indigenous, renewable resource [Flavin, 1986]. In addition, because schemes are frequently linked to irrigation systems, and/or Tend to be of a similar size to these they are considered to have minimal, or at least tolerable, environmental impact [United Nations, 1989].

In regions where there is a reliance on diesel motors for mechanical power, and kerosene for lighting, micro hydro schemes can reduce fuel consumption, or even, in some instances, completely replace traditional fuels. Where wood stoves are used for cooking, as they are in most areas of the Third World, it has been suggested that micro hydro schemes can supply electricity for cooking. In practice this has been successful only where the electric cookers have been matched to local cooking methods and diets [Mackay], [Islam].

Unless micro hydro schemes are funded directly by a foreign aid group it is often the case that the financial restrictions on the design and installation of the scheme can be very tight. This is especially the case for electrification schemes. In addition, scaling down the design principles used for large scale hydro-electric schemes has been found to be unsuited to the situations surrounding micro hydro-electric installations. These factors have prompted the development of design methodologies suited to micro hydro power in developing countries, which would be regarded as unconventional in the developed world. Designs for such schemes tend to be low-cost and to rely on locally manufactured components as much as possible [Holland]. Schemes will be designed to produce an energy mix which is often uniquely tailored for the particular communities in which they are situated. Examples of this include the tea estate schemes which abound in Sri Lanka, [Brown], the Baindoang village electrification project in Papua New Guinea, [Robinson], and the Mohantar milling and electrification scheme near Gajuri in Central Nepal [Anderson], among many others.

1.2 : The Role of Micro Hydro Power in Developing Countries

Since the oil crisis of the 1970s, the governments of Third World† countries have been constrained, in their drive towards development, by the need to reduce their reliance on oil-based fuels. This constraint has been added to by the growing awareness of the cost of environmental degradation, which has prompted a move away from the burning of biomass* in rural areas. In addition, developing nations have realised that using indigenous resources conserves their foreign exchange reserves. A review of the mature renewable energy technologies which are now available for exploitation will not be attempted here. The reader is referred elsewhere [Randell], [United Nations, 1989], [Foley, 1989], [Daey Ouwens], [Islam et al], if further information on these is required.

1.2.1 : The Energy Transition and Development

Development

"Development" can be characterised in a number of ways. At one end of the spectrum is the macro-economic definition of the transition from subsistence agriculture to the cash economy. At the other is the target of meeting basic human needs, and according basic human rights, (including employment, self-reliance and the preservation of cultural diversity), to all people, regardless of their status in society. A review of the various political and philosophical paradigms surrounding such definitions is outwith the scope of this thesis, and the reader is referred elsewhere if any further discussion of this is required [Goldsworthy,

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† The term "Third World" is used throughout this thesis to refer to the regions of the world which do not enjoy the benefits of modern society to the same extent as the majority of the inhabitants of Europe and the United States of America. A treatment of the terminology of development studies can be found in "Sociology and Development" [Barnett].

* "Biomass" is a general term used to denote wood, dung, agricultural residue and any other organic matter which may be burned as fuel.

1988], [Barnett], [Elliott].

Development is generally pursued by:

- governments and powerful agencies which take a "top-down" approach,

- people or communities in crisis or in chronic need who use a "bottom-up" strategy,

- outside third parties which act as a catalyst to one or the other or a mix of these two approaches [Goulet].

Although most governments are concerned primarily with the political and macroeconomic state of their country, they claim that the needs of the people predominate. In practice this is often the case only in the run-up to democratic elections.

> "There is a strong tendency for the actual outcomes of would-be welfarist development schemes to be shaped by patterns of power rather than by patterns of need."
>
> [Goldsworthy]

Equally, on a local level, there is a parochial attitude to the necessity of meeting basic human requirements which is often given a priority which obscures any awareness of the resources available to meet them at a national level.

Intervention at the local level by third parties such as aid agencies can empower local people and increase the transfer of skills and technology from centralised agencies into rural areas. The third parties which are most effective in their intervention for development are those which recognise that local initiatives are at best ineffective if a political environment of macro policies is not created which favours the level of local participation engendered [Stewart]. This is especially true of the diffusion of energy technologies into rural areas [Barnett].

The Energy Transition

Where "development" can be characterised in different ways, development of the energy profile of any Third World country invariably refers to the transition from biomass as a primary fuel for cooking, lighting and space heating. While the oil crisis of the 1970s had an impact on national energy policies, at the local level, rural areas were largely unaffected (if the price rise in kerosene for lamps is disregarded) [Smith]. The fuel crisis at the rural level has been precipitated largely by the increasing shortage of fuelwood. This has been exacerbated in some places by a loss of agricultural productivity caused by the reduction in the amount of animal dung used as fertiliser because rural people have resorted to burning it as fuel [Eckholm].

The methods by which energy technologies are transferred into rural areas are myriad, and to date no model has been developed which can describe all the processes involved [Barnett]. Several features have, however, been identified as the framework within which energy transition programmes must operate.

- A demand for the technology must exist. This can be due to potential financial benefits to the user or installer, or to perceived benefits due to ease of use and reliability of the technology. It can also be due to the alleviation of some pressing discomfort, such as the time required to gather fuelwood for cooking food and heating and lighting a family dwelling.

- The technology must be either manufactured locally or imported. Economies of scale associated with large scale manufacture may be outweighed by ease of delivery or prompt repair and maintenance servicing from local manufacturers. The reliability of established firms may outweigh the benefits of using equipment from less experienced, but less expensive small scale producers [Hurst].

- It has been suggested that user-led innovation is a critical element in the development of appropriate technologies† at all levels [Gamser,1988].

- While the diffusion of technologies in rural areas can only occur via channels which exist in these areas, a favourable political environment must also exist at a national level [Goldsworthy].

These factors are present, to a greater or lesser extent, in the mechanisms by which micro hydro power is diffused into rural areas.

1.2.2 : Micro Hydro Schemes Supplying Mechanical Power

Micro hydro schemes can supply mechanical power only, electricity only, or a combination of the two. Where mechanical power is supplied by a scheme (usually for milling,) it is thought to bring with it:

- A decrease in the amount of time required for grain milling and agro-processing, with an attendant increase in the amount of disposable time available for, say, increased agricultural work or educational purposes.

- An increase in the yield of consumable products from the same harvested quantity, resulting in a possible stimulus to trade due to the generation of surplus food.

- An improvement in the quality of life for women, who are traditionally responsible for the arduous task of manually grinding and pounding food grains prior to cooking for the extended family.

- The promotion of cottage industries such as small scale saw mills, and power looms.

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† The term "appropriate technology" will be treated later in this thesis.

Although it is possible that all of the above benefits will be associated with the provision of mechanical power, in reality other effects often occur. An increase in the amount of disposable time available often results in more time being spent in the tea shops and bars which spring up around successful milling schemes [Acharya and Bennett]. Additionally, it is by no means certain that generation of excess agro-products results in increased trade. In Nepal, for instance, the lack of a transport infrastructure renders attempts to increase trade by improving agro-processing efficiencies useless. (See section 1.3.3)

There is no doubt that the quality of life of women is vastly improved by the reduction in the time spent processing food grains using traditional methods. However, it has been found that women, who derive some status in the household because of their role as the preparer of food, and who often trade locally with any surplus they produce, can find their standing eroded if grains are taken to a mill, perhaps by the male members of the household. Women can often find that their participation in household matters is reduced by their loss of this traditional role, which can have an adverse effect on maternal and child health [Acharya and Bennett].

1.2.3 : Micro Hydro Electric Schemes

It is widely held that improving rural energy supplies is a major step towards development [Hurst], and that electrification of rural areas, where some 70% of the population of the Third World live, [Flavin, 1986], is of utmost importance. Rural electrification is widely thought to bring with it the benefits of:

• Improved lighting, with a corresponding extension of the working day, and better oppportunities for children to study in the evenings.

• Refrigeration, which can be used in the storage of vaccines in rural health centres, and increases the lifetime of stored food, improving standards of nutrition.

- Water heating, (often used as a dump load where load controlling systems are used in de-centralised schemes), which improves general levels of hygiene.

- Increased use of radio sets, which exposes people to life outside of rural areas, and is thought to improve quality of life, as well as allowing educational broadcasts on subjects such as preventive health care and farming techniques.

- Use of television sets, which improves quality of life in much the same way as radio sets.

- Pumping for clean drinking water supplies.

- Heating for agro-processing, e.g. cardamom and ginger drying, coffee drying [Whittaker], or tea drying [Hislop].

- Cooking, where this is carefully matched to local diets and cooking methods.

- Electric fans, which improve quality of life.

In addition, politicians often perceive that rural electrification is an election issue [Flavin, 1986], [Randell], and that electrification schemes are popular. In some countries (e.g. Bangladesh) there are constitutional commitments to the provision of electricity for the total population. This is often perceived as a way of uniting a nation composed of diverse ethnic groups. In spite of these political commitments, the rural areas of the developing world do not, on the whole, have electricity. Table 1.1 gives some indication of the extent of rural electrification in the Third World.

In fact it has been found that even the social benefits listed above rarely have an impact on the rate of development in rural areas, no matter how this rate of development is assessed [Meier, 1985], [Integrated Development Systems]. Experienced observers maintain that to have an impact on the rate of development in any

Table 1.1 : Extent of Electrification in Developing Countries

Country	Share of Population in Rural Areas (1985)	Share of Total Population with Electricity (1982)
South Korea	43%	95%
Mexico	30%	81%
Costa Rica	52%	80%
China	79%	60%
Brazil	32%	56%
Colombia	33%	54%
Philippines	63%	52%
Senegal	58%	36%
Indonesia	78%	16%
India	77%	14%
Kenya	84%	6%
Nepal	94%	5%
Bangladesh	85%	4%
Niger	84%	3%

Source: Christopher Flavin, "Electricity for a Developing World: New Directions.

country, electrification must be accompanied by an increase in industrial activity [Foley, 1990]. In rural areas this is likely to take the form of cottage industries, or tourist services such as hotels. For instance, in Nepal, trekking lodges provide a source of income for areas of outstanding natural beauty, and electrification schemes tend to flourish in these regions.

In fact, electrification alone is unlikely to act as a spur for development, [UNC-TAD], and governments now direct their energies towards coordinating joint programmes, where electrification is more likely to be part of a larger project [Wade],

[Randell].

Alongside this is the realisation that electrification schemes which are justified and promoted for altruistic reasons often have end results which in reality are far removed from the ideal. Examples of this include a 10-mile strip of bars and fast food outlets which sprang up in the wake of an electrification scheme along the west coast of Jamaica, [Foley, 1990], and a scheme known to the author, where batteries charged by a micro hydro electric scheme were used to power a very lucrative pornographic video cinema. Evening classes and maternal health clinics are posited in funding proposals, with little mention being made of the more likely uses to which the energy might be put. The population of rural areas, which has very little disposable income, is, however, prepared to pay for electric lighting at rates sometimes in excess of double the rate paid in the UK. This gives some indication of the high priority which is given to electrification in developing nations, even when productive uses of electricity are not immediately apparent to foreign observers.

1.3 : Development in Nepal

The kingdom of Nepal is situated on the southern slopes of the mid-Himalya mountain range. To the south it is bounded by the Indian states of Uttar Pradesh and Bihar, to the north by the Tibetan region of the Peoples' Republic of China and to the east by the state of Sikkim and the North Bengal division of India (See figure 1.1). The land area of the country is about 147 000 square kilometres, making Nepal just smaller than Bangladesh. Its paucity of natural resources and extremely rugged terrain account in part for its situation alongside Bangladesh as one of the poorest nations of the world.

The country is well known for its spectacular mountain ranges and for the wide range of cultures which exist within its borders. Set against this splendour is the squalor of an acutely underdeveloped nation, with very few means for improving the lot of its people. With no mineral deposits and no coal or oil reserves, Nepal has very little, other than its forestry and hydro resource, upon which it can depend as a basis for development.

Nepal is home to about 17 million people, of whom at least 15.5 million live in rural areas. Agriculture accounts for the livelihood of over 90% of the population, [Shah], and supplies an estimated 80% of Nepal's total export revenue [World Bank], and 60% of its GDP. The country is, however, teetering on the brink of an ecological crisis, as the steadily increasing population accelerates its rate of fuelwood use, and struggles with a declining rate of per capita food grains production [World Bank].

1.3.1 : Geophysical Characteristics of Nepal

Nepal can be divided into three distinct regions, each characterised by its elevation above sea level. The Mountain and Hill regions together constitute around 77% of the land area, with the southern plains, known as the Terai, making up the remaining 23%. The Mountain region is sparsely populated, and has an alpine climate over 5000m. The Hill regions (at 1500-3000m) contain 33% of Nepal's cultivated land, and provide a home to over 60% of its population. The Terai is warm and sub-tropical, is home to 36% of the country's population and contains 62% of the cultivated land.

Nepal suffers acutely from a lack of natural resources. In fact, its most important economic resource is its forests, which covered around 38% of the land area in 1981 [HMGN]. Its energy sector is dominated by dependence on fuelwood and the absence of any commercially exploitable fossil fuel resource such as oil, coal, gas or lignite. It has no mineral deposits which would serve as a basis for industrial development, and the lack of a skilled labour force also hampers any attempt

PEOPLES' REPUBLIC OF CHINA (TIBET)

FAR WESTERN REGION   MID WESTERN REGION

WESTERN REGION

Jumla

Muktinath

•Jomsom

Marpha•

Surkhet•   CENTRAL REGION   EASTERN REGION

Pokhara

National Boundary
Regional Boundary   Butwal   Syangje•   Kathmandu
Roads

Dhankuta•   Ilam

Saptari

INDIA

Figure 1.1 : Map of Nepal

to strengthen its industrial base.

Apart from its lack of natural resources, development in Nepal is constrained largely by its terrain. In the space of around 200 kilometres the ground elevation passes from the high Himalya, with peak elevations above 8500 metres, to the north Gangeatic plain, at elevations of around 200 metres [Warnock]. The topographical characteristics of the country present unique problems in the fields of transport, communications and infrastructural development.

1.3.2 : Agriculture and Human Development

Although the most common means of survival is subsistence agriculture, and over 90% of the population depends on farming for its livelihood, [HMGN], there is acute pressure on farming land in Nepal. Table 1.2 shows the estimated pattern of land use in Nepal.

In the Hill regions especially, the average size of a family holding is too small to provide for the needs of all family members [Seddon]. Population density on agricultural land already exceeds that of Pakistan, India and Bangladesh [World Bank]. Although landlessness is much less pervasive in Nepal than in neighbouring countries, the Land Reform Act of 1964 was not completely successful, and loopholes in the legislation have allowed the top 8% of households to retain ownership of almost 40% of the land, while the bottom 40% own only 10% [Seddon].

Despite an increase in the use of fertilisers and higher yield strains of seeds, Nepal's food-grains supply is deteriorating rapidly, and as the population increases at a rate of 2.5% per annum, [HMGN], more and more marginal land has been brought into cultivation using painstaking terracing techniques [James]. Intensive farming is reducing the fertility of agricultural areas, to the extent that in the East Hills region it has been estimated that up to 38% of the total land area has been abandoned because of waning productivity [Eckholm]. When these terraced slopes are exposed to monsoon rains without protective vegetation, the resulting

Table 1.2 : Land Cover in Nepal

Land Use	Area (km^2)	Percentage of Land Covered.
Forest	55 334	37.6
Agriculture	26 533	18.0
Snow	22 463	15.3
Pasture	19 785	13.4
Water	4 000	2.7
Settlements and Roads	1 033	0.7
Other (including waste land, adandoned farm land, and landslides)	18 033	12.3
Total	147 101	100

Source: The Seventh Plan (1985 - 1990), Part 1, National Planning Commission of Nepal.

landslides carry away fertile soils as well, initiating a vicious cycle of ecological deterioration. Nepal suffers more than many other areas in the developing world from a deteriorating natural environment, which is growing in importance as a major cause of poverty.

Malnutrition is widespread and is thought to affect all castes and ethnic groups in the months (March to May) directly preceeding the monsoon. It is estimated that 85% of Hill people and 50% of Terai households exist below minimum subsistence, and, in common with many other developing nations, it is certain that in Nepal under-employment is now more of a problem than unemployment in rural areas [Elliott].

Although malnutrition is probably the single largest factor affecting the health of the population in general, there are other contributory factors. Only 9% of the population has access to clean drinking water supplies, [HMGN], and basic health care and hygiene programmes are lacking in most regions. Health programmes are hampered by the fact that there is, on average, only one doctor per 90 000 people outside the Kathmandu area [Dalrymple]. Despite the population growth rate of around 2.5% per annum, Nepal spends less per capita on family planning programmes than many other developing countries, [Acharya and Bennett], and life expectancy for women is, on average, lower than that for men, reflecting poor standards of maternal health care. The dilemma facing the country is that any funding for health and literacy programmes must be at the expense of food production, as the country's financial resource is limited.

The severe shortage of food grains in the Hill regions is having a profound effect on both the Hills and the Terai, as large sections of the population move into the lowlands on both a seasonal and permanent basis. (The rate of population increase in the Terai is half as much again as for Nepal as a whole [Eckholm].) It is obvious that population migration provides only a temporary alleviation of one of the symptoms of environmental pressure, and that consolidation within rural areas, aiming for higher self-sufficiency, is more likely to succeed in the long term. Nepal has large fertile valleys which can be exploited for the good of their inhabitants. The Marpha Horticultural Research station high in the Upper Thak Khola valley (see figure 1.1) has demonstrated this, promoting improved agricultural techniques and new seed strains in the region, encouraging developments in agro-processing and trade to the extent that the valley is now self-sufficient in all foodstuffs apart from salt [Pasang K. Sherpa].

1.3.3 : Economic and Infrastructural Development

In the 1950s, the drive for development began in Nepal, at a time when the country had practically no infrastructure. Transport and communications relied almost exclusively on travel by foot. Initial development efforts concentrated on

preparing the ground for future programmes, with the establishment of a Central Bank (1956), the Planning Commission (1959), the Nepal Industrial Development Corporation (1959) and, in 1963, the Agricultural Development Bank (ADB). These institutions, with their orientation towards development, have combined with the (until recently) stable political climate to provide a theoretically ideal environment in which change could occur.

Despite this, and the fact that Nepal has received large amounts of foreign aid (in the 1980s, foreign aid amounted to around $200 million per year, or about 10% of the then GDP [Shah]), progress has been slow. It is arguable that the country's inefficiency in its implementation of development programmes is the primary cause of this, as the aid resources available to it are more than sufficient to meet its current development needs.

Table 1.3 : Population Distribution by Region in Nepal

Region	Population	Percentage of Total Population
Eastern	4197300	24.69
Central	5555600	32.68
Western	5071100	29.83
Mid-Western	2213400	13.02
Far-Western	1494300	8.79

Source: Central Bureau of Statistics (1987), Statistical Yearbook of Nepal, National Planning Commission, Kathmandu, Nepal.

The country is divided into five development regions, each of which (apart from the Far-Western Development Region) incorporate three of the 14 "zones" into which the country is divided (the Far-Western Development region incorporates the zones of Seti and Mahakali). The population is distributed between the

regions as shown in table 1.3.

Programs to improve agricultural productivity have been implemented and invest-
ment in agriculture increased from about 10% of the development budget in the
mid 1960s to over 30% of the budget in the mid 1980s. Despite this, food grains
production only rose by 1 million tons in the 25 years from 1961, reflecting a per
capita decrease from 337 kg to 253 kg per annum, i.e. a 25% decline over that
period. Although income from tourism, light industry and urban sector activities
increased by about 5% in the same period, there was no shift in the proportion
(91%) of the population earning a living from agriculture, suggesting that only the
urban elite benefitted from such increases, masking the serious deterioration in
living standards for the rural poor. Table 1.4 indicates Nepal's ranking in terms of
important social indicators, among the low income countries of the world.

With its foreign exchange resources decreasing steadily and the foreign debt now
at a level in excess of one quarter of its GDP, Nepal is desperate to increase its
foreign exchange earnings. It is argued that the country should be looking to
increase its investment rate substantially over the next few years in order to pro-
mote infrastructural development. However, despite an increase in investment
from 6% to over 20% in the period between the mid 1960s and the mid 1980s,
there was no observable improvement in the standard of living of the majority of
the population [Shah]. Infrastructural improvements such as road construction
and the setting up of an electric grid system and large hydro electric power sta-
tions have little impact on a population which is largely concentrated in hill areas
accessible only via the network of paths trekked by porters and mule trains which
has served Nepal for centuries.

The maintenance cost of the skeleton road system alone places such a huge finan-
cial burden on the country's development budget that it has been argued cogently
that development expenditure should be directed away from such large capital-
intensive projects towards more diffuse, small-scale targets such as improved

Table 1.4 : Social Indicators for Third World Countries

Country	Population (millions)	Per Capita Income (US$)	Food Production Per Capita (kg)	Energy Consumption Per Capita (kg of oil equivalent)	Life Expectancy at Birth (years)	Infant Mortality Rate(under age 1 per 1 000)
Nepal	17	160	116	17	47	133
Bangladesh	100.6	150	110	43	51	123
India	765.1	270	120	201	56	89
Pakistan	96.2	380	114	218	51	115
Sri Lanka	15.8	380	98	139	70	36
Thailand	51.7	800	119	343	64	43
Malaysia	15.7	2 000	116	826	68	28

Source: World Bank (1987), World Development Report.

footpaths and suspension bridges [Joshi and Chitrakar]. The World Bank has emphasised the need for Nepal to increase its annual growth rate in agriculture to about 3%, making an overall growth rate of 4% possible for the economy in general. This growth will occur only if the marketing links between regions of the country are strengthened considerably, as presently an area with a food-grain surplus has no mechanism by which this can be traded or exchanged with other regions. Improved transportation would have the added advantage of improving communications between different regions of the country, aiding the creation of internal markets.

It is undoubtedly the case that the open border which is maintained with India is a mixed blessing for the country. On the one hand, India's well-established industrial base has effectively deprived Nepal of any control over its market

development. On the other, India provides an ideal market for the agricultural and cottage industry outputs which supply over 80% of Nepal's export earnings. Tourists, from India especially, will be an increasingly important source of foreign exchange for Nepal in the future, and Nepal's immense hydro power resource can supply not only its own energy needs, but also firm electrical power for export to the North India Grid.

Nepal has very little in the way of natural resources which may be used to involve it in the exchange of raw materials for value added goods which usually interlocks the developing and developed worlds. It does, however, have the means by which it can become largely self-sufficient in food production and could implement extensive programmes of energy substitution which could drastically reduce its dependence on oil based fuels [Shah].

1.3.4 : Deforestation, Reforestation and the Energy Transition in Nepal

Around 95% of the energy used in Nepal is consumed in the domestic sector, with 76% of this being used for cooking. (See figure 1.2)

It has been estmated that over 97% of the energy consumed in the domestic sector in Nepal is in the form of traditional biomass fuels [RAPA]. These fuels are mainly fuelwood, (78.2%), agricultural residue, (11.7%), and dung, (8.9%). Commercial fuels, including kerosene, diesel and electricity account for the remaining fraction. It is therefore apparent that fuelwood is a basic necessity for survival. This creates enormous pressure on the forest resource, which is added to by a dependence on the forest for fodder for animals. In the dry season especially, gathering fodder can damage the forest beyond the level where recovery is possible [Hamand].

Figure 1.2 : Energy Demand by End Use in the Domestic Sector in Rural Nepal

Cooking   76.0%

Other 2.3%
Lighting 1.7%

Agro Processing 15.0%

Space Heating 5.0%
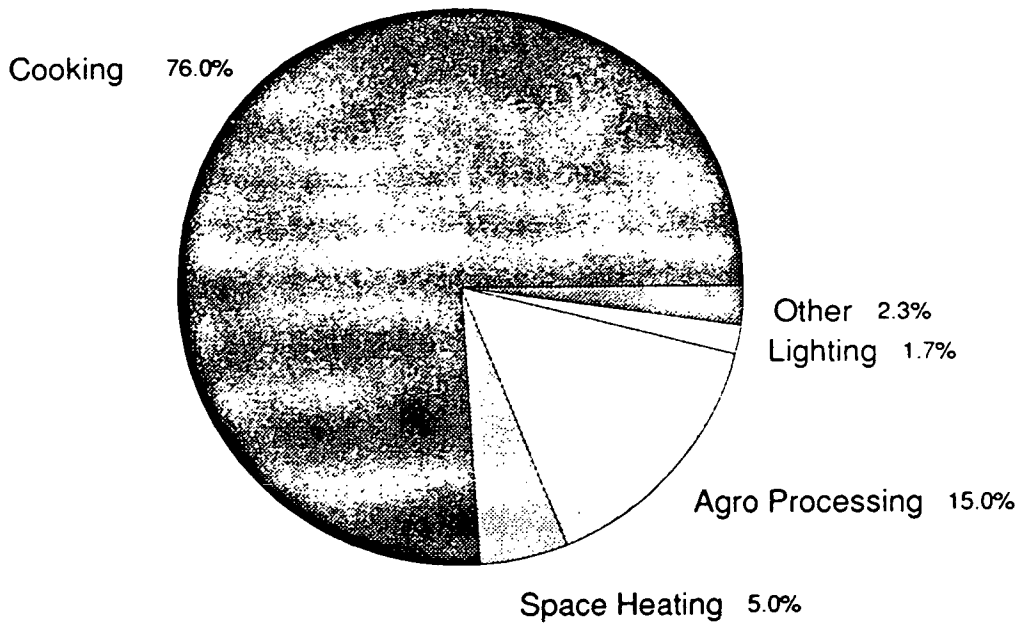
Source: Arun Doj Adhikary, (1988), Fuelwood Use and Deforestation in Nepal.

Reforestation

Nepal's forests have been vanishing for some time, and it has been estimated that forest cover shrunk from 6.4 million hectares in 1963/4 to 4.3 million hectares in 1980 [RAPA]. This is reflected by a survey conducted first in 1970 and again in 1980, which found that during that decade, the time required to collect a load of wood from the forest had increased from between 4.1 and 4.6 hours to between 5.2 and 6.3 hours [Sattaur].

Tree planting programmes have been set up, and it has been calculated that a planting rate of 50 000 - 100 000 hectares per annum is required during the 1990s

if the problem is to be contained by the year 2000 [RAPA]. This ambitious target is unlikely to be met as Nepal has neither the financial resource nor the infrastructure to support such a venture. Nevertheless some steps have been taken towards that goal as the Ministry of Forest and Soil conservation has established community projects throughout the country. There are also local initiatives which have been set up in conjunction with foreign aid groups, such as the Nepal-Australia Forestry Project east of Kathmandu, [Sattaur], the CARE Reforestation Project at Begnas Tal, north of Pokhara, [James], and the AREA Passive Environmental Development Centre at Ghorepani, [Jones], which provide solutions on a micro level which could be adopted country-wide.

Biogas

In addition to the drive for reforestation, the country is committed to a campaign promoting the production and use of biogas†. Installations are partly financed by the Agricultural Development Bank, and a total of around 2000 plants were installed in the period from 1974 to 1985. There was further provision made for the installation of 4000 plants in the five years from 1985/6 to 1989/90, but there is no information presently available on the success or failure of this [HMGN].

Improved Cooking Stoves

The traditional earthen cooking stoves used throughout Nepal are estimated to be between only 15% and 18% efficient. In addition, they cause respiratory problems due to the lack of vents or chimneys which can carry smoke away from general living areas [Shrestha]. In response to these facts the government has set up an Improved Cooking Stove (ICS) programme, where the Agricultural Development Bank has supported the development and installation of a more efficient stove. Fuel savings of between 40% and 50% have been claimed for these stoves

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† "Biogas" is the gas produced by allowing the controlled decomposition of, animal dung and vegetable waste matter. In Nepal, only cattle and buffalo dung are likely to be used, for reasons of ritual cleanliness.

and a target of 70 000 installations by 1990 was set in the Seventh Five Year Plan. There is no data on the number of stoves actually installed.

Mechanical Power and Electricity

The subject of micro hydro power in Nepal will be treated in detail in later sections. It must be stated here, however, that as hydro power is the country's only known energy resource, the energy transition away from the consumption of biomass, and especially away from the depletion of the country's forest resource, must involve a switch to the utilisation of hydro power as the only alternative.

1.4 : The Hydrological Resource of Nepal

The river system of Nepal is made up of three main rivers and their tributaries, the Koshi river, to the East of the country, the Gandaki river, which drains central Nepal, and the Karnali river, which drains western Nepal. The Koshi system is composed of seven smaller rivers, resulting in the fact that it is referred to as the Septa Koshi (the seven-river Koshi). The Gandaki, which is also composed of seven smaller rivers, becomes the Narayani river after the place where its tributaries meet [HMGN]. The map in figure 1.3 shows the location of these rivers.

Estimates place the hydro resource of Nepal in the region of 83 000MW, [Warnock], a figure which is thought to exceed the combined capacity of Canada and the United States [Shah].

Although the capacity which is judged to be economically feasible for development is well below this, (assessments range from an optimistic 65% to a more realistic 30%,) in fact only 165MW have been developed, representing a fraction as low as 0.2% of the potential [Litscher and Kapali]. The large scale schemes which have been developed are listed in table 1.5. In addition to these, there are

RIVER SYSTEM OF NEPAL

Karnali
River System

National Boundary
Hydrological Station
Major River

Narayan
River System

Bagmati
River System

Kosi
River System

Figure 1.3 : The River System of Nepal
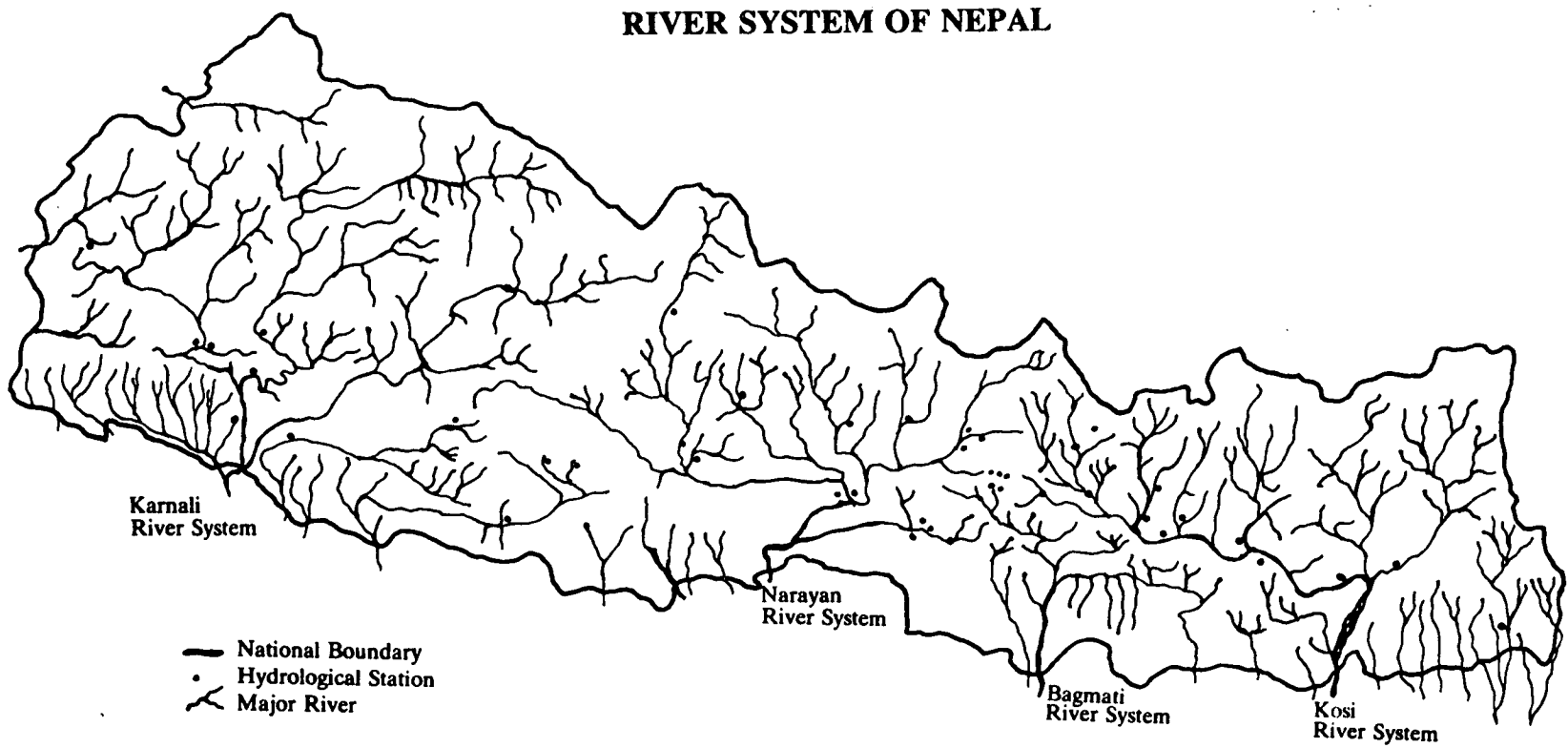
Table 1.5 : Major Hydro Power Schemes in Nepal

Sun Kosi	10.5 MW
Trisuli	21 MW
Kulekhani-I	60 MW
Devighat	14.1 MW
Gandak (on an irrigation canal)	15 MW
Kulekhani-II	32 MW

Source: C.K.Sharma, (1989), Nepal's Hydro Schemes: Progress and Plans, Water Power and Dam Construction.

plants under construction at Marsyangdi (69 MW), Andhi Khola (5.1 MW), and the ARUN III project (402 MW) is under design and discussion.

Hydro power is Nepal's major energy resource, apart from forestry, and thus is a major force both for the generation of much-needed foreign exchange and for the development of infrastructure within the country itself. As is usual in developing countries, exploitation of large-scale power resources rarely benefits the rural poor directly, and Nepal is no exception. The schemes listed above have been essential to the expansion of the grid capacity within the country, and have provided a bargaining chip in negotiations with Nepal's most significant neighbour, India. In fact the scheme at ARUN III was proposed mainly with the market in northern India in mind, as there is no grid system in Nepal which could deliver such large amounts of power to the rural communities in this region. In common with rural communities in other developing countries, those in Nepal have neither the demand profile nor the infrastructure which would make such a scheme economically viable.

To give some idea of the order of magnitude discussed here, small scale power schemes were expected to contribute about 7% of the country's total installed generating capacity (i.e. roughly 10-11 MW,) in 1983 [UNCTAD]. This numerically

small fraction, however, belies the impact of small scale hydro power on a predominantly rural population. Exploitation of small scale power systems has a direct effect on the lives of rural communities and therefore can have an immediate impact on the lives of the 93% of the population which lives in rural areas [UNCTAD].

It is apparent that Nepal's hydro resource is perhaps the key to its development in general. It can be regarded as a commodity for export under the guise of large scale hydro electric plants, providing the country with a much-needed source of foreign exchange. It can also be realised as a decentralised source of motive and electric power for small scale schemes in rural areas, which will have a major impact on rural people, who in fact constitute over 90% of Nepal's population.

1.5 : The History of Micro Hydro Power in Nepal

The technologies surrounding the harnessing of water power have been developed in the hills and mountains of Nepal for millenia, as the traditional *ghatta*, or water wheel, has provided mechanical power for milling flour from various grains. It is estimated that there may be around 25 000 of these units operating at any one time in the hill and mountain regions [UNCTAD]. (See Figure 1.4)

Ghattas are often run from irrigation networks, and such is the peoples' familiarity with weirs, conduits, aquaducts, etc, that they are almost able to assess the capacity of any stream to supply their power needs at a glance. As a development from the *ghatta*, systems now exist which supply motive power for rice hullers, oil expellers, saw mills and even Tibetan-style prayer wheels, in places such as the temple of Muktinath, close to the country's northern border.

Figure 1.4 : Diagram of Typical *ghatta* **in Nepal**
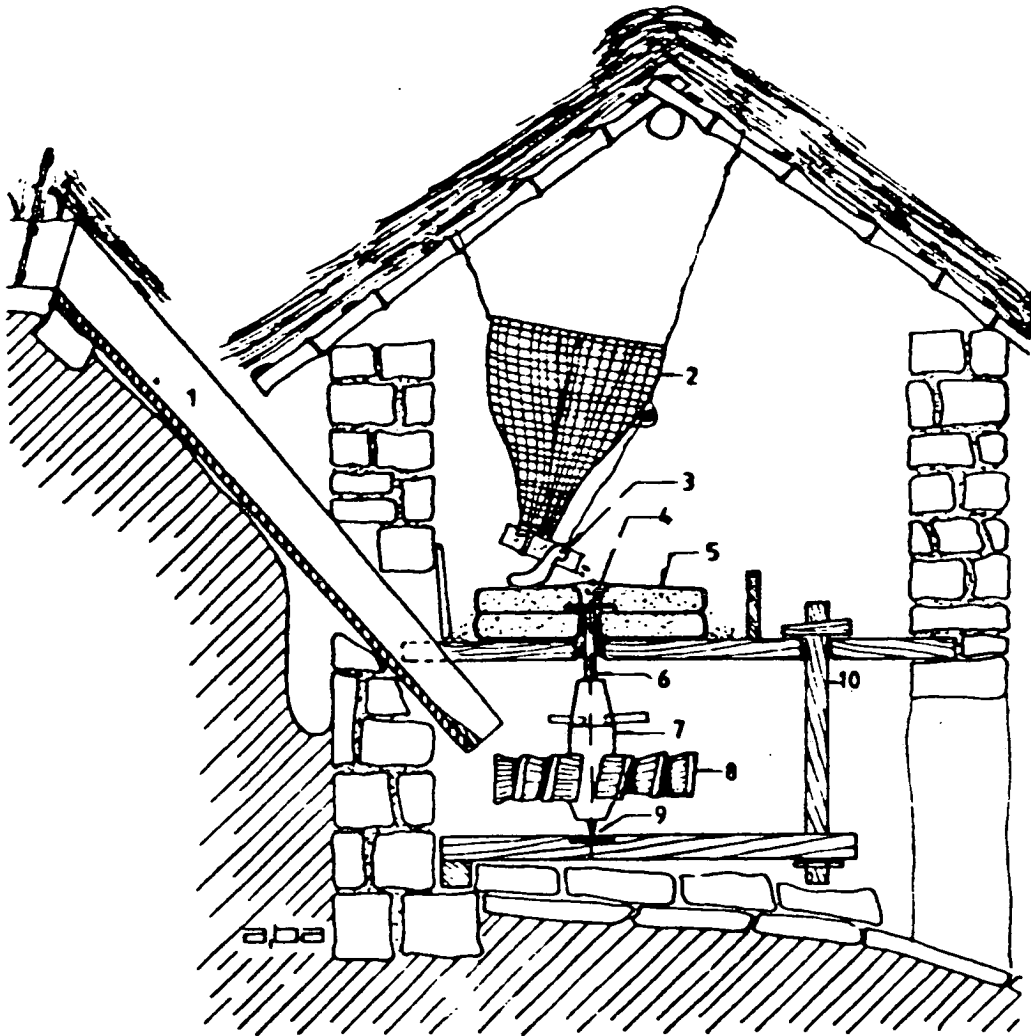
1.	Water chute	6.	Metal shaft
2.	Grain hopper	7.	Wooden hub
3.	Bamboo grain feeder tube	8.	Wooden blades
4.	Metal link from drive shaft to grindstone	9.	Metal pin and socket
5.	Grindstones	10.	Lever for adjusting gap between grindstones

Source : Bachman and Nakarmi: New Himalayan Water Mills

Micro hydro has been largely promoted by the private sector in Nepal. Individual entrepreneurs usually obtain bank loans to finance scheme installation [Inversin].

The cross-over between the state where local mill owners fabricated and installed their own mills, and the state where outside agencies are called in to install more sophisticated units occurred in the 1970s, when a joint venture between the Swiss and Nepali governments set up the engineering company Balaju Yantra Shala (BYS) on the outskirts of Kathmandu. BYS was responsible for developing and promoting the use of propeller turbines for mills in its early stages. Problems with turbine wear occurred due to particulate matter entering the runners, and this gave rise to maintenance problems. BYS has since been at the forefront of the development and installation of the Nepali Crossflow turbine, which is widely used for micro hydro schemes within the country.

At around this time the United Mission to Nepal (UMN), a confederation of around 40 christian mission groups and aid agencies, set up the Butwal Training Institute (BTI) in Butwal. This ran, and still runs, a mechanical engineering training course, and, together with Development and Consulting Services (DCS), another UMN agency, became involved in a pilot hydro project in 1975.

Since that time, UMN has had a prominent role in the micro hydro programme in Nepal, and has, via its Small Turbines and Mills Project (STMP), installed hundreds of schemes in the mountain and hill regions of the country. Some of the schemes have included "add-on"† electrification, others have supplied electric power only, but the majority have been schemes which supply motive power to mills for crop processing.

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† "add-on" electrification schemes are those which provide motive power for milling during the day, and have an alternator attached by a drive belt system in the evening to provide electric lightng for the local community. These are invariably owned by the mill owner, and provide him with an extra source of revenue when crop processing is not taking place.

The Multi Purpose Power Unit (MPPU) is another development which is directed towards the provision of motive power. The MPPU is, in practice, an improved *ghatta*, which is used to drive a shaft to which drive belts from a number of milling units can be attached, (See figure 1.5). These may be grain mills, rice hullers, mustard oil expellers.

The MPPU was developed by the Kathmandu Metal Company [Bachmann and Nakarmi], [UNICEF], and manufactured by the National Structure and Engineering Company. UNICEF funded many of the projects as part of its programme to improve the standard of living of women in rural areas. The Agricultural Development Bank also extended credit facilities for the installation of 160 units.

As this programme developed, there was a growing interest in micro hydro-electric schemes, and in 1985/6 the policy of providing a subsidy of 50% of the cost of electrical equipment used in schemes was introduced. This was extended, in 1988, to the provision of subsidies of 50% of total costs, and 75% of total costs in remote areas [Mackay].

1.6 : Prospects for the Promotion of Micro Hydro Power in Nepal

In Nepal there are unique problems which hinder the promotion of micro hydro power. These have given rise to some ingenious solutions, which have provided models which can be applied elsewhere.

1.6.1 : Transportation

Nepal's unique terrain and lack of infrastructure pose the largest problem for any engineering project within the country [Litscher and Kapali]. With no road access into rural areas, all components and construction materials are carried either by

Figure 1.5 : Typical Arrangement of an MPPU

1. Penstock
2. Grain Hopper
3. Grindstones
4. Alternator
5. Drive shaft
6. Drive belts
7. Rice huller
8. Metal frame
9. Metal turbine
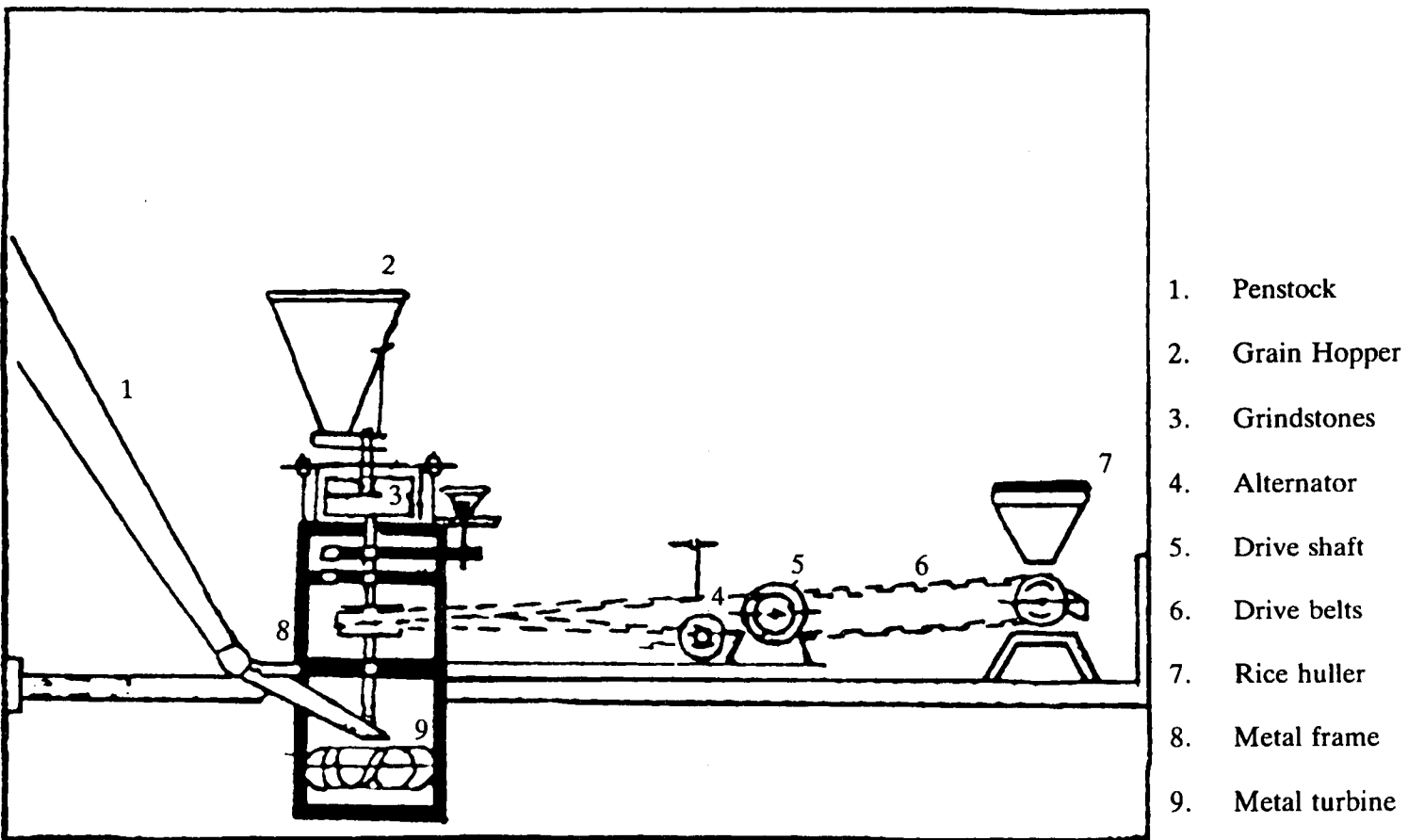
Source: Bachmann and Nakarmi : New Himalayan Water Mills

porters or by mule trains. This sets an upper limit on the weight of any single piece of equipment, and necessitates careful planning. In addition, local manufacturers have developed components which are appropriate to this situation, for example the "telescopic" transmission poles developed at the Butwal Engineering Works [Mackay].

1.6.2 : Communications

The poor communications network in Nepal means that links between the site owner and the installers are precarious. It is not uncommon for schemes to take up to five years to install, from ordering to commissioning [Meier, 1989]. Where repairs are required, it can take days or even weeks for a message to travel from the scheme, and it can take engineers a similar amount of time to make the journey to the site. The accuracy with which information reaches its destination is also a problem. The author visited one site where the turbine runner was 30mm (3cm) in width. The manufacturers later admitted that the turbine had been undersized by a factor of three, due to their miscomprehension of a message from the site. The scheme installation had gone ahead despite this, but the power output was, of course, much smaller than the potential which had been assessed at the survey.

1.6.3 : Landscape

The monsoon rains which occur from May to September in Nepal can have a catastrophic effect on the landscape of the country. There are flash floods, river flow rates can rise by a factor of 1000 [Litscher and Kapali], and the terrain is impassable in some regions. The unstable soil cover, which is further weakened by the loss of protective forests, is eroded every year by the torrential rains. Landslides are a part of daily life, and where they take away fertile soil, can have a ruinous effect on local agriculture.

In addition, clearing the ground for the construction of a micro hydro site can weaken the land around. Schemes have been known to slide away down the

hillsides, lock, stock and barrel. The author visited the scheme in Tatopani in the Kali Gandaki river valley in 1987, to find that there was no longer a scheme there, as it had disappeared down a river bank in the monsoon rains a few weeks earlier. (The same monsoon had also carried away a mill and the only bridge over the river, leaving the villagers to transport everything over a temporary structure made by lashing three saplings together.) (See figure 1.6)

1.6.4 : Gauging the Hydrological Resource at the Site

One of the most common reasons for the failure of micro hydro power schemes in rural Nepal is the lack of data on the hydrology of the sites [Meier, 1989]. Where gauging is carried out, it will usually be for a year, at most, and there will be no data on neighbouring catchment areas with which it can be compared. This is discussed in greater detail in chapter 5.

1.6.5 : Electricity Tariffs and Load Factor

Micro hydro-electric plants in Nepal generally begin their operating life with a load factor of around 20% - 25% [NEA], [Meier, 1989]. To improve scheme economics it is necessary to increase the load factor by promoting off-peak consumption of the electricity. Unlike electricity from a diesel generator, micro hydro-electricity fuel costs are zero and marginal costs are low. In order to maximise the use of electricity at off-peak times, the concept of paying a fixed value per month has been adopted in most schemes. This method was first used in Norway, which had a power supply based on isolated hydro-electric systems in the early days of electrification [Mackay].

In developed nations, the consumption of electric power is metered using kWh meters, and consumers pay according to the energy consumed. In developing countries such as Nepal, however, the cost of kWh hour meters is too high, and if it were necessary to install them, schemes could become economically unfeasible due to the capital cost of the meters alone.

Figure 1.6 : Temporary Bridge to Tatopani, 1988

There are several methods by which consumers can pay for their electric power. In rural Nepal these include:

- Flat rate depending on "shares" in the scheme.

  This occurs where the scheme is paid for partly, or in full, by the consumers, each of whom is entitled to a share of the electric power according to the fraction of the capital cost which they contributed at the inception of the scheme.

- Flat rate depending on wattage

  This is by far the most common method of tariffing in Nepal. Consumers pay a certain monthly tariff, and depending on this, they are allowed to draw a certain number of watts from the scheme at any one time.

Users are then supplied with devices such as the *bijuli dekchi* (low power cooker) produced by DCS in Butwal, which is ideal for cooking rice and pulses, the Nepali staple diet [Pandey]. When the lights are not in use, during the day or overnight, users can switch the electric circuit to the *dekchis*, either for cooking or water heating. Users have paid for a certain wattage per month, which they usually decide on the basis of the power required to light their homes. The *dekchi* effectively allows them to use the rest of the power at no further charge.

1.6.6 : Illegal Use of Electricity and Load Limiting

It is immediately obvious that the methods of payment described above make no allowance for illegal use of electricity, i.e. consumers drawing more power than they have paid for. In Nepal it is estimated that almost a third of the generated electric power is lost every year, and it is thought that the majority of this is to illegal users [World Bank]. Organisations such as Development and Consulting Services in Butwal have pioneered the use of current limiting devices as a solution to the problem. The most common device used is the positive temperature coefficent diode (PTC), which is installed so that if the current exceeds that which corresponds to the agreed maximum power for the consumer, the supply is cut

until the load is reduced [Brown, 1990], [Neuhas].

1.6.7 : Governors and Load Controllers

Traditional hydro-electric governing equipment can double the costs of the elec-
tro-mechanical part of a scheme. Increasingly, load governing is being used to
regulate micro hydro-electric schemes [Henderson, 1992]. Load governors oper-
ate by switching ballast load in and out to maintain a balance between hydraulic
input and electrical output power as other elements of the load vary [Whitby].

1.7 : Problems For the Promotion of Micro Hydro Power in Nepal

The particular problems facing the promotion of micro hydro power in Nepal are
numerous, and they are compounded by several general problems which are com-
mon to engineering projects in the Third World in general. The categories into
which these problems fall are outlined below.

1.7.1 : Professional Expertise

In many developing countries there is a lack of personnel with professional train-
ing in many of the engineering disciplines. A field such as micro hydro power is
affected by this lack to an even greater extent, as professional expertise is required
in the fields of hydrology, power demand assessment, civil engineering, mechani-
cal engineering, electrical engineering and economics if a scheme is to be
designed and installed to make the most of the resources available to any commu-
nity.

In organisations concerned with the promotion of micro hydro power it is usual to
find workers who have professional training in some of the above fields. It is rare,
however, to find an organisation which is large enough to contain within in it

representatives of all the specialisms. Engineering projects in the Third World are a rich source of consultancy fees for engineers in the developed world precisely because of these gaps in expertise.

Where the organisation is based in a developing country, however, there may be an added problem. The purchasing power of such organisations is low, especially if they are supported by aid agencies and groups from another nation. The cost of professional engineering expertise may therefore be prohibitive.

1.7.2 : Experiential Knowledge

Many of the organisations working in micro hydro power in Nepal are populated by committed and enthusiastic engineers who (especially in organisations based in Europe and the USA and committed to development in the Third World,) work for very little financial reward. It is inevitable that many of these people have a limited working life in the field, as family commitments and the proverbial "burn-out" make claims on their time and energy. When this happens there is a loss to the organisation not only of their professional expertise, but also of their experiential knowledge, gained, in some cases, from years of exposure to the idiosyncrasies of micro hydro power in the real world.

New engineers will either have the theoretical training together with experience of working in industry, or are likely to have hands-on experience in a developing country. It is rare that new workers will have both of these attributes and their inexperience means that it will be some years before they reach the levels of competence attained by the old hands. In a country such as Nepal, experiential knowledge is invaluable precisely because of the unique conditions pertaining to the field.

1.7.3 : Standardised Design Criteria

In later sections of this thesis, the design methodologies of engineers working on micro hydro will be discussed in greater detail. Suffice it to say at this point that

there are as many ways of designing a micro hydro scheme as there are people designing them, and that this is not necessarily a bad thing. What does hinder the promotion of micro hydro power is the lack of accepted criteria by which scheme designs can be assessed.

In Nepal, some steps have been taken to address this matter, with the introduction of guidelines for micro hydro-electric schemes [Waltham], by which such schemes can be assessed both by the scheme installers and by the officials of any body (such as the Agricultural Development Bank of Nepal) which may be considering applications for loans to enable the installation of such schemes.

1.7.4 : Documentation

One problem which recurs in descriptions of the micro hydro programme in Nepal is that of the lack of proper documentation. This has been raised in conjunction with almost of every stage of the proposal, design and installation processes.

The lack of a hydrological database in Nepal was mentioned in the previous section, [Wesselink], and the lack of data on the variation of demand patterns with the lifetime of a scheme has been raised elsewhere [Edwards]. Databases of materials and equipment incorporating information on specifications and suppliers are nonexistent, as are databases on equipment used in micro hydro schemes and how this performs over time.

Finally, most installers maintain paper file systems which cover the schemes for which they were responsible, but these have proved difficult to manage and maintain, and frequently have not yielded up vital information when this was required. (See chapters 13 and 14.)

1.8 : Developing Approaches to Micro Hydro Power in Nepal

To some extent a body of knowledge and practice has been developed which answers some of the problems set out above. Practitioners in organisations such as the Intermediate Technology Development Group (ITDG), in the UK, the National Rural Electric Cooperative Association (NRECA) in the USA, the Swiss Centre for Alternative Technology (SKAT) in Switzerland, and Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) in Germany, have established methodologies for assessing the power resource at any potential site, for designing a scheme and for computing the economic viability of a scheme. Perhaps more importantly, organisations such as Development and Consulting Services (DCS) allied to the Butwal Engineering Works (BEW), and Balaju Yantra Shala in Kathmandu in Nepal, also have their own methods and techniques, which are often far removed from western or northern-hemisphere standards.

Many of these organisations, in recognition of the loss of experiential knowledge which occurs when workers leave the field, have developed quite sophisticated documentation to aid new engineers and assessors. Perhaps the best known of these is the "Micro Hydro Power Source Book" [Inversin], which is suppported by numerous texts which treat specific problems in more detail [Brown], [Inversin and Yoder], [Crawford and Thurin]. Comparable texts are "Micro-Hydro Power : A Guide For Development Workers." [Fraenkel et al.], and the excellent "Local Experience with Micro Hydro Technology" [Meier].

It must be said, however, that no matter how detailed a manual or handbook may be, it is often possible for new practitioners in any field to misread or to misinterepret the text. It is often also possible for workers without formal training to slip into habits which avoid routines which are difficult or which are necessary only in unusual circumstances. If the above situations arise, it is possible that scheme design will be unsound, as the usual engineering procedures may not have

been followed correctly, or with scant regard for particular local conditions. In cases such as these, a procedure checker would be appropriate.

This is in fact one of the findings of the "Micro Hydro Technical Assistance Project", a project set up by the Nepal Electricity Authority in 1987. Although the project only operated for two months, the main priority of the project workers appears to have been the development of a simple set of data entry programs, based on a spreadsheet format, which allowed some simple checks to be carried out to support any decision on whether or not to grant a loan for the development of any proposed scheme [MHTAP]. The project identified that this would not only standardise any method of data collection, but would also ensure that engineers carried out at least one set of basic checks on the data collected. It was also suggested, in the project's final report, that the use of the system would generate, almost inadvertently, a database on the micro hydro schemes installed subsequently throughout Nepal.

It is into this situation that this project steps, where the problems facing the further development of micro hydro in Nepal, and in fact elsewhere, are being addressed, but further steps are needed to support initiatives at all levels. This project initially aimed to investigate the possibility of using computing, and especially Expert Systems, to provide this support for scheme designers and assessors. The intial funding for this investigation was provided by the Science and Engineering Research Council (SERC), as part of a postgraduate studentship.

As the project progressed it became more apparent that Expert System could provide some measure of support to workers in micro hydro in Nepal. It also became apparent, as discussions with these workers progressed, that they were in fact interested in what Expert Systems could offer them, and that they were keen to see a system which would carry out tasks they judged would be helpful. It also became apparent that to produce such a system would take more time than was available under the terms of the SERC studentship, so the UK Overseas Development Administration was approached for further funding. This was granted, and

the programming work continued with a more practical bias.

The next chapter examines some of the features of Expert Systems, and discusses the ways in which they might be an appropriate technology for use in a developing country such as Nepal.

Chapter 2

Artificial Intelligence :
An Appropriate Technology
for Development

This chapter introduces the concept of Artificial Intelligence (AI) and defines Expert Systems (ES) and Decision Support Software (DSS). The way in which AI has been used in developing countries to date is reviewed, and computing packages for the design of various components of small scale hydro schemes are examined.

2.1 : Artificial Intelligence

Artificial Intelligence is the name given to the branch of computing which attempts to reflect the working of the human mind. It includes computing systems which appear to be intelligent, to understand language, to control the movement of robots, to reason and to solve problems. Computers can only carry out calculations and logical reasoning if the method for doing so is specified in complete detail. The field of AI has therefore also come to incorporate research into the psychological and mental processes by which human beings carry out such processes, how we represent problems in order to find solutions, how context can affect ease of recognition, how we learn from situations and so on.

2.2 : Expert Systems

The area of AI which has been of most interest to engineering and industry is that of expertise manipulation. AI techniques can be used to build up programs which act as an intermediary between human experts in a field and users of the software. These Expert Systems (ES) are essentially problem-solving programs, and are known as *knowledge based* because their performance depends on the use of factual and heuristic knowledge obtained from experts [Stefik et al].

2.2.1 : Tasks of Expert Systems

The tasks carried out by ES range from *formation* type problems, (such as prediction, planning and design,) where the system takes lower level data and builds it into an overview of the problem, to *derivation* type problems, (such as diagnosis, interpretation and monitoring,) where the system accepts a body of data and reduces it to its component parts in order to identify the state of a system.
These tasks are further described below:

Interpretation

Interpretation is the analysis of data to determine its meaning. This can often mean analysing partial or even contradictory information. Where data is unreliable, some measure of confidence in the interpretation may also be required. Candidate interpretations should not be discarded until there is sufficient evidence to rule them out. An example of an interpretive ES is the DENDRAL system which analyses data from a mass spectrometer, finds candidate molecular structures and then simulates their behaviour in the spectrometer in order to find the closest match between spectographs [Barr and Feigenbaum].

Diagnosis

This is the process of fault-finding in a system, which can include the diagnosis of disease in a human being or animal. This process requires the analysis of data in the same way as interpretation, but must also include an understanding of system organisation. It must allow for the fact that symptoms of a fault may be masked by those of other faults, and must accommodate intermittent faults, and incorporate procedures for checking for faulty diagnostic equipment. In attempting to identify a fault, the system must find consistent, correct and incorrect interpretations of the data. The most well-known example of a diagnostic system is MYCIN, a system which uses symptoms and patient history to diagnose infectious diseases [Jackson]. There is a multitude of other tasks to which diagnostic systems can be applied. These include the monitoring of foetal heart signals, [McDonnel], speech recognition, [Lesser et al], and power systems event diagnosis [Keronen], among many others.

Monitoring

Monitoring is the continuous or intermittent interpretation of faults, with the ability to diagnose alarm conditions and give warning of these. Alarm conditions can be situation specific, so the monitoring process must often take account of system status before testing for these conditions. Monitoring systems are used in engineering and medical applications (e.g. see [Bronzino et al]).

Design

This is the creation of a specification for a system or an artefact which satisfies particular requirements. The specification is usually constrained by material resources and time scales, as well as personnel and equipment available for the construction of the system or artefact. Design problems can be so large that the designer may not be able to understand the interaction of subsystems within the design, this means that some element of experiment or exploration is often part of the design process. Design ES have widespread application throughout

engineering, ranging from the design of small components [Goodwin], to the design of large hydro power schemes [Salembier and Isambert].

Planning

Planning is the creation of a program of actions which can be carried out to achieve certain goals. The goals must usually be achieved within a defined time period, and without consuming excessive resources. Planning requirements can change with time so the planner must be able to be flexible. Planning also involves some elements of prediction.

Prediction

This is the process by which a model of the past is used to forecast future events or the future status of a system. It requires an awareness of the way systems vary over time, and works with incomplete information. Prediction should admit the possibility of several candidate futures, and that events further off in time will be affected by events happening in the near future. This can include tasks such as economic forecasting or predictions of flow rates into or out of reservoirs after rainfall [Floris et al].

Although ES have been used for numerous applications, there still exists no standardised method by which an ES designer can produce a system to carry out any of the above tasks. Similar tasks have, in the past, been approached from vastly different angles, and similar approaches have been used to solve apparently different problems. There are, however, some features which are common to most ES, and these will be described below.

2.2.2 : Characteristics of Expert Systems

Conventional rule-based ES have three main components, the Knowledge Base, the Inference Engine, and the Man(sic)-Machine Interface (MMI). (The subject of blackboard architectures will not be treated here, the reader is referred elsewhere (e.g. [Hayes-Roth, 1983], [Hayes-Roth, 1985] and [Laasri et al]) if further information is required on these.)

The Knowledge Base

This section of the ES contains the knowledge obtained from the experts. The knowledge is usually expressed as a collection of assertions and rules, although systems have used such devices as decision trees, semantic nets and predicate calculus to represent knowledge. Knowledge generally falls into one of the four categories outlined below.

Heuristic Knowledge

> This refers to the "rules of thumb" used by experts in making decisions in their field. These can be passed down informally between experts or are gained by experience. This knowledge can usually be represented using rules, and is thought to be an efficient way of achieving good ES performance [Holman and Cookson].

Structural Knowledge

> Where it is possible that rules may interact and affect each other in unpredictable ways, it is common practice to organise individual pieces of knowledge into groups which reflect the structure of the domain of expertise under consideration. This can help to direct the reasoning process, especially if it is used in conjunction with strategic knowledge.

Support Knowledge

> This is the name given to theoretical knowledge which is incorporated into the ES to support the heuristic knowledge obtained from an examination of

the praxis of experts. It is thought that access to support knowledge equips ES to supply suggested solutions in situations where the heuristic knowledge fails or supplies contradictory information.

Strategic Knowledge

This refers to the knowledge used in the decision making processes in the ES. While the decision-making role is, in part, taken by the inference engine, many researchers have suggested that this "metaknowledge" (i.e. knowledge about knowledge), is better represented in the knowledge base. (Where a commercial ES shell is used, the system programmer has no choice but to represent metaknowledge in the knowledge base.)

The Inference Engine

The inference engine is the software programmed to process the rules. It chooses which rules to process, where to obtain data and when to move to another rule. There are two basic reasoning strategies which the inference engine can use.

Forward Chaining.

Forward chaining or "data-directed" reasoning is the process by which the ES takes the basic data and uses the inference engine to move towards a hypothesis or hypotheses about the system under consideration. For this reasoning, all data must be present at the start of the process, and the reasoning method may not be obvious to the user.

Backward Chaining

Backward chaining or "hypothesis-directed" reasoning involves the search for the data required to reach a certain conclusion about the system under consideration, i.e. it moves backwards from the basic hypothesis by breaking the problem into smaller and smaller sub-problems. In such systems the user is usually asked for information as it is required and the reasoning strategy used by the ES is therefore more obvious.

The MMI

This is the section of the ES which allows interaction with human beings. It includes the means by which the ES asks the user questions, accepts data inputs and displays data and conclusions to the user. The ES should be able to communicate with the user in a straightforward manner which is natural for the application under consideration [Fischler and Firschein]. The communication process should be simplified by the use of default values and questions should have restricted answer sets where possible [Robert and Marche].

The MMI also includes the methods by which the ES interacts with the knowledge engineer, and can incorporate programming tools such as traces, windows and debuggers.

2.2.3 : Building an Expert System

Expert Systems can only be used in areas where knowledge can be expressed by rules. These areas must be well-documented and well-organised, and preferrably have experts who have a consensus view of their field. Such domains include engineering, medicine and science, and ES are used in all of these as diagnostic and design tools.

Building an ES involves two separate groups of tasks. The first is that of software engineering, and involves construction of the three components (the knowledge base, the inference engine and the MMI,) described above. The second involves the acquisition and manipulation of knowledge to represent the expertise in a field. The knowledge is then encoded in the knowledge base of the ES.

The first task will not be described here as the particular project described in this thesis used a commercially available software shell, which already contained the inference engine and MMI as well as the routines for structuring a knowledge base (See chapter 3). If any further information is required, the reader is referred to other texts. (e.g. [Pederson], [Jackson], [Hayes-Roth et al,1983]) The process

of acquiring data and factoring it into a knowledge base will be described below.

Knowledge Acquisition

This is the process by which data and information is obtained from consulting technical literature and interviewing experts. The knowledge engineer is only rarely an expert in the area under consideration, so this process is fraught with difficulty. During the course of knowledge acquisition the knowledge engineer can become a domain expert to a certain extent, but at the beginning of the process they must often use technical literature as a foundation for the system. This general theoretical knowledge can then be overlaid with the case specific, heuristic knowledge of the expert.

Knowledge Analysis and Identification

In order to find some coherence in the data, the system programmer must find some way to organise it. The way in which this is done should be defined by the domain experts. This can give rise to problems, however, since domain experts have often long-since forgotten the rules which they used to apply when they were new to their field, and can find it hard to express their reasoning to a non-initiate in the field. Often the most productive approach is for the knowledge engineer to use the data acquired to formulate the problem and then test this formulation with the experts.

Knowledge Representation in the Knowledge Base

Where.the knowledge used in the ES is not visible to the user, the system builder can represent it in a way which is suited to the tools being used to construct the system. Where the user is required to interact with the ES, however, the knowledge must be represented in a manner which is natural to them.

2.3 : Decision Support Software

Decision Support Software (DSS) is a sub-group of ES, and consists of systems in which the course of the reasoning can be changed by the user, should they wish to override the system at some point. The concept of DSS arises from the belief that:

> *"In no domain in which people exhibit holistic understanding can a(n expert)*
> *system based on heuristic rules consistently do as well as experts."*
> [Dreyfus and Dreyfus]

In a sense, DSS accommodates the limitations of the process by which ES are constructed and allows that unforseen conditions may result in ES making incorrect decisions and coming to erroneous conclusions.

DSS is rarely used for monitoring or diagnostic systems, which are generally programmed to react to unforseen conditions with warnings to the system operator. Design, planning and predictive backward-chaining ES, which are to some extent organised to allow speculative attempts at a solution, and which rely on interaction with a user, are far more suited to configuration in DSS format.

The extent to which the user is allowed to override the program obviously depends on the system designer, and the application. Usually the user will not be allowed to affect the outcome of procedures such as mathematical calculations, but there are systems which allow the user to step in and force the system to take an almost opposing path from the one the system would take given the result of preceding calculations.

ES have been disappointing in practice, as there is no method by which they can be "trained" to spot when the reasoning is following an incorrect, or even ridiculous, path. In addition, users can become dependent upon them, especially for design procedures, to the extent where they hamper expertise almost to the same

extent as ignorance. DSS have the advantage that the user is involved at all levels of the program and can choose to define the path of the ES at a local level, a sectional level or a global level, depending on the constraints imposed by the program builder.

2.4 : Computing as an Appropriate Technology for Developing Countries

The term "Appropriate Technology" (AT) conjures up the image of a technology which has been produced in a developing country, using local materials, skills and expertise, in answer to a particular, localised need. Many engineers refer to this perjoratively as the "bamboo and string approach", and AT generally has little credibility in mainstream engineering.

In fact, there are as many definitions of AT as there are people working in the field, [Stewart, 1987], all of which have their advantages and disadvantages. The definition which has been used in this project is as follows:

> Appropriate Technology is the set of techniques which make optimum use of available resources in a given environment. It is the technology choice which maximises social welfare.

This definition may seem very utilitarian, and also seems to ignore some basic tenets of conventional AT (such as non-violence, and environmental neutrality), but it can be flexible in its application. While it may seem that this definition accepts only one configuration of the available resources as optimal, and therefore dismisses all other technologies as inappropriate, this in fact depends on how the "optimum use" is assessed. The crux of the definition is the term "social welfare", and how this is determined.

There is no doubt that to advocate the use of computers in regions where there are insufficient resources to meet the basic human needs of the population is irresponsible and unethical. The project under consideration did not, therefore, recommend that any organisation should purchase computing equipment in order to make more efficient use of their resources. It did, however, assess the computing equipment which was present in organisations working on micro hydro power, and aimed to employ this computing resource in the most efficient way possible. In this way the most appropriate use would be made of an existing resource.

Computers have already been employed to some effect in various disciplines implementing projects in developing countries. Interest in the use of AI in developing countries is growing, to the extent where agencies such as the UK Overseas Development Administration will provide funding from already over-stretched budgets for AI projects. Research institutes in the developed world are becoming more aware of the possibility of applying AI to technologically unsophisticated fields, and the number of software systems being developed is increasing rapidly. This thesis is primarily concerned with ES applications, so some diagnostic and design medical and engineerng ES are reviewed below.

2.4.1 : Medical Expert Systems

In developing countries, the relative scarcity of doctors demands that new solutions be found to the problem of health care in rural regions. This rarity of expertise has been addressed in part by the development of ES for use by primary health care workers in outstations of health centres [King and Beck].

The most common task assigned to these ES is that of referral, i.e. it helps the primary health care worker to decide which cases require attention at the next level of the health-care hierarchy, reducing the number of inappropriate referrals and ensuring that the most urgent cases are treated first. Examples of this include the SASEP system, which was developed and tested in South Africa, [King and Beck], and the SYMPMED system, which was developed and tested in India

[Uplekar et al].

ES are also used in treatment programmes, which hold prescription information on a range of the most common diseases, together with pharmaceutical information on a range of basic drugs. An example of this is the TROPICAID system, developed in France and tested in Chad and Zaire [Auvert at el]. ES also exist which display a combination of treatment recommendations, with the last of these being referral, if the problem appears to be outside the scope of the primary health care unit. An example of this is the system for primary eye care developed by Kastner et al [Kastner et al], in the USA.

2.4.2 : Engineering Expert Systems

In developing countries, the shortage of professional engineering expertise can result in projects such as the design of sanitation systems, drinking water supplies or small hydro power schemes being carried out by personnel who:

- have technical expertise only,

- have professional training in only one field of the many required by the project,

- are unaware of local material resources or expertise levels,

- are unaware of unique local conditions.

Engineering ES can provide a unique service in developing countries in that they can contain a knowledge resource which is normally only available from several expensive engineering consultants. Where the knowledge of several disciplines is required to produce a design, ES can provide access to specialist knowledge from each of these. In addition, an ES can provide decision support to an engineer who is inexperienced and take a designer through an exhaustive design path, ensuring that essential steps are not missed out. It has been suggested that ES can be used as a training tool, allowing trainees to become familiar with the consequences of

various design decisions in a safe environment. ES can also act as a vehicle for the transfer of safe design practices into organisations without the resources to consider these.

Given all the points above, it is surprising that ES have not found their way into every engineering organisation in the Third World. It is worth remembering, however, that AI is an intimidating field for most of the uninitiated and that the impetus for the promotion of ES in developing countries is relatively new. There are, however, some systems which have been at least tested in developing countries. An example of this is the TREAT software for the preliminary design of drinking water treatment systems [Kelsey].

2.5 : Computing for Small Scale Hydro in Developing Countries

A review of the software available for the design, optimisation, management and control of hydro power schemes in the developed world will not be attempted here. The problems of Third World designers are vastly different to those encountered in developed countries, as are the material and expertise reources available for their solution. Consequently, this section will now consider the problems associated with small scale hydro in developing countries to which computers have been applied to date.

2.5.1 : Engineering Calculations

Workers in the field of micro hydro have long used computing techniques to perform calculations quickly and reliably either in the office or in the field. The software ranges in sophistication from simple routines to carry out flow rates to whole systems of checklists to ensure that engineers have completed every stage of a design process. The hardware on which these routines have been mounted ranges

from the programmable calculators to the IBM-compatible PC. Although the author knows of several programs used by practitioners in the micro hydro field, only some of these have been documented and released into the public domain. Some of the documented routines are discussed in greater detail below:

The NRECA method for Calculating Monthly Runoff Values

This method is published by NRECA in "Hydrologic Estimates for Small Hydro-electric Projects." [Crawford and Thurin]. It is written in FORTRAN and carries out hydrologic calculations based on soil moisture storage, catchment area, etc. It is unlikely to be useful in the field, because micro hydro schemes are rarely installed in regions where data on soil conditions is available.

The NRECA method for Calculating Flow Duration Curves

This is published in the same book as the monthly runoff values calculation and is further expanded in notes produced by ITDG for participants on their micro hydro courses [ITDG]. It has been implemented as a spreadsheet-type calculation, and as a BASIC program. It also depends on the site assessor being aware of quite sophisticated hydrological parameters.

The Gumbel method for Flood Flow Prediction

Gumbel argued that flood flows could occur on any day of the year, and therefore that the distribution of floods would conform to a normal distribution. He produced equations which predict the frequency of flood occurrence using these principles. Although this method has never been empirically verified, it is used in some organisations to give an indication of the likelihood of floods. ITDG have implemented this as a BASIC program [ITDG].

Iterative Program for Head Loss in Pipes

ITDG have been responsible for the dissemination of much of the literature which is now associated with the practicalities of installing micro hydro schemes. They

have also been responsible for many of the publicly released software listings which are associated with this. They publish a routine which uses Mannings method for calculating head loss due to turbulence in pipes in the notes referenced above. The program can save an engineer hours of tedious and error-prone calculation.

Surge Pressures in Pipes

The risk of surge pressures occurring in pipes due to their sudden closure is high where the pipe bore is narrow and accidental closure can occur due to an object suddenly covering the pipe inlet. This is often a risk for micro hydro schemes. An inexperienced engineer may be tempted to leave this calculation out of any asssesment of the suitability of pipe wall thickness, and the routine which ITDG have produced to carry out the calculation removes any anxiety that may exist over the evaluation.

2.5.2 : Economic Viability Assessment

In addition to the routines written to carry out engineering calculations, there have been programs written to carry out assesments of the economic viability of micro hydro schemes. Some of these programs have originated in organisations which are concerned with installing micro hydro schemes, but some have originated with funding bodies, which have to determine whether or not a micro hydro scheme is the best way to make a return on an investment. Between these two extremes lie the organisations which have money to use in the promotion of micro hydro, but which have to ensure that the schemes they actually choose to fund will make the best use of the financial resource available.

It is not possible to examine most of these routines, as they have not been released into the public domain, but an example of the type of program available is that developed by the Micro Hydro Technical Assistance Project of the Nepal Electricity Authority [MHTAP]. This uses a basic spreadsheet format to carry out simple economic checks on proposed micro hydro schemes. It is part of larger set of

programs which can be used as a checklist for someone assessing a funding proposal.

Chapter 3

Decision Support Software for Micro Hydro: A Specification

This chapter considers the way in which a system of Decision Support Software (DSS) was set up to support workers in the field of micro hydro in Nepal. In common with most software systems, the system will be referred to by the acronym MICADO, the letters of which were extracted, with some imagination, from the phrase:

MICro hydro Assessment Design and Optimisation

The specification for the system, which was defined by the user group, is described, as is the way in which it was programmed using the commercially available expert system builder CRYSTAL together with LOTUS 1-2-3 files for data storage. Finally, the knowledge resource which was programmed into the system is discussed.

3.1 : Tasks Specified for the MICADO System

The MICADO system was set up in response to a need expressed by engineers working in micro hydro power in developing countries. Accordingly, the system carries out tasks which these practitioners judged to be useful. These are listed below, and will be described in more detail as they occur in subsequent sections.

- Routine calculations and checks as a "safety net" to ensure that designers do not make basic mistakes, e.g. checking that demand for power can be met by the potential power available at the proposed site.

- Iterative calculations, such as the determination of penstock wall thickness, which can be very time consuming and are prone to errors if carried out on paper.

- Speculative evaluations, where the designer can experiment with the effect of varying parameters in the scheme design. (It was requested that this should not take as long as the full evaluation process).

- Graphical representation of demand assessment so the designer can see the way demand varies over a 24 hour period.

- Record keeping, especially lists of parts used at each site and the particular design quirks of each scheme.

- Maintenance record keeping, including reminders for other operators who might access the file on a certain scheme.

The possibility of implementing a routine for sketching powerhouse layout, (which could be called from the main DSS as required,) was also discussed. There is, however, a wide range of machines, each with their own peculiar graphics drivers, printers, mice, (or the absence of mice,) used throughout the organisations concerned with micro hydro in Nepal. Eventually it became apparent that it

would be a waste of programming time and disk space to include such a routine in the MICADO system.

One of the main problems which faced the development of the system was the overabundance of information which exists in an academic environment. For each specialism pertaining to the design of a micro hydro scheme there is no shortage of documentation and of experts willing to discuss their particular field. For a knowledge engineer unfamiliar with the field, the temptation was to include as much expertise as possible so that all eventualities were covered. This is not possible if the software is to be at all practical, to run on machines which people have available in their offices, within a time scale which helps rather than hinders the design process.

The system was also required to produce answers having some relevance to actual conditions at the site, conditions which are far removed from the ideal of a laboratory environment.

The use of CRYSTAL imposed limitations on the size of program which it was possible to create, and this, together with the recommendations of workers in the organisations discussed above, provided criteria which could be used to judge the level of detail which could be used for each of the tasks required for the design of each scheme.

3.2 : The CRYSTAL Environment

Because this system of DSS was to built in a limited period of time, in order to be used by workers in the field rather than academics in laboratory conditions, it was apparent that the knowledge engineeringshould take priority over the development of an inference engine in any of the conventional AI languages. Accordingly, the inference engine was structured using the commercially-available "Expert System

Builder" CRYSTAL, released by Intelligent Environments.

The CRYSTAL Expert System Builder does not in fact allow a programmer to build an ES which can learn, which can induce new rules, or which handles uncertainty [Linderholm], [Wallsgrove]. In fact "Expert System Builder" is a misnomer for a software environment which does not in fact allow the building of expert systems at all. CRYSTAL does, however, provide a very quick and easy way to structure a system of software which can follow a design path defined by an expert, carry out calculations and access information files. In this sense it is appropriate to describe it as a "DSS builder" and it was used for this purpose in this project.

The University of Edinburgh has a site license for the CRYSTAL development system, allowing it to be used for academic projects. When the MICADO system became the property of the Overseas Development Administration, a version of the CRYSTAL run-time system was purchased, as the software was to be used outwith the academic environment agreed in the terms of the site license. When the software was completed, the run-time system, together with the MICADO code were assigned to the ODA, which is now free to release the MICADO code to any other user in possession of a CRYSTAL run-time system.

The CRYSTAL environment will be described below, together with the way in which the LOTUS 123 spreadsheet manager was used for the storage of data on the schemes assessed and evaluated using the MICADO code.

3.2.1 : IFs, ANDs, and ORs

CRYSTAL allows the program builder to enter rules in natural language, and to link the rules entered with logical IFs, ANDs, and ORs. The CRYSTAL environment takes no account at all of the text entered in each rule box, and merely links the rules as directed by the programmer. For example, consider the rules shown below:

    IF   Hydrological resource is assessed.

AND   Demand is assessed.

AND   Scheme flow rate is selected.

As far as CRYSTAL is concerned, this list will be processed in exactly the same way as the list:

    IF   Hydrological resource is assessed.

AND   Demands are made in parliament.

AND   Scheme flow rate is selected.

Each rule can only be logical ANDed with others following it if it is logical TRUE. If a rule is not logical TRUE, then the program leaves the set of ANDed rules which it is evaluating, and either moves to the next logical **OR**, or, if there is no alternative, stops the rule evaluation altogether.

For example, if, in the list below,

    IF   Hydrological resource is assessed.

AND   Demand is assessed.

AND   Scheme flow rate is selected.

    OR   Typical demand levels are assumed.

the rule,

    Demand is assessed.

is not TRUE, then CRYSTAL will not evaluate the rule following this.

The program will move to the rule:

Typical demand levels are assumed.

rather than the rule:

Scheme flow rate is selected.

How the program determines whether each rule is TRUE or not is determined by the programmer, who can set a list of subconditions, consisting of other rules, requests for data or calculations, for each rule entered.

3.2.2 : The Tree Structure

CRYSTAL programs operate by invoking a tree structure while running. The system is rigidly backward-chaining, in that it works from a "Master Rule" which embodies the final conclusion of the system. This rule is only logical TRUE, i.e. the evaluation succeeds, if the list of conditions entered by the programmer and linked by logical ANDs are all true. Each of these rules may also have a list of rules as sub-conditions which must all be satisfied if it is to be logical TRUE. These pre-conditions may have pre-conditions, and so on indefinitely. An example is shown below, or one of the rules in the canal designing section of the economic assessment section of the MICADO system.

Scheme is economically viable.

This rule has itself a set of rules which are conditions which must be satisfied if the rule is to be logical TRUE. These are shown below.

IF   Revenue data is summed.

AND   Outgoings are summed.

AND   Outgoings are less than revenue.

This level of logic again goes to another level. Each of the rules above has a set of conditions which must be satisfied before the rule can be logical TRUE. For instance the rule

Revenue data is summed.

is only logical TRUE if the set of conditions listed below are also logical TRUE.

IF Revenue data is read from file.

AND Revenue data is loaded into arrays.

AND Summing calculations are carried out.

This can continue almost indefinitely. For instance, the rule

Revenue data is read from file.

has itself the list of conditions:

IF Data file is found on disk.

AND Data file is opened.

AND Data file is searched for revenue data.

AND Revenue data is read into program interface.

AND Data file is closed.

Each of these rules again has sub-levels, as do all the un-expanded rules listed above.

This means that CRYSTAL lends itself to structured programming, where each task to be carried out by the software can be divided and subdivided until the task is completely specified. Each of the descriptive rules at the higher levels must be completely broken down into its component tasks. It also means that while running the program, the user may encounter only a fraction of the rules entered by the programmer, as they follow only one path through the tree structure.

3.2.3 : Functions, Commands, Screens

Functions

CRYSTAL supports a full range of mathematical functions which can be called from the function dictionary and entered into any of the rule spaces by the programmer. For the full list of functions supported, the reader is directed to the CRYSTAL developer's manual.

Commands

CRYSTAL also supports a system of commands, which the programmer can also enter in any rule space. These can be divided into input/output commands and rule execution commands. For example, the input/output commands are listed below:

COMMAND	PURPOSE
ASSIGN VARIABLE	Assign a value to a text or numeric variable. Specific syntax is required.
BEGIN EXPLAIN	Make explanation display available to user.
CONCLUSION DISPLAY	Display text of rule being evaluated.
DISPLAY FORM	Display screen to user with current values of variables in fields set up by programmer. Used for data input/output and display.
END EXPLAIN	Switch off explanation display.
HELP EXPLAIN	Change explanation display to full screen size.
INIT.VARIABLES	Initialise all numeric and text variables.
MENU QUESTION	Present the user with a menu choice.
PRINT FORM	Send a screen to a disk file or printer.
VIEW FORM	Display a form while continuing with rule processing.

These commands will not be examined here, as a full description of their function together with that of all the rule execution commands is given in the CRYSTAL developer's manual.

Screens

The user has no access to the structure of the program, or the way in which CRYSTAL links the rules. The user sees only a sequence of screens, which either display information or request information from the user. There are three types of screen with which the user is required to interact:

The Display Screen

This screen can be structured by the programmer to either display data to or request data from the user. The programmer sets up "Input fields" and "Output fields" on the display screens, which contain variable names. When the program is running, the variable name is not displayed to the user. Input fields operate by assigning the text or numeric value entered by the user to the variable named in the field. Output fields operate by displaying the current value of the text or numeric variable named in the field. Display screens can contain a mixture of input and output fields.

Display screens can also be used, together with text strings such as the bar and diamond, and the CRYSTAL LENGTH command the represent the relative sizes of values for display. The MICADO system uses this method for several bar charts in the Demand Assessment module. Examples of all the uses made of the display screens in MICADO will be given later.

The Yes/No Question

This screen contains a box into which the programmer can type a Yes/No question.

Figure 3.1 : A Yes/No Question Screen
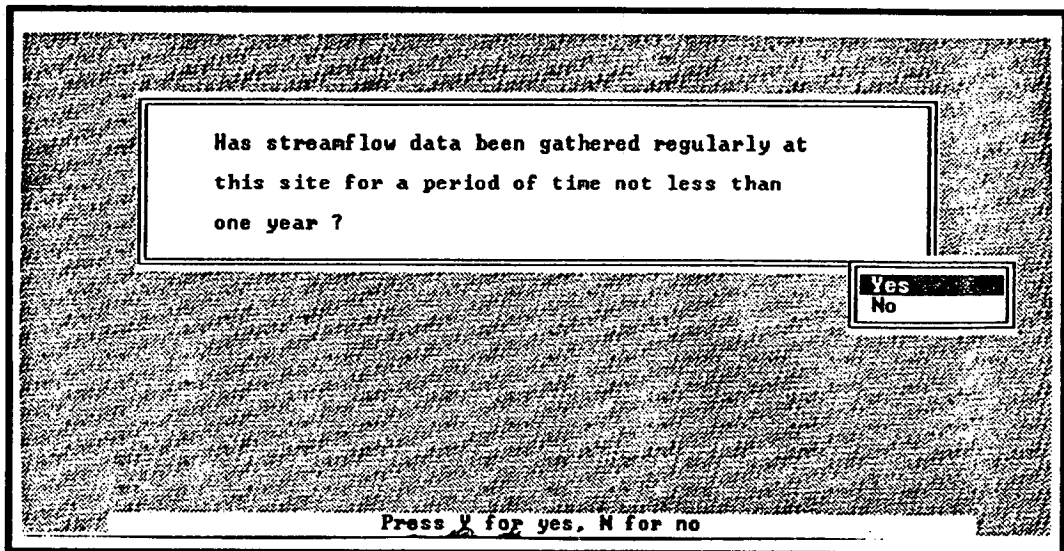
The user can answer the question either by moving the cursor between the
YES and NO boxes, or by pressing the "Y" or "N" keys. A "yes" answer
sets the rule value to "succeed", a "no" answer sets the rule value to "fail".
An example of a Yes/No screen used in the MICADO system is shown in
figure 3.1.

The Menu Screen

Menu screens allow the user to move the cursor between options listed on
the screen and to press the return key when the cursor as situated at the cor-
rect place on the screen. The CRYSTAL environment then automatically
assigns a value to the "menu variable" entered by the programmer, depend-
ing on the location of the cursor on the screen. These screens can be used in
a number of ways, and provide a flexible tool which:

•   can force a user to select from a restricted list of options.

•   can be used in conjunction with the CRYSTAL **SPECIAL RULE** and
     RESTART RULE commands to set up a "what-if" loop.

•   can be used to allow the user to make a subjective assessment of the cer-
     tainty of a value by progamming the choices as a sliding scale which the

cursor moves along from left to right. The MICADO system uses this in an instance where the user is asked to assess the likelihood that rainfall data has been taken for a typical year.

Examples of these uses of the menu screens will be given later.

The View Screen

This is a screen which allows the programmer to display information to the system while the program is running. It is useful if a calculation or data-manipulation process takes more than a second to carry out, when the user may worry that they stopped the program in its tracks. View Screens are used most in the MICADO system to display

Please Wait....

messages, where the line of dots after the message increases in length as the calculation proceeds. This means that the user is reassured that they are waiting because the system is carrying out a task and not because it has crashed.

3.2.4 : Memory Requirements of CRYSTAL

The CRYSTAL environment requires at least 640 kBytes of RAM in order to run. In fact somewhat less than this amount of memory is available for development of the rule base, as the environment reserves a portion of this for carrying out *dos* commands called from within an application, and requires about 4 kBytes for each screen format programmed by the system builder.

CRYSTAL can operate using expanded memory, but as a primary aim of this project was to produce a system of software which was portable, expanded memory was not an option available to the system builder. Accordingly, each of the knowledge bases included in the system was limited to around 104 kBytes storage capacity for the rules entered.

In chapters 5 to 14, where each module of the MICADO system is described, a table at the beginning of each program description summarises the rule base size and the memory usage for each rule base. Some of the design modules were too large for inclusion in one knowledge base, and are composed of two or three modules chained together. Where this is the case, the knowledge base programs are described separately.

3.2.5 : The Building and Development Tools

CRYSTAL operates in the first instance by the use of pull-down menus, which allow the user to choose between file-handling routines, setting system conditions or using programming tools. These will not be described here, as full details are available in the developer's manual.

The environment also sets up a rule dictionary, which lists every rule entered in alphabetical order, from which rules can be called int the rule base, without the programmer having to type them out in full. An alphabetical variable dictionary is also set up by CRYSTAL, which has the useful facility of allowing the programmer to set constraints about each variable. This means that where the user is asked to enter, say an integer between 1 and 10, the programmer can define this in the variable dictionary, so that any other entries will not be accepted by the system. The MICADO software uses these conditions in all of the modules, as a means of reducing errors which could occur when the user is entering data.

CRYSTAL also contains standard program development tools, such as a sophisticated rule trace and a screen painter.

There is another useful tool known as "Snapshot", which allows the programmer to capture a screen map of any screen prepared using a graphics package. This is then stored in a file which can be called up for display while a CRYSTAL program is running. An example of such a screen is given in figure 3.2.

Figure 3.2 : Example of a "Snapshot" Screen.
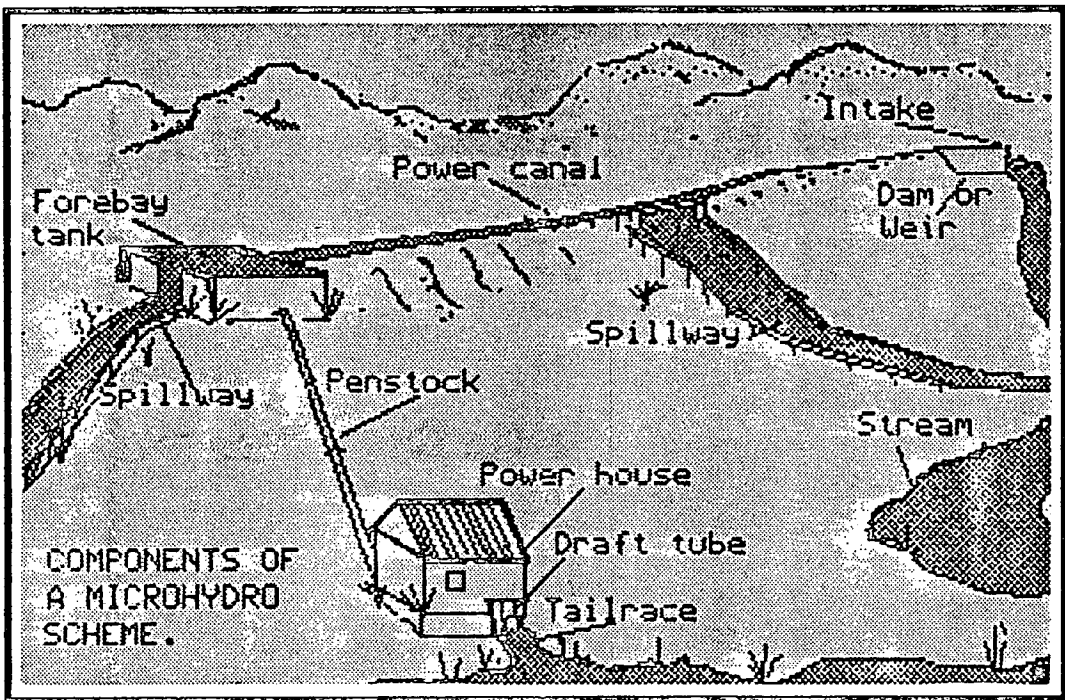
3.2.6 : Interface Routines

The CRYSTAL environment contains several interface routines which allow it to interact with LOTUS and dBase III files. This is invaluable where the application being developed requires any sort of data management. CRYSTAL has a set of routines by which programmers can pass data between knowledge base files, but these are limited in their application, especially where large quantities of data are concerned. In addition, the environment has a facility by which programmers can write their own interfaces in "C" which can be used to interact with any program they wish.

The MICADO software uses the supplied CRYSTAL interface to the LOTUS 1-2-3 software for database management. This contains a series of commands for file handling, file searching and data input and output. The software writes data to and reads data from a LOTUS 1-2-3 file throughout the evaluation of each scheme. When the user wishes to save the data produced during the evaluation this is done using the file set up by the MICADO system and by using *dos* commands called from within the CRYSTAL environment.

3.2.7 : Data storage in LOTUS 1-2-3

The LOTUS spreadsheet software will not be described here. The reader is referred to texts such as "Using 1-2-3" [LeBlond and Cobb], if further information is required on this.

The MICADO system does not use any of the LOTUS 1-2-3 data manipulation or mathematical functions. The spreadsheet is used solely as a data store, and values written to it are read into the data buffer set up by CRYSTAL as required. Each module of the MICADO system writes to a specific area of the spreadsheet, and there are also areas reserved for data management variables. These record information such as the number of modules which have been carried out and the number of maintenance visits carried out.

3.3 : The Knowledge Resource

One of the prerequisites for the production of a knowledge-based ES or DSS is that the knowledge resource for its development should be concise, amenable to modularisation, and readily available to the knowledge engineer. In a sense this is true of the knowledge resource for the design of micro hydro schemes, especially for that section of it embodied in semi-technical literature such as handbooks and design manual.

In another sense, it is not, because the engineers who have worked on micro hydro schemes in developing countries are at odds with each other when it comes to their design methodologies. Their knowledge of developing countries also means that they do not use many of the techniques and knowledge used in developed nations which are inapplicable where material and skill resources are very limited.

For the purposes of this project, the primary experts were taken to be those people with practical experience of micro hydro power in developing countries, rather than the people with professional expertise gained in a developed country. The primary experts provided the criteria by which the knowledge gained from all other sources was assessed. These sources are all described below.

3.3.1 : Semi-Technical Literature

Semi-technical literature was by far the most important knowledge resource available at the inception of the DSS for micro hydro. The many manuals and handbooks available to the designers and installers of micro hydro schemes provided a valuable template against which preliminary versions of the DSS could be specified. (See Section 1.8 for a discussion of these.) The preliminary versions outlined primary formulations of the problems facing micro hydro designers, which could then be tested by the domain experts.

3.3.2 : Preliminary DSS Tests

A preliminary version of the DSS was produced in 1987 and tested on machines belonging to organisations concerned with the promotion of micro hydro in the country. Because of the unfamiliarity which these organisations had with AI, this first set of software was an introduction to the very concept of software systems acting in a design role. Although the test run allowed the experts to express their agreement, or disagreement with the *content* of the program, in most cases the subject of most interest was the way in which they reacted to the MMI and the mode of operation of the software. Organisations which tested the preliminary DSS included Development and Consulting Services (DCS) in Butwal, Nepal, Balaju Yantra Shala in Kathmandu, Nepal, the UK-based Intermediate Technology Development Group, the ICIMOD centre in Kathmandu, Nepal, and the Agricultural Development Bank of Nepal.

In all these organisations, there were people who displayed an intial reluctance to become involved with the testing, and who were apprehensive of unfamiliar

software. This initial reluctance was, in most cases overcome if the preliminary screens displayed by the software were viewed. These screens include the introductory logo, (see figure 3.3)

Figure 3.3 : Introductory Logo for MICADO

```
MICADO

MICro hydro scheme Assessment Design and Optimisation system.

Press any key to begin.

(c) T.M.Anderson. May 1992.
```
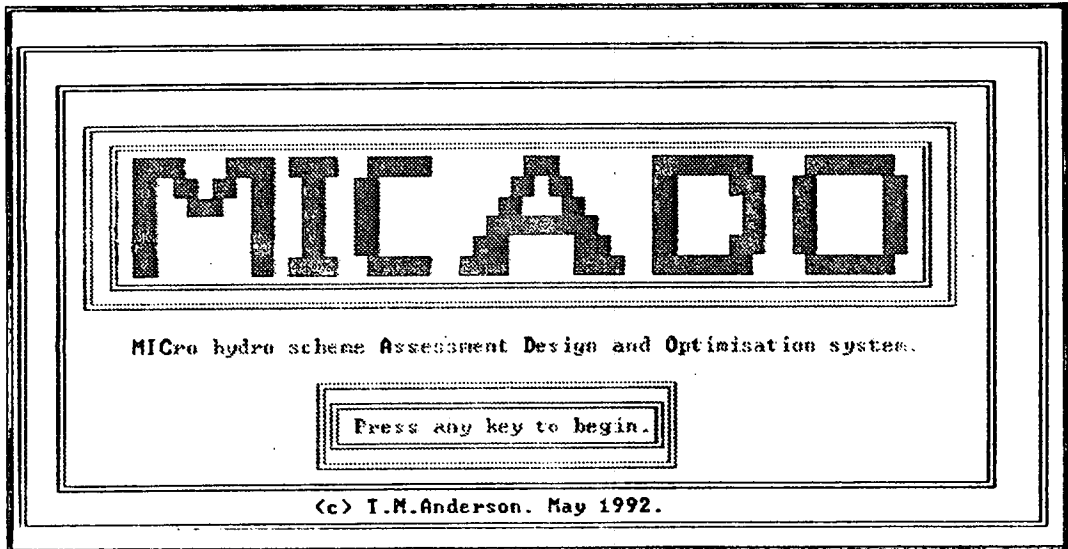
which caused much mirth, and broke the ice, and the initial graphic screen of the software (see figure 3.2), which was immediately recognisable to anyone who had either worked on a micro hydro scheme, or was familiar with the body of semi-technical literature available.

Once their initial reluctance was overcome and people gained confidence, the next task was to accustom them to the idea of software carrying out major engineering and design tasks. This was done mainly by guided trials of the software, where the author began a run of the DSS and asked the expert present to supply answers and data when these were requested by the system. The expert was gradually encouraged to take over the run when they became sufficiently confident of their ability to cope with this.

The initial trepidation felt by many of the experts evaporated quite quickly, and was, in a majority of the cases, replaced by a relieved dismissal of AI and everything that goes with it. In most cases, the expert was not particularly computer-literate, and had no grasp of the fact that the system could be re-programmed to

carry out exactly the tasks which they specified, in the manner in which they specified. Some explanation of the way in which the software was constructed was necessary in most cases, where the author changed the way in which the software carried out a specific task while the expert was present.

The experts then had to be re-involved in the process by a question-answer session which allowed them to say what they actually thought of the software, the procedures it carried out, the way in which it interacted with the user and the way in which it presented suggestions and answers. Wherever possible the author left the expert to consider the possibilities which DSS offered, and returned later to ask the expert what they believed would be useful in the software.

It must be said here that in a few of the above-named organisations, there were personnel who were either un-intimidated by computers or were enthusiastic about the possibility of new developments within the field of micro hydro. As is the case for technology transfer into rural areas of developing countries, technology transfer into organisations with a more sophisticated level of techological development is aided by contact with one highly motivated individual in the recipient group. Fortunately for this project, there were eventually such individuals in most of the target groups.

3.3.3 : Interviews with Experts : Questionnaire/Discussion sessions

In the early stages of project development, the specification of the structure of the DSS was defined by the semi-technical literature and then by the results of the prelimnary testing sessions with experts in Nepal and the UK. The methodologies which these experts used to produce designs for micro hydro schemes were as varied as the people producing them. This is very common in the process of heuristic knowledge acquisition. It became apparent, therefore, that the best way forward was to seek a consensus between the experts on the tasks on which they disagreed.

Accordingly, a questionnaire was designed which approached all the design tasks over which the author had noted disagreement. As well as asking questions on all of these topics in order to elicit the heuristic knowledge which the experts had gained over years over experience working in the field, the questionnaire repeated itself by asking the same questions a number of times in different ways. Each topic was categorised in as many of the different sections of the questionnaire as possible, as a way of revealing the structural knowledge which the experts unwittingly possessed. (See Appendix 2 for the full text of the questionnaire.)

The questionnaire was sent to a number of experts who agreed to meet with the author and give their answers. The experts knew that other experts would be present, but agreed not to discuss the questionnaire with the others before the meeting. Full notes were kept of the meeting, in order that the experts did not feel that any particular attitude was of interest to the author. In fact, the points of especial interest were those of disagreement, and particular note was taken of the way in which the experts resolved the disagreements among themselves and came to a collective answer to the question of interest. There were many of these disagreements, and the meeting provided an insight into the criteria which the experts used when deciding among themselves how they would approach a scheme if they were designing it together, rather than individually.

3.3.4 : Interviews with Experts : Question/Answer Sessions

After the primary formulation of the software and modularisation of the domain for knowledge acquisition, the next step was to carry out in-depth interviews with experts in the various disciplines which are drawn together in order to design a micro hydro scheme. These include civil engineers, electrical engineers, academics with a background in electrical systems, engineers designing load controllers, turbine experts, electrical power distribution experts, economists and software engineers. If it was possible, the interview with the expert was accompanied by a demonstration of the particular section of the DSS which related to their field.

In the case of the software engineers, their assessment of the whole system, and especially of the MMI, was sought, rather than their opinion of the engineering tasks carried out by the software. In these cases, in opposition to the nervousness of the micro hydro workers faced with AI, the software engineers found the technical details of the evaluation more intimidating than the idea of the DSS itself.

3.3.5 : Technical Literature

Once the structure of the DSS was defined by the semi-technical literature, consultation with experts and testing of the preliminary DSS, the "gaps" in the software, as assessed by experts in the domain covered by each module, could then be filled by consultations with technical literature. These "gaps" were formed mainly by the lack of equations and definition of fundamental assumptions in the semi-technical literature.

3.3.6 : DSS Testing

The subject of testing the final version of the DSS will not be treated here, but will be discussed in the concluding chapter of this thesis. Suffice it to say that the testing process is itself part of the further development of the system, and it is thought that this will continue for some time.

3.4 : Constraints on Software Development

The aim of this project was to produce a suite of software which would meet most of the needs expressed by the engineers working on micro hydro in Nepal. As such a system is only of use to the aforesaid engineers if they can run it on the computer systems they already have, their computing resource defined many of the parameters of the software. During fieldwork in Nepal, and in consultations with aid workers, the author discovered that the ubiquitous IBM PC compatible

was available to almost all of the people working in this area. The first constraint, therefore, was that the software should run on these.

The next constraint which emerged was the difficulty in communication between the UK and Nepal. Telephone contact is impossible, faxes often go astray, telexes are garbled and letters can take three or four weeks to arrive. In the light of this, it became apparent that a system of software was required which needed minimal support and maintenance. It was also apparent that the software should be almost self explanatory, so that the supporting documentation would not bear the brunt of explaining the system to the user. Software documentation is notoriously difficult to write, and equally notoriously difficult to understand, the best efforts of the writer(s) notwithstanding.

Apart from these major constraints, the project was scheduled to finish within four years, so the research and programming work, including field trials and the release of a final version, supposedly of commercial standard, was to be carried out within this time.

Chapter 4

Overview of the MICADO System

This chapter examines the overall characteristics of the MICADO system of Decision Support Software (DSS) and outlines the basic assumptions underlying the development of the program. It explains the structure of the software and the ways in which the programs which constitute it interact. Interaction with the user via the screen and via the user manual are also covered.

4.1 : Software Philosophy

This project was directed towards producing a system of software specified by the user group (i.e micro hydro power engineers and workers), and tailored to their specific needs and computing resource. This has necessitated detailed discussion with the indentified user group at all stages of the project.

It was intended from its inception that the software should be accessible to a wide range of users, and that it should not intimidate them with jargon or quasi-technical terms. The user-machine interface has therefore been of special concern throughout the development and production of the software package. Another issue of particular importance has been the promotion of safer standards of design and operation for micro hydro power.

The program incorporates a large portion of code dedicated to preventing user errors. This has an immediate impact on the users' confidence in using the system, and has a more long term impact on safer design levels in general. The MICADO software also incorporates a record-keeping system.

4.1.1 : Man-Machine Interface

It was ascertained by the author during fieldwork in Nepal and field trials of early versions of the MICADO system that people who may be quite familiar with using computers to carry out word processing or accounting tasks, find it quite intimidating to be faced with a software system which is related specifically to engineering projects, and carries the "Artificial Intelligence" label. The potential users interviewed were uneasy when faced with a series of one-line questions which they were expected to answer without any explanation of how their answers were received or processed by the system. When faced with a more sympathetic man-machine interface, which informed them of the way in which each question should be answered, and which asked the user to confirm or change any input which was called into question, the potential users were less intimidated, and said that because they felt more in control of the program, they would be more inclined to use the software.

This prompted the consideration of very interactive form of program, where the user was drawn into the task of assessing the potential micro hydro scheme, and was part of the decision-making process at all points in the evaluation. Each screen in the MICADO software is therefore self-explanatory, and information screens are interspersed with graphics screens and menus to keep the user's level of interest high.

The above reasoning has, of course, had an impact on the amount of space required to store and run the MICADO programs, but it was judged that if the software had a lower level of communication with the user then it may not be used at all.

4.1.2 : Bias to Safe Design

While attempting to be objective and impartial at all stages of the development of the software, the author accepts that it is not possible for any scientist or engineer to be totally divorced from the society in which they are operating. In the light of this it was decided that the software, which would undoubtedly unconsciously reflect the author's view of micro hydro power and her perception of the specification of the system, should also consciously reflect some of the basic assumptions of the engineers involved in micro hydro power in developed countries. Thus, while the user group in Nepal defined the tasks which they would like the system to carry out, the program ensures that these are carried out to standards defined in countries where hydro power is at a more sophisticated level of development.

The MICADO system, therefore, recommends at all stages that micro hydro schemes have safety standards which are more usual in developed countries than in countries such as Nepal. While it is accepted throughout the program that these standards may not be complied with for reasons including economics and expediency, there is, nevertheless, a bias towards them. It is hoped that this bias will result in the standards becoming more familiar to workers in Nepal, with a corresponding move towards the design and installation of safer schemes in the long run.

4.1.3 : Error Trapping and Default Values

In an attempt to ensure that even an inexperienced user can proceed through the system without having to stop for lack of a specific number, the system uses menu screens wherever possible. If this is not possible, and the user is asked to enter a specific value or string variable, then the program contains set boundaries within which the value must fall. This might be, in the case of a string variable, a restriction to a certain set of letters (e.g. see screen display in figure 4.1)

Figure 4.1 : Example of Restricted Input Values Screen

```
ESTIMATED DEMAND FOR ELECTRICAL AND MECHANICAL POWER.

As demand for electrical and mechanical power often occurs at different
times of the day, you can now enter a rough estimate of the size of the
most important sections of demand, and the times of day at which these
are likely to occur.
Remember:  * enter demand in units of kW,
           * use the 24 hour clock for the time entries.
           * enter "m" for mechanical and "e" for electrical demand,
             "n" to fill any gaps left in that row.
           * enter zero values where there are any gaps left in the
             bottom three rows.
```

Electrical or Mechanical ("E" or "M")	1	2	3	4	5	6	7	8
	e	e	m	m	n	n	n	n
Demand (kW)	1	10	3	3	0	0	0	0
Start (hrs)	22-00	18-00	6 -00	10-00	0 -00	0 -00	0 -00	0 -00
Finish (hrs)	4 -00	22-00	18-00	0-00	0 -00	0 -00	0 -00	0 -00

```
Enter values and then press RETURN or ENTER to continue.
```

A numerical variable is often restricted to fall within a certain range, or to take only an integer value. In the MICADO system, most of the variables are surrounded by this "safety net" to prevent any unforced errors, and the user is informed of this.

The system also contains default values, where it was judged that these would help the user to move through the program, and where the value entered would be used as information, rather than as an input to a calculation which would affect the outcome of the MICADO assessment. An example of this is the specific speed of the turbine to be used at the site. The user may not be familiar with the concept of turbine specific speed, or may not know the specific speed of the particular turbine which is proposed for use at the site. The software contains a table of default values for turbine specific speeds, and assigns one of these to the specific speed variable Ns, depending on the turbine type, before the user is asked to enter a value for this.

4.1.4 : Bias to Improved Record Keeping

Several of the micro hydro engineers interviewed by the author in Nepal asked if the MICADO system would be able to store records of the assessment process

carried out for potential sites, and if the system could have some record of the components used in any scheme which could be accessed easily and quickly.

The paper records kept by the organisations in which these engineers worked were often inadequate, and as the humidity and general office conditions meant that the records had to be renewed from time to time, the engineers felt that this time-consuming and error-prone procedure could be eliminated by using computer diskettes as a primary record, with the computer generating print outs as a back up system. It should be noted at this point that computer diskettes are also susceptible to the atmospheric conditions described above, and that the author encountered problems with both high temperatures and high humidity levels while demonstrating software in Nepal. However, it should also be noted that where engineers habitually used computers, they expected these problems and took them in their stride.

The MICADO system was therefore designed to generate a system of records during each evaluation of a potential site (see Chapter 13) and to produce a set of maintenance records each time a consultation or site visit was carried out. (see Chapter 14).

4.2 : Outline of Software Structure

Because the MICADO system is designed to run on PCs and compatibles there are attendant restrictions on the amount of space available for storing program code and for actually running the evaluation. This, coupled with the choice of the CRYSTAL expert system shell for the system environment, dictated that the system be split into several programs which could be accessed from a menu system, and chained without the user being aware that one program had finished and another had begun. In order that this could be done, the concept of the "data

exchange file" SCRATDAT was developed, where the data from each section of the evaluation is written out to the file as it is produced, enabling the sections of the system to pass data between them.

The MICADO system therefore consists of a network of three menu programs, thirteen evaluation programs, two record manipulation programs and a data exchange file. The features which characterise the program system are described in greater detail below.

4.2.1 : Modular Structure

The MICADO system carries out the evaluation of any potential micro hydro site using thirteen programs, some of which are chained together, creating eight "modules" which carry out calculations and assessments in the eight main areas of micro hydro scheme design. These are:

- Preliminary assessment of up to three possible site configurations,
- Hydrological resource assessment,
- Assessment of demand for power,
- Specification of general layout of scheme,
- Design of civil works†,
- Selection of mechanical and electrical equipment,
- Design of transmission and/or distribution network (if required)
- Assessment of economic viability of scheme.

Each module produces a set of data which is stored in a particular area of the data exchange file. The data exchange file is consulted at the beginning of each module, and the relevant information from previous modules is read in as required. The modular structure is shown in figure 4.2.

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† "Civil Works" is the term commonly used in the field of micro hydro to refer to the intake at the river or stream, the water transport canal and any attendant features such as spillways and settling basins.

Figure 4.2 : Modular Structure of the MICADO System
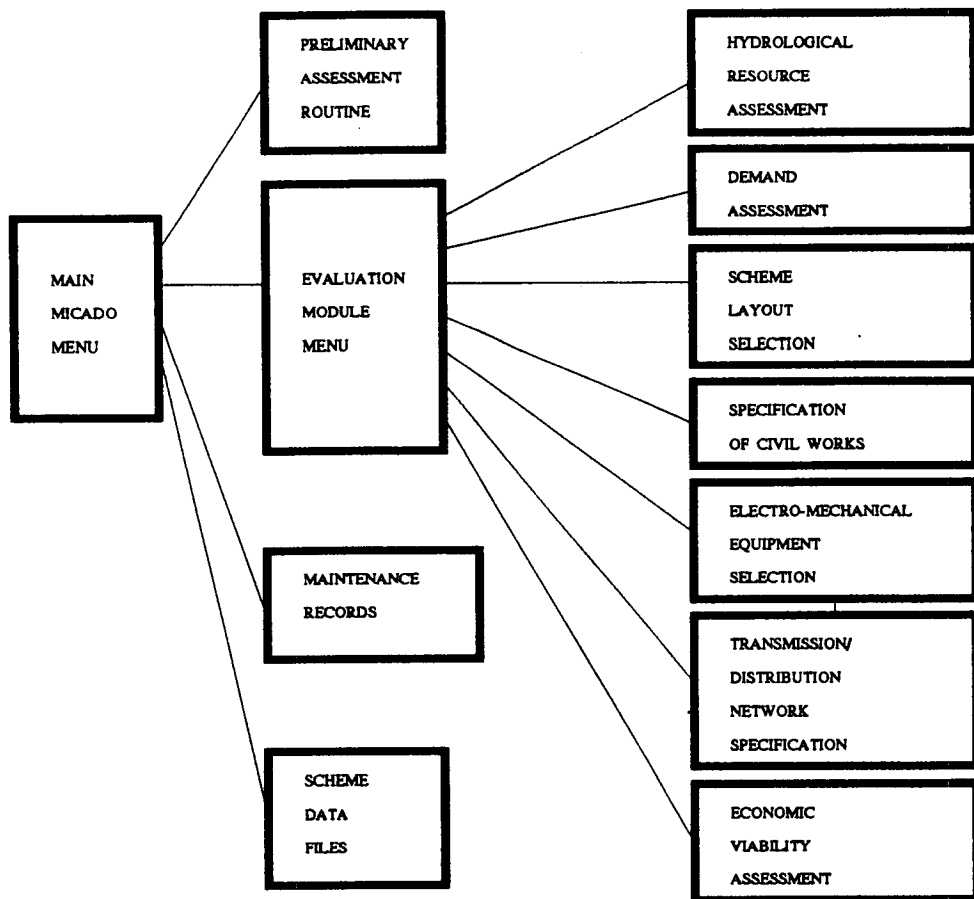
Because it is possible that the user may not be able to run the system   from a hard disk, where the program code and data exchange file are resident on the same disk, the system begins with a short program STAR2, which displays system logos and asks the user to input the drive letters for the program and data disks. These letters can, of course, be the same, if the user has a machine with a hard disk, and has managed to find space on it for the MICADO code. Whatever the disk drive configuration, the program STAR2 writes the variables containing the letter of the drive containing the program code ($so\$$), and the letter of the drive containing the data files ($da\$$) to the first two entry spaces in the data file. These two spaces are interrogated at the beginning of every single program in the MICADO system.

4.2.2 : Flow of Control in the MICADO System

The STAR2 program is followed by a menu which allows the user to choose between carrying out an evaluation of a completely new scheme, or continuing an evaluation which was not completed during a previous run of the system. If an evaluation is to be carried out from scratch, then the system requests the scheme owner's name and the location of the site. As stated above, it also asks the user for the *so$* and *da$* variables, before storing these and then loading the main system menu program OPT2. Figure 4.3 shows the flow of control between the programs of the MICADO system.

Figure 4.3 : Flow of Control Between Programs of the MICADO System
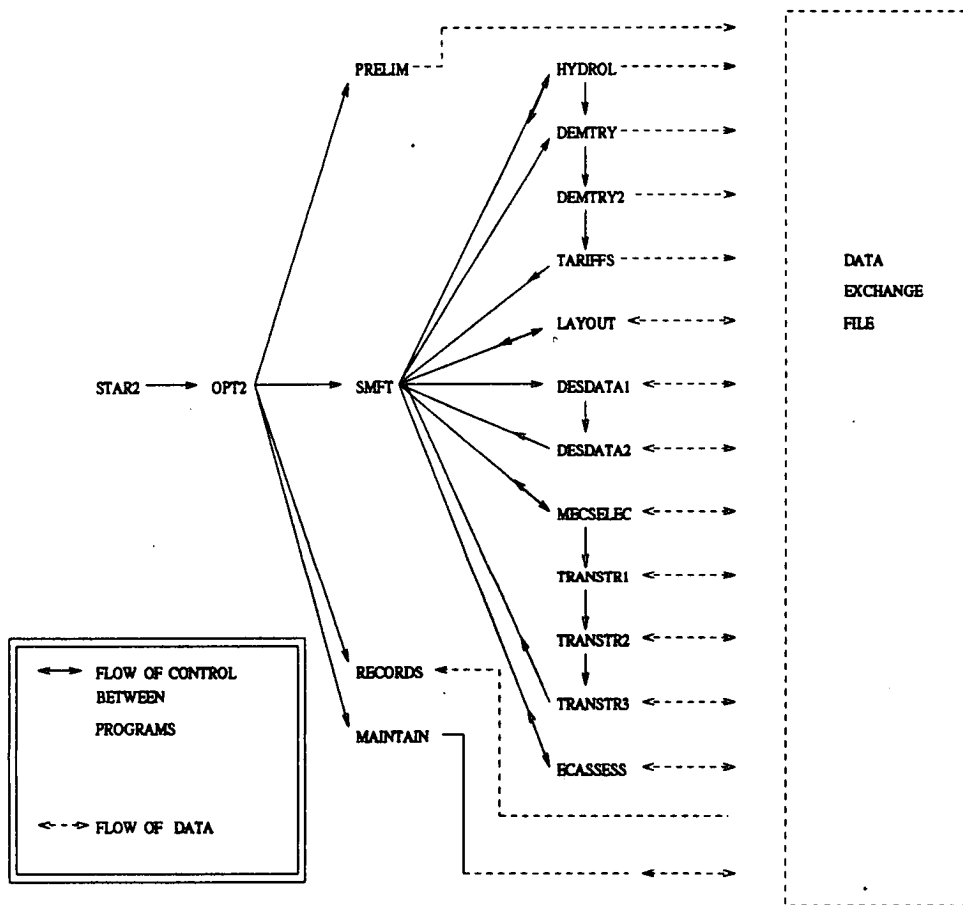
If a previous evaluation is to be continued, the program requests the path which it is to use to search for data files, and then uses *dos* commands to move to the correct directory and/or subdirectory. The names of the data files in the directory are

called into RAM and written into the *scheme$[#,#]* array. These array elements are then displayed in a menu format, allowing the user to select the file relating to the scheme in question. The file is copied over onto the data exchange file SCRATDAT, and the system then loads the menu program which allows access to the evaluation modules, SMFT, rather than the main MICADO menu program OPT2. (It was judged unlikely that the user would wish to carry out the preliminary evaluation program again.) The user can, of course, move back to the main system menu from the main MICADO menu, if this is required.

Menu Program OPT2

The menu program OPT2 follows STAR2 and is the main controlling menu for the whole MICADO system. The menu which the user sees is displayed in figure 4.4.

Figure 4.4 : Menu for OPT2 Program
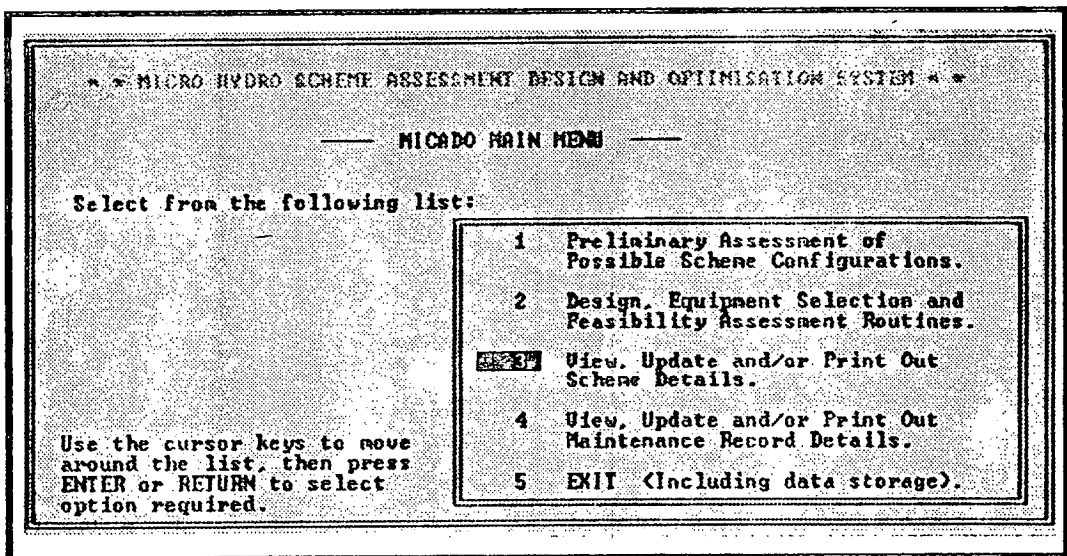
The options are as follows:

1. Load and run the program which carries out a preliminary evaluation of three configurations of the potential scheme,

2. Load and run the menu for the main evaluation modules,

3. Load and run the maintenance logging program,

4. Load and run the record keeping program,

5. Exit routine (including data storage procedure).

Selecting any of the first four options listed results in another program being loaded into RAM and run. Before the preliminary evaluation program PRELIM is loaded, the system checks whether or not it has been run previously. If the user wishes to run either the record handling program RECORDS, or the maintenance record handling program MAINTAIN, then the program checks if any data has been entered so far for the scheme under evaluation. As both of the above programs operate by overwriting the data exchange file with the file for the scheme of interest, any data which is required at a later date must be saved in another file, so that it is not lost when the overwriting takes place. The data is saved using the same routines as are called by the exit routine which follows option five in the list. The fifth option is put into action by code which forms the largest part of the OPT2 program.

Before the user is allowed to leave the system, there are several checks to ensure that any data entered during the evaluation is not lost. The user is prompted either to save any data entered, or to state definitely that the data should not be saved. If the user chooses to save the data, then the program puts into action a procedure which copies the SCRATDAT file over onto the file named by the user. The user is first asked if they want to save the data. If the answer is YES, then the system requests the path which should be used to store the file, i.e. disk name, directory name and subdirectory name, if this is required. The user is also asked to enter a name for the file itself.

If the file does not already exist, the system copies the file from the data exchange file to the file specified by the path and filename just entered. If the file already exists, the system detects this, and asks the user if the intention is to overwrite the file which already exists, losing all the data which stored in it. If this is not intended then the user is given an opportunity to enter an alternative filename before the above routine is called again.

If the user intends to overwrite a file which already exists, this will only be allowed if the correct system password is entered. If the password is entered incorrectly then the program loops back and allows the user either to return to the main menu, or to lose the data which has been stored in the data exchange file. If the correct password is entered then the file is copied over as required.

Menu Program SMFT

This constitutes the controlling menu for the part of the MICADO system which is concerned with the evaluation of the potential micro hydro scheme. It contains the options listed in section 4.2.1, together with a "Return to Main Menu" option. When the user selects any of the modules, the appropriate program is loaded into RAM from disk and run. The menu screen is displayed in figure 4.5.

Figure 4.5 : Menu Screen for SMFT Program
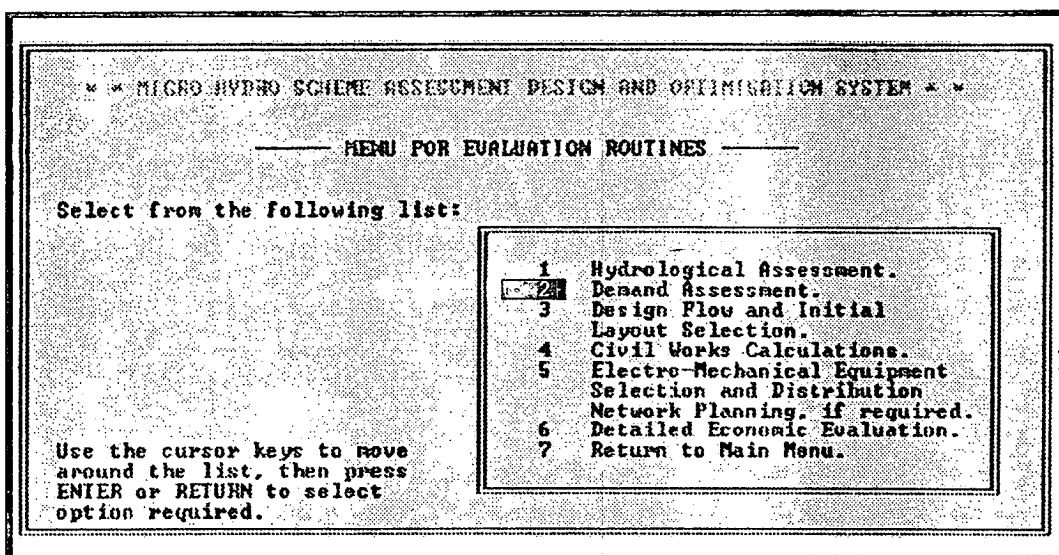
If the "Return to Main Menu" option is selected, the system loads and runs the main MICADO menu program OPT2.

4.2.3 : Communication Between MICADO Modules

As described earlier, because of space restrictions, the MICADO system is divided into a set of distinct programs which exchange information via a data

exchange file. Data entered and generated while each program is running is writ-
ten out using standard CRYSTAL interface commands to a LOTUS 123 workfile
named SCRATDAT. Variables from each program are stored in designated areas
of the data file, and are loaded into subsequent programs if required for calcula-
tions, or for display on information screens.

In order that the user does not overwrite information entered on a previous pass
through any one program, the MICADO system logs each module which has been
run as the module finishes. If the program checks the log and finds that the user is
trying to run a module which has already been executed, then it warns the user
that there is a danger of overwriting the data which was entered on the previous
run. If any module is run again, then the system adjusts the log so that the data
produced using output from the previous run cannot be accessed by the system.

In practice, the data is not erased from SCRATDAT, but it cannot be read by the
program, so to all intents and purposes it has been removed. The user must carry
out the evaluation routines following the re-run module again, so that new, consis-
tent data can be produced and written to the correct area of SCRATDAT.

4.3 : Interaction with the User

As stated above, one of the main priorities for the MICADO system was the cre-
ation of a man-machine interface which would encourage the user to interact with
the program at all stages of the evaluation. In order that this should be maintained
throughout the program, each screen has full instructions on how to proceed, and
directs the user to enter information in the correct way. While the system uses
menu screens where possible, data input screens are also used, sometimes in the
form of question/answer screens and sometimes in the form of data tables.

4.3.1 : Menu Screens

CRYSTAL menu screens are used in three different ways in the MICADO system. These are as follows:

1. List format,

2. "All Data Entered" format and

3. Sliding Scale format.

These are described below.

List format

In this form, the menu is laid out as a simple list, from which the user is required to select one option. This is done by moving the cursor to the correct choice and pressing the RETURN key. According to the rank of this choice in the list, a number is assigned to the menu variable which was set up during the programming of the system. This variable can then be used as required. An example of this type of screen is given in figure 4.6.

Figure 4.6 : Example of Menu Screen


```
Please select the most appropriate description of
the canal from the list below.

   1. Straight and uniform in cross-section
   2. Winding canal, but clear of debris
   3. Canal contains grass, some weeds
   4. Canal has soil bed and rubble sides
   5. Canal unmaintained,contains dense weeds


              Use cursor keys then enter to select
```
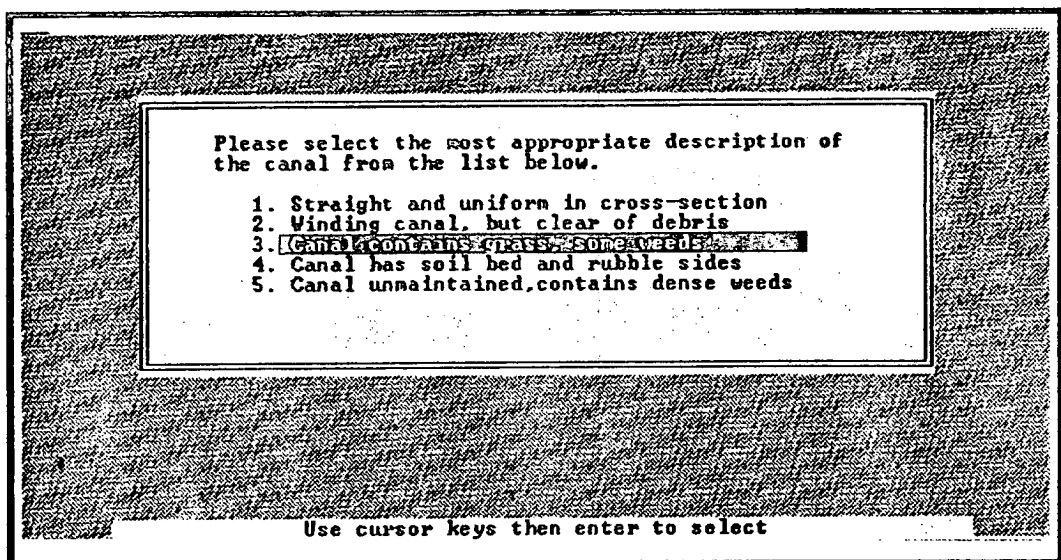
"All Data Entered" format

This list of items is used when more than one of the choices can be selected by the user. Usually each item in this type of list is paired with an element of a text array (i.e. a string variable), indicating whether or not it has been selected. The last item on the list is labelled with the text string "All Data Entered". This item is set at the bottom of the screen, away from the rest of the list, and is not paired with a string variable.

Figure 4.7 : Example of "All Data Entered" Menu Screen

Selection of an item in the list is by the same procedure as described above. Then, as each selection is made, the program checks whether the last item has been selected. If it has, then the program moves to the next section.

If another option has been selected, the program moves into a loop which tests the value of the element of the text array which relates to the item in question. The program then toggles the element so that it has the alternative value. For instance, if the value is "Item selected for use", then it will be switched to "Item not selected for use", or vice versa. The menu screen is then re-displayed, with the updated text variable included. This loop is repeated until the user selects the "All Data Entered" box, as described above. Figure 4.7 shows an example of an "All Data Entered" menu screen.

Sliding Scale Format

This format is used only in the hydrological resource assessment section of the MICADO system. The menu fields on the screen are set up in a horizontal line with a scale positioned above them. The menu fields do not contain text variables and appear to the user as boxes, one character wide, on the screen.

Figure 4.8 : Example of a Sliding Scale Menu Screen
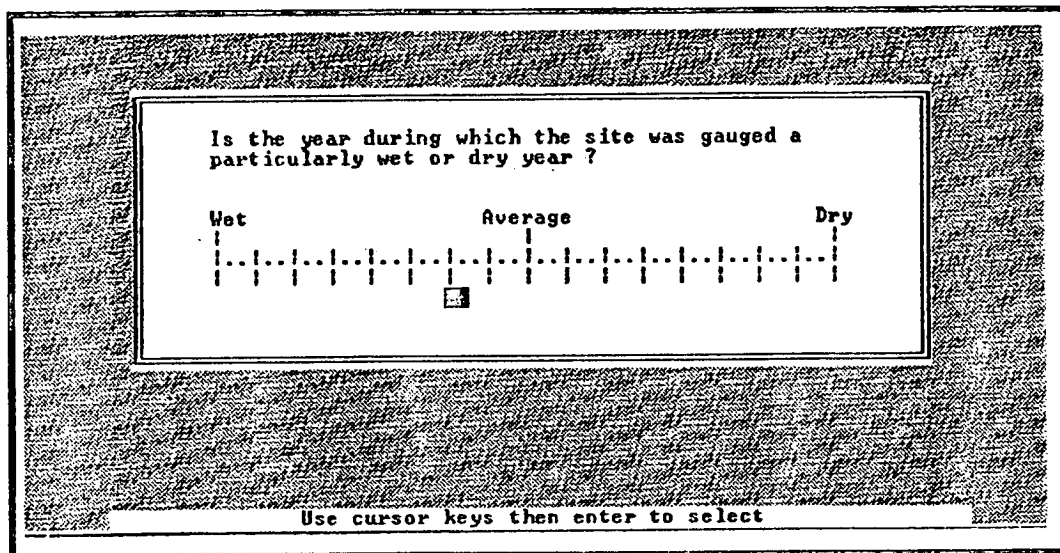
The user moves the cursor along the line, and press RETURN when the cursor is judged to be positioned correctly. This format allows for the subjective assessment of flow rates in comparison with previous years. The system tests if the menu variable falls within certain ranges and then uses this to decide which branch of the program should be carried out subsequently. Figure 4.8 shows the menu screen seen in the hydrological resource assessment section.

4.3.2 : Data Input

Data entry is carried out using the CRYSTAL display screen facility, together with data entry fields, which can be for text or numeric data.

Question/Answer Screens

On these screens the user answers a question by entering data in a box on the screen.

Figure 4.9 : Data Entry Screen


```
NUMBER OF YEARS FOR WHICH READINGS TAKEN.

Enter the number of years for which monthly
readings of flow rates have been taken:

        Number of years:  2

<Data for up to FIVE years may be entered>


                    Please type a number
```

The data can be text or numbers. These screens always have a variation of the command

> "Type answers in space(s) provided above,
>
> then press ENTER or RETURN to continue."

written along the bottom of the screen. An example is given in figure 4.9

Table Screens

These screens present the user with a table into which data should be entered. The data entered in these tables is ideal for storage in arrays, but due to a quirk of the CRYSTAL shell, it is not possible for the error trapping procedure to be extended to individual members of arrays. It is sometimes necessary, therefore, to use intermediate values in the data entry fields in the table, and then load the data into an array afterwards. Full instructions as to how the data should be entered are written along the bottom of the screen. An example of a table entry screen is

Figure 4.10 : Table Entry Screen

```
ESTIMATED DEMAND FOR ELECTRICAL AND MECHANICAL POWER.

As demand for electrical and mechanical power often occurs at different
times of the day, you can now enter a rough estimate of the size of the
most important sections of demand, and the times of day at which these
are likely to occur.
  Remember: * enter demand in units of kW,
            * use the 24 hour clock for the time entries,
            * enter "m" for mechanical and "e" for electrical demand,
              "n" to fill any gaps left in that row.
            * enter zero values where there are any gaps left in the
              bottom three rows.
```

Electrical or Mechanical ("E" or"M")	1	2	3	4	5	6	7	8
	e	e	m	m	n	n	n	n
Demand (kW)	1	10	3	3	0	0	0	0
Start (hrs)	22-00	18-00	6 -00	18-00	0 -00	0 -00	0 -00	0 -00
Finish (hrs)	4 -00	22-00	18-00	0-00	0 -00	0 -00	0 -00	0 -00

```
    Enter values and then press RETURN or ENTER to continue.
```

given in figure 4.10.

4.3.3 : Display Screens

Display screens containing diagrams, pictures and graphs are used as much as possible in MICADO in order to maintain the level of visual interest for the user throughout the evaluation.

Graphics Screens

The CRYSTAL expert system shell used for this system does not have an integral graphics package. It does, however, have a facility called "Snapshot", which allows the programmer to store images prepared using other packages in a form which the CRYSTAL shell can retrieve while running. Several of these screens were prepared for the MICADO system, including pages where diagrams and text appear together. An example of this is shown in figure 3.2

Bar Charts

Although the CRYSTAL shell has no graphics facility, it is possible to create bar charts using text variables.

Figure 4.11 : Bar Chart Used to Display Demand for Mechanical Power

```
DEMAND vs TIME PLOT FOR GRAIN MILLING/RICE HULLING UNITS.

   Time Period

   0-01 -  2-00 hours   |
   2-01 -  4-00 hours   |
   4-01 -  6-00 hours   |
   6-01 -  8-00 hours   |
   8-01 - 10-00 hours   |
  10-01 - 12-00 hours   |
  12-01 - 14-00 hours   |
  14-01 - 16-00 hours   |
  16-00 - 18-00 hours   |
  18-01 - 20-00 hours   |
  20-01 - 22-00 hours   |
  22-01 - 24-00 hours   |

                        |
                        |_____  Demand
                        0         2.00          4.00       (kW)

                  Press any key to continue
```
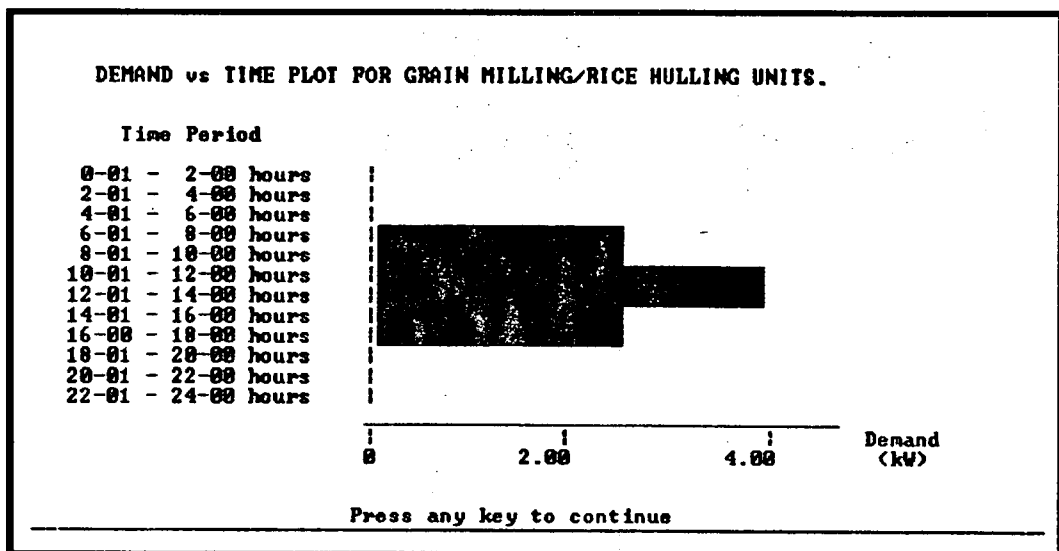
The length of the text variables is determined by the relative sizes of the numerical variables to be displayed. These screens are used in the demand assessment module to display the variation of demand for electrical and mechanical power over a 24 hour period. Figure 4.11 shows and example of a bar chart used to display the demand for mechanical power at the proposed scheme.

4.4 : The Manual

The MICADO system is accompanied by a manual as is any other piece of software. This tells the user how to install and start the system and contains back up instructions in case the user is, for some reason, not sure of the instructions given on the screen. The manual consist of the seven sections listed below:

1. Introduction

2. Description of the system.

3. Instructions for starting up the system.

4. Description of the intial stages of the program.

5. Instructions for menu screens.

6. Instructions for data entry screens.

7. Description of the data storage procedure.

A detailed description of the manual will not be given here, as the full text can be found in Appendix 1.

Chapter 5

Hydrological Resource Assessment

The potential power available at any proposed micro hydro site must be assessed before any scheme designs can be considered for feasibility assessment. Evaluating the hydrological resource at any site basically consists of computing the potential power present in the water by virtue of the height through which it falls, (known as the *head* at the site), and the mass which falls through this distance, (given by the volumetric flow rate). The density of water and the acceleration due to gravity are then combined with these two parameters in a version of the potential energy equation to give the energy which is theoretically available for extraction from the water.

Beyond this simple calculation, however, there are a number of complications.

1. The flow rate at a site is usually unknown

> In most developing countries it is rare for minor streams and rivers to be gauged, and selection of the design flow rate of a scheme is often made on the basis of very few measurements. Measurement techniques are rarely accurate [Meier, 1989], and the limitations of many of the methods are often not applied by practitioners.

2. The flow rate at a site is unlikely to be constant

> In temperate countries there are seasonal variations in river flow rate, (generally within one order of magnitude), with the summer months usually being the driest. In tropical and sub-tropical countries, however, monsoon flow

Figure 5.1 : Block Diagram Showing Location of Hydrological Resource Assessment Module in MICADO
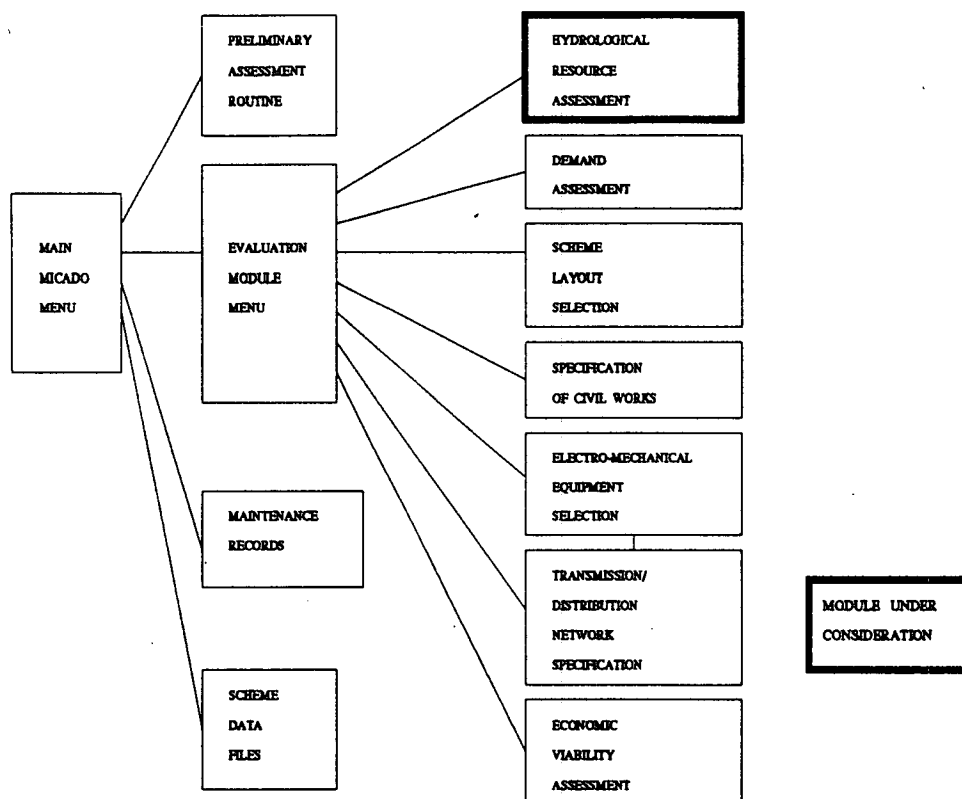
rates are unpredictable, and can be 1000 times higher than those of the dry months [Litscher and Kapali].

3. Only a fraction of the flow may be available for exploitation by a micro hydro scheme

There may have to be a minimum flow left in the original stream bed e.g. for irrigation purposes or to prevent desiccation of vegetation which maintains the stability of a hillside.

Many of the problems associated with faulty or sub-optimal micro hydro power site stem from poor assessment of the hydrological resource at the site. This chapter examines the way in which the resource can be calculated, given that data gathering techniques are unlikely to be changed in the near future.

5.1 : Problems with Hydrological Resource Assessment in Nepal

As discussed in chapter one, the technologies which surround the harnessing of water power have been used in the mountains and hills of Nepal for milllenia. There are an estimated 30 000 traditional *ghattas* in the hill and mountain regions, [UNCTAD], and the Nepali people are so familiar with the flow regimes of their areas that they are reputed to be able to assess the power capacity of any stream at a glance. With multi-purpose schemes, however, where fractions of the power may be used to drive machinery other than heavy grindstones, or for the production of electricity, the received wisdom of a rural culture is not enough.

Hydrological resource data is generally obtained from raingauges and from assessment of the hydrological characteristics of regional landscapes. Although there is, or has been a network of some 260 raingauging stations throughout the whole of Nepal, only 50 or so of these can be said to have continuously measured the flow in any catchment area [Wesselink]. Even if all 260 raingauges were considered to be operational at the same time, the average area covered by each station is around $600km^2$ per station. This is in comparison with an area of 100 - $250km^2$ per station recommended by the World Meteorological Organisation (WMO) for gauging in mountainous areas [WMO]. This shortcoming has been exacerbated by the fact that the gauges are not equally distributed, with no stations at all above 3800 metres, and the Kathmandu valley, the most densely populated area of Nepal, being measured by some 20 gauges at various points in time.

The WMO recommendations themselves may not be rigorous enough to provide a sufficiently detailed picture for the assessment of any micro hydro power resource. It is estimated that the average micro hydro site would have a catchment area which would range in magnitude from $10km^2$ to $100km^2$ [Wesselink], which is at the lower limit of the gauging area recommended by the WMO.

The length of time for which records have been kept varies widely, as old stations are closed down and new ones started up. Rainfall in Nepal varies from season to season, with a build up of about four months to the monsoon period, when, as stated above, flood flows can be up to 1000 times higher than the flows in the drier months. It has been estimated that in such a climate, in regions where the topography is unstable, records should be kept for around fifty years before the data can be relied upon [Wesselink].

Precipitation in Nepal also varies with altitude, with the highest gauged sites recording the lowest annual rainfall, (e.g. 248mm at Jomsom) and the areas in the lowlands recording annual sums around a factor of ten greater (e.g. 3153mm at Syangje) [HMGN]. (See figure 1.1). Unfortunately, such broad generalisations are of no use in estimating the flow in a catchment for a micro hydro site, as on such a small scale, stream and river flows are disrupted by local phenomena. The broader picture takes no account of reduced infiltration due to deforestation and cannot allow for siltation of rivers or flash floods due to landslips which can occur each monsoon season [Eckholm].

An alternative approach to hydrological resource assessment must therefore be adopted, an approach which draws on the more conventional knowledge of hydrologists in developed countries, where this is appropriate, but which also incorporates the expertise of practitioners working in micro hydro power in the field.

As described earlier, methodologies have been developed which incorporate both the text book approach which is appropriate to developed countries, and the more unorthodox approaches developed in response to particular local conditions. Documentation of these approaches exists, but is sometimes unwieldy and difficult to use. Worse still, it may not accurately reflect the experience of local practitioners. Although expert systems and DSS can not attempt to replace handbooks, they can provide a net with which to catch this elusive expertise. The HYDDATA1 program of the MICADO system carries out just such a function for the assessment

of hydrological data. The program is described in the next section.

5.2 : Program HYDDATA1

Filename:	HYDDATA1
Program size:	82432 bytes
Number of rules:	87
Number of commands:	277
Number of variables:	59
Text space:	31kbytes

5.2.1 : General Description of HYDDATA1

As this is the first program to be described which has a true "tree" structure, this is an appropriate juncture at which to point out the difficulties which may be encountered in documenting such a program with minimal confusion. As the user proceeds through the program, questions and menus, which allow a number of answers, are presented to them. Each of these answers leads to another set of questions and menus, which differ widely depending on the original answers given. This process is, of course, compounded at each stage, with the result that the user may not pass through the program the same way twice.

Rather than going through each path exhaustively, the description of the modules in the MICADO system will be broken up into levels, with the main options available at each level being explained before any subsequent routines are examined. As the data from each level must be normalised to facilitate communication

between sections, the output from say, the flow assesssment routines, will always be a flow rate, no matter how complex or esoteric the method by which the number was obtained. It is appropriate, therefore, that the methods by which the flow rate at the site is calculated should be described together, before moving on to the description of computation of the potential power available at the site. This method of description will be used throughout this thesis.

For the purposes of the MICADO system, the information gained from interviews with engineers and others working on micro hydro in Nepal have been used to determine the approach to the assessment of hydrological data. As discussed in chapter two, the methods for assessing streamflow at a site were as numerous as the people interviewed, but there was some consensus on the methods outlined in section 5.3. It should be noted, however, that even this brief menu is unlikely to be used to its fullest extent as the methods usually used consist of

1. estimations of flow rate based on one visit to the site sometime after the rainy season, or

2. estimations of flow rate based on one year's (often incomplete) gauging at the site.

While it is preferrable that more data be accumulated before any potential scheme is assessed, in reality it is unlikely that this will happen. The MICADO system was prepared with this in mind. The methods used are explained in the next section, together with corresponding notes on any programming details particular to each routines.

5.3 : Data Required for Assessment of Micro Hydro Site

Wesselink avers that the flow data required for the best assessment of a micro hydro site are as folows:

1. The flow rate which is exceeded, or occurs, during most of the time, say 80% or 90%.

2. The month(s) in which the flow is(are) below this threshold flow.

3. The peak flow that could be expected once every 5, 10 or "n" years.

4. The minimum flow that could be expected for a period of some days or weeks once in every 5, 10 or "n" years.

This is in keeping with the practice of most operators in the field.

The most likely flow must be assessed so that the power system can be sized accordingly.

The peak flow must be recognised so that precautions against damage to the scheme can be taken, either by incorporating spillways or by siting the power-house so that it is not in the path of the likely flood flow, or so that any electrical equipment is not below the flood water line.

The minimum flow which can be expected must also be taken into account. This has an effect on the likely economic viability of the proposed scheme.

In addition, the head of water at the proposed site must be measured.

5.3.1 : Assessing Flow Exceedance Curve Where Flow Data Exists

The first task of the evaluation is to determine if the flow data which exists for the site is sufficient to allow assessment of the flow regime. If sufficient flow data exists then the flow regime in a typical year can be easily determined, and the

power exceedance curve calculated for the range of heads available at the site.

For the DSS to carry out this task, additional information must also be supplied, such as the duration of the measuring period, the regularity with which stream gauging is carried out, and the reliability of the data. From these parameters the number of data points available for assessing the flow regime is calculated and the user inputs data which is then extrapolated to create the flow exceedance curve. Data reliability is usually assessed initially by determining if the stream has been gauged for a sufficiently long period of time, but also by the very subjective method of asking local people if the gauging period covered any particularly wet or dry seasons. The program allows this to be entered on a sliding scale, with a 25% exclusion section set up at both extremes of the scale. (This screen is displayed in figure 4.8) If the user indicates that the gauging period falls into either of the extremes then the program is redirected to one of the flow regime estimation sections.

5.3.2 : Assessing Flow Exceedance Curve Where Flow Data Does Not Exist

If flow data does not exist, or is not reliable, then the user must use one of the flow estimation routines in the program. There are four of these, and the user can select which is the most suitable from a menu screen. The routines are as follows:

1. Use Run-Off Data

> In order to use this method the user must have values for the mean annual rainfall in the catchment are of the site, the drainage area for the particular stream in question, and must know the run-off coefficient for the catchment area. In addition, the expected mean annual flow in the stream must be estimated.

2. Use Ratio of Areas Method

This method operates by comparing the flow at the site under assessment with the flow at a similar site in the area for which flow data exists. The method cannot be used unless the sites both have the same mean annual rainfall and run-off coefficient. The data from the gauged site is scaled with the ratio of the two catchment areas.

3. Use Flow Correlation Method

Where there is insufficient data at a site, or the data is judged to be unreliable, it is possible to use what data is available if it is found that the data correlates closely with data from another site. In order to calculate the correlation between the two data sets, *pairs* of data points (which have been read at the same time at the two sites) must be compared, and the relation between them analysed. In the MICADO system the regression between the two sets is calculated using least squares fit, as is usual in the case of micro hydro schemes [NRECA]. If the correlation coefficient is greater than 0.75 then the data sets are judged to be correlated to a significant level, and the deficient data set at the proposed site is extrapolated using the data from the site which has been gauged previously.

4. Use Estimate of Streamflow Method

Although this is the least accurate method of assessing the power available at a proposed site, it is in fact, the method which is used most frequently. In this method, the user enters an estimated mean and minimum annual flow at the site, and the system then treats these with the same credence as is given any mean and minimum flows calculated by more rigorous methods.

5.4 : Calculating Power Exceedance Curve

Information on flow variations extracted from the raw data entered in the routines described previously is passed to the next section where the user is asked to enter an estimate of the gross head available at the site.

Figure 5.2 : Example of an Exceedance Curve
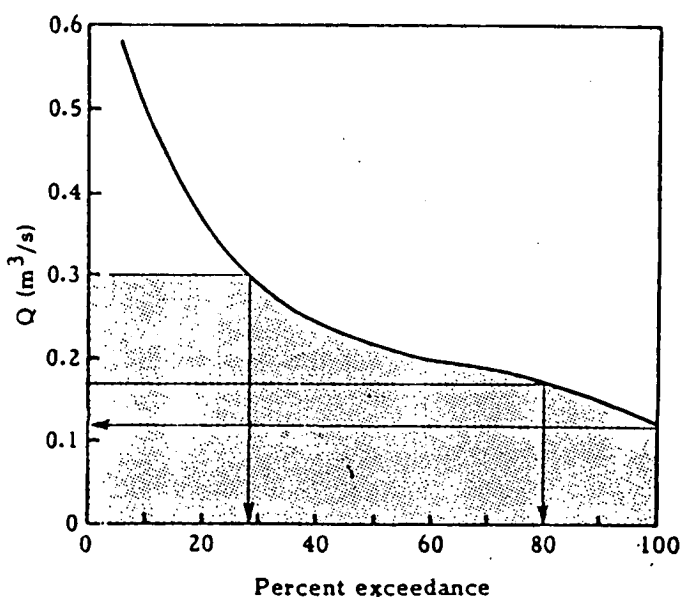
Depending on the flow data available (i.e. either a flow exceedance curve, or just mean and minimum annual flow values), at this point the system either calculates a power exceedance curve, or calculates the expected mean and minimum power available annually. In both cases the user is asked to enter an estimate of the expected efficiency with which an installed scheme could extract useful power from the potential power, and this is used to display to the user the expected output of the site.

It is conventional, when carrying out hydrological resource assessments, to present the data in terms of a flow exceedance curve (see figure 5.2), but the

limitations of the CRYSTAL system and the hardware available to the user group have dictated that exceedance data in MICADO is presented in tabular form (see figure 5.3).

Figure 5.3 : Exceedance Data Display Screen

```
FLOW REGIME AT SITE

From the data you have entered, the flow regime at the suggested micro
hydro site has been calculated. The exceedance values are displayed below:

            ┌───────────────────┬───────────────────┐
            │   Flow rate       │ Percent Exceedance │
            │   (cubic m/s)     │                   │
            ├───────────────────┼───────────────────┤
            │     0.800         │      0.00x         │
            │     0.600         │      0.00x         │
            │     0.575         │      0.33x         │
            │     0.463         │     20.83x         │
            │     0.350         │     29.17x         │
            │     0.230         │     45.83x         │
            │     0.125         │     75.00x         │
            │     0.013         │     95.83x         │
            │     0.000         │    100.00x         │
            └───────────────────┴───────────────────┘
                                              Press any key
                                              to continue
```

5.5 : Data Storage and Return to Menu

At the end of each module the MICADO system writes data to the data exchange file SCRATDAT, which is then available to subsequent modules. For example, the module which deals with matching power potential to demand will need data from both the module described above, and the module in which the user enters data on the demand profile of the scheme.

This particular module saves flow and head data, together with exceedance values, if these are appropriate. It also updates the appropriate variable in the flag column, to indicate to any future interrogations that this particular module has been completed and has written out data which will enable the rest of the program to proceed.

The last command of the module is that which re-loads the menu dealing with the evaluation modules.

Chapter 6

Demand Assessment

Micro hydro power schemes are only installed if there is some demand for the power which they will produce. The accurate assessment of the size of this demand is essential before the scheme output can be sized and its economic feasibilty can be assessed.

Figure 6.1 : Block Diagram Showing Location of Demand Assessment Module in MICADO
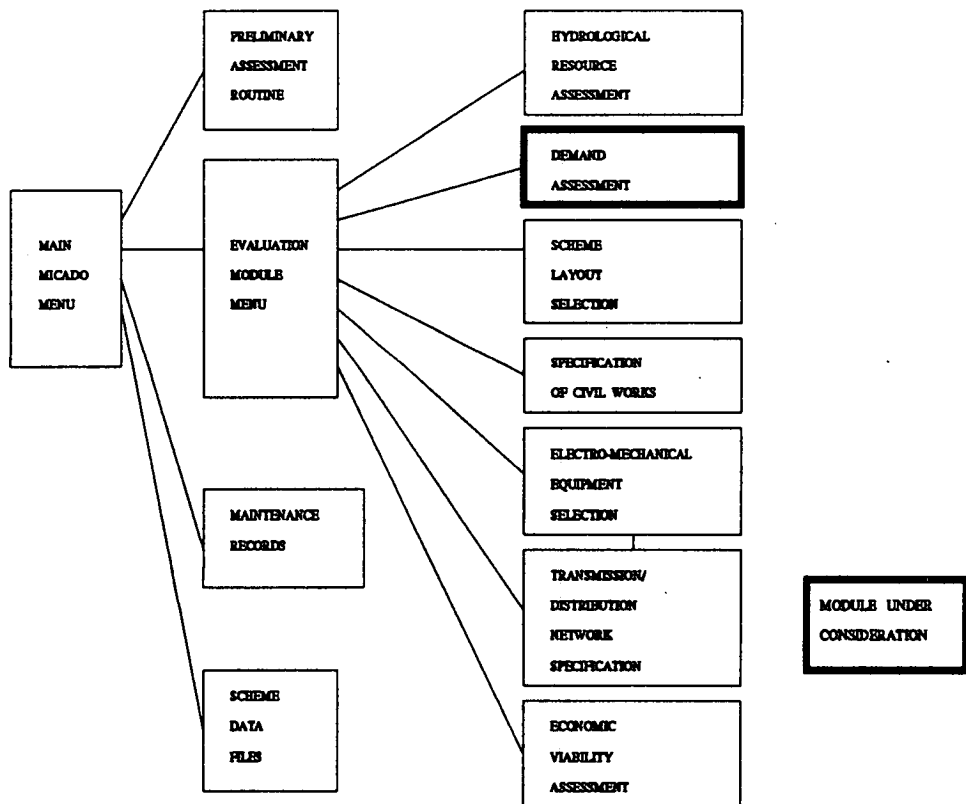
The assessment of demand for electrical power is generally a black art, with engineers using a variety of methods which they are often reluctant to disclose. The

assessment of demand for mechanical power is rarely carried out in developed nations, so methods for assessing this must be drawn from the developing world.

The methods generally used for micro hydro schemes are described below, together with the way these were incorporated into the MICADO system. The block diagram in figure 6.1 shows where the demand assessment module fits into the DSS as a whole.

6.1 : Estimation of Demand for Electrical and Mechanical Power in Rural Areas of Developing Countries

It is usual, when considering demand for electrical power in rural areas of developed countries, to consider existing demand patterns, and to extrapolate from these in order to predict the way in which an improved supply will affect patterns of power consumption [Brass]. In developing countries also, [Randell], existing demand profiles are often used to give some indication of the demand which may be expected if a new or up-graded scheme is installed. Where a supply has existed previously, (e.g. where diesel sets have been used), this is relatively easy to gauge [Thakor].

The demand for mechanical power is usually estimated by asking the current mill owner to specify the number of mills which would be needed to process crops within a certain walking distance. Problems occur where electrical or mechanical power has not been supplied previously, especially if loads other than lighting are to be considered.

Methodologies for predicting the likely demand for power vary widely; indeed, some approaches to micro-hydro scheme design ignore this aspect altogether, assuming that demand profiles will be shaped by the availability of the power produced [NCST].

To obtain data, most of the organisations currently installing micro hydro schemes in Nepal will conduct painstaking local surveys, visiting each household in the demand centre, assessing the demand for power for lighting and cooking and discussing the impact of the tariffs on the household finances. Surveys carried out by Development and Consulting Services of Butwal, for instance, detail the wattage appropriate to each household and note any particular issues raised by the consumers. [DCS]. If there is to be a single large commercial consumer of electric power, then the scheme will often be tailored to meet the demand of this consumer, (who is often in this case the person who has commissioned the scheme).

Demand for electricity in rural areas in Nepal has, however, been mainly restricted to the domestic sector, with the "spontaneous growth of industrial load" [UNCTAD] failing to materialise, and seeming unlikely to do so, without other conditions changing [DCS] [HMGN, 1990].

6.2 : Tariffing and Scheme Income

The income from the mechanical power supplied by the scheme is usually collected as the power is used, e.g. a farmer will pay a certain amount per sack of grain milled. The collection of income from the electrical power supplied is often more complicated, as the tariffing structure itself can affect the pattern of electricity use.

As discussed in chapter 1, in developed countries, where electrification is widespread, the domestic consumer pays for the amount of energy consumed, which is usually measured using a kWh meter. In the mountains of Nepal, however, the industrial consumer is vitually non-existent, and a good load factor must be obtained from domestic consumption alone. As explained previously, the use of kWh meters will hinder, rather than aid, this process, (besides introducing extra

equipment costs), so the previously described approaches to tariffing are more appropriate to the situation.

These approaches have included the promotion of low power cookers and the use of PTCs. In the long term, there is also the added attraction that the use of electric cooking begins to address the need for a reduction in the consumption of fuelwood for cooking and water heating, which is vital, given the rate of deforestation that Nepal is currently suffering [Eckholm].

The demand assessment module of the MICADO system is divided into three distinct sections: one for data input, one for evaluation and one for revenue estimation.

In the first section, which constitutes the program DEMTRY, the user is asked to enter the details of the power requirements of the scheme clients, characterising these by the size of demand "blocks" and the time at which these "blocks" are expected to start and finish.

In the second section, which constitutes the program DEMTRY2, the system carries out checks as to whether the peak and mean demands for power can be met by the flow and head available at the proposed scheme.

In the third section, which constitutes the program TARIFFS, the expected income which will be generated by the scheme is calculated.

6.3 : Program DEMTRY

Filename:	DEMTRY
Program size:	106496 bytes
Number of rules:	128
Number of commands:	406
Number of variables:	64
Text space:	54kbytes

6.3.1 : General Description of DEMTRY

As indicated in the section above, in the program DEMTRY, the user is asked to enter details of demand "blocks" which can occur at any period of time in 24 hours.

The program itself is in two sections, one of which deals with the demand for motive power for agro-processing, and with any demand for electrical power for crop processing or preserving, or for any small scale industry. The other section deals exclusively with the demand for electrical power from domestic consumers, and allows the user to enter details of lighting and low-power cooking, as well as other loads, if these should be necessary.

The program is characterised by the display routines included throughout so that the user has the option of viewing the way in which the each demand block affects the variation of the total demand over any 24 hour period. This is useful for load scheduling, where an engineer may be trying to improve the load factor of a scheme in order to increase its economic viability or to smooth the expected load variation for other purposes.

6.3.2 : Demand for Power for Agro-processing and Small-scale Industry

To date, hydro-power in Nepal has been harnessed almost exclusively to drive mechanical loads such as rice-hullers, maize mills and oil expellers. The economy of the country is such that subsistence agriculture provides the main source of food and income for over 90% of its population, and as the infrastructure for the transport and sale of cash crops does not exist, there is no demand for the larger-scale milling operations to process food at the rate that this would require.

The demand for motive power for small-scale milling units has, therefore, not abated and where micro hydro schemes are considered, the most important section of the demand, as far as the scheme commissioner is concerned, is often the mechanical section. In a country which does not have the electrical appliances which are necessary to everyday life elsewhere, a 24 hour supply of electricity may not be required and it is usually feasible to install a scheme which generates intermittently. Electrical power is frequently regarded as the icing on the cake, an extra indulgence which the villagers can buy in the evening when the light for agro-processing has gone, and the drive belts can be un-hooked from the *chakkis* and maize grinders and looped around the shaft of an alternator for a few hours.

This section of DEMTRY begins by asking the user to enter the numbers of each type of equipment which will be required. Then, for each piece of machinery, the user is asked to specify the rating in watts and the times of day between which it will be in use. These then constitute the demand "blocks", which are added for each hour in the 24 hour clock, so that a picture of the demand variation can be built up.

Depending on whether the demand is for electrical or mechanical power, the routine for each type of equipment begins by assigning the value 1 to the variable *useelec* or the variable *usemech*. Future routines in the system can then interrogate these variables to find out whether demand for electrical or mechanical power actually exists.

The arrays *mechpower[#,#]* and *elecpower[#,#]* are used as bins to store the demand which occurs at each hour in the 24 hour clock. The array indices *mechindex* and *elecindex* are incremented every time the demand for another unit is added to the bin arrays, so that the data is not overwritten after each display screen.

The variations in mechanical and electrical demand are displayed using two different string variables so that the user can distinguish between these on the final display screen. The string variables are scaled so that the whole string represents the maximum demand which occurs, and fractions of the string are used to represent smaller values, building up a bar chart on the screen. Figure 6.2 shows an example of a bar chart showing demand variation.

Figure 6.2 : Bar Chart Showing Variation of Demand


```
                 DEMAND vs TIME PLOT FOR CROP-DRYER UNITS.

      Time Period
      0-01  -   2-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆
      2-01  -   4-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆
      4-01  -   6-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆◆
      6-01  -   8-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆
      8-01  -  10-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     10-01  -  12-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     12-01  -  14-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     14-01  -  16-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     16-00  -  18-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     18-01  -  20-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     20-01  -  22-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆◆
     22-01  -  24-00 hours   I◆◆◆◆◆◆◆◆◆◆◆◆◆

                          I                I                I    Demand
                          0               1.75             3.50   (kW)

                    Press any key to continue
```
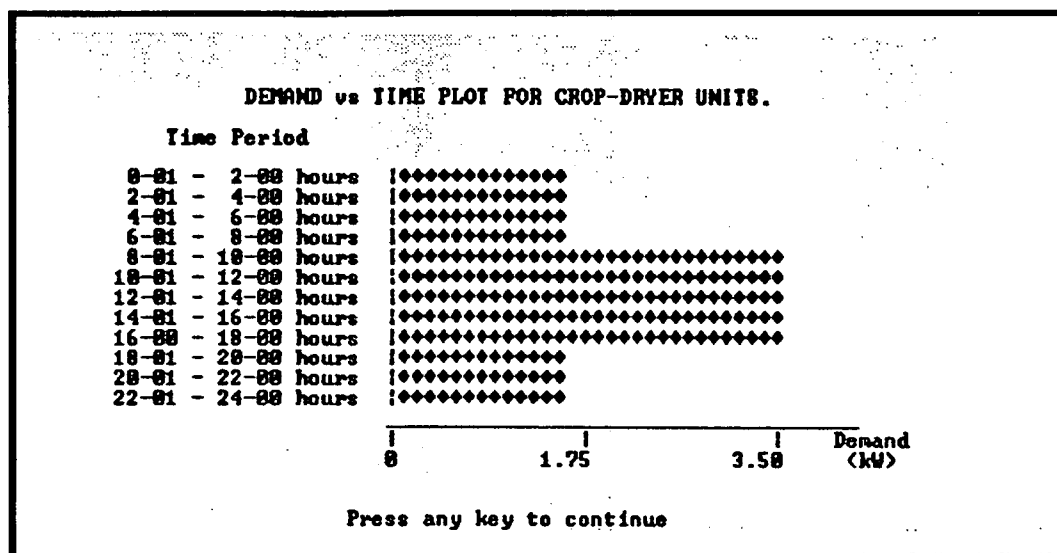
6.3.3 : Demand for Power from Domestic Consumers

The data on demand for power from domestic consumers are also loaded into the *elecpower[#,#]* array, although in this instance the method of data entry is slightly different, with the user being faced with data input screens with 24 hour time slots for each demand type. This is done for domestic lighting, low power cooking, refrigeration, lighting of communal buildings and water heating. Demand is effectively binned already, as it is entered in time slots, and these are added

directly to the array holding data on total demand.

6.3.4 : Estimated Increase in Demand

As the installation of the scheme itself is likely to have an effect on the demand profile of the local community, it is usually neccesary to include some estimate of demand increase in the assessment of scheme viability. The estimation of the expected increase in demand for any scheme is largely empirical.

In this particular software, the user is merely asked to enter the estimated demand increase, and the method for calculating this is left to the user's discretion, allowing the maximum flexibility.

Figure 6.3 : Bar Chart Showing Variation of Total Demand
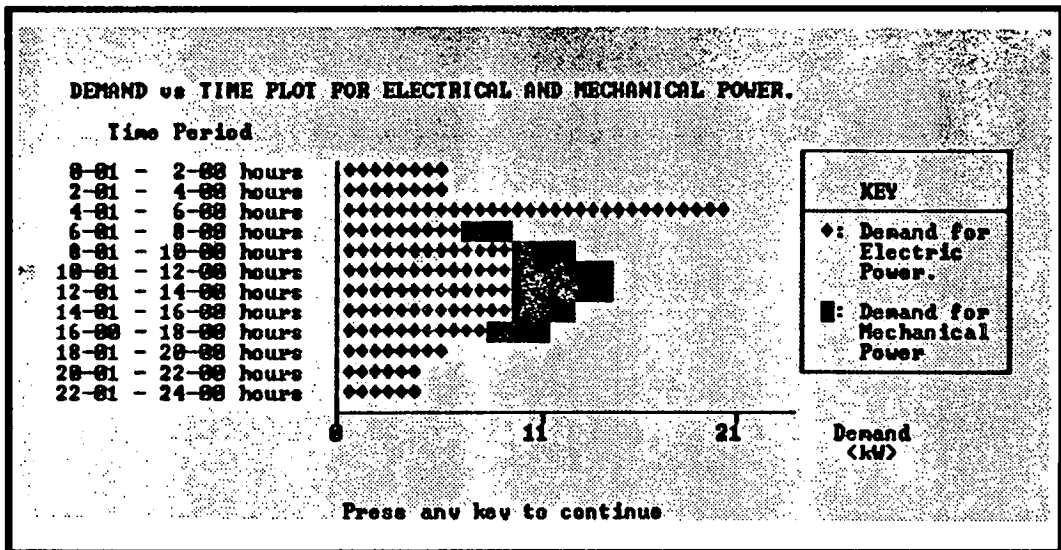
After the demand increase has been entered, the user is given the option to take this into account or not, so the total demand can be scaled (or not), according to the data entered.

6.3.5 : Data Display, Data Storage and Return Path

The data entered so far is then displayed using the strings described earlier so that the user can see the joint variation of both the electrical and mechanical demand. Figure 6.3 shows an example of such a display routine.

Then, as usual, the user is given the option of either returning to the head of the program, or of continuing to the next stage. If the program is directed to re-start, all variables must be re-initialised before the rerun begins.

If the user chooses to proceed to the next section (which is held in program DEMTRY2), then the data generated in this program must be saved in the data exchange file SCRATDAT. Only then can the DEMTRY2 program be loaded.

6.4 : Program DEMTRY2

Filename:	DEMTRY2
Program size:	59392 bytes
Number of rules:	34
Number of commands:	123
Number of variables:	29
Text space:	8kbytes

6.4.1 : General Description of DEMTRY2

The program DEMTRY2 is part of the safety net set up in MICADO to ensure that, although the program remains flexible, the user is not hampered by the possibility of entering data which is inconsistent, and is not led through the whole of the evaluation when it may be apparent at an early stage that the scheme is not viable. This is the first major check carried out in the MICADO system.

At this point the maximum mechanical, electrical and total demand are calculated and the times at which these occur are logged. Then the flow and head data is

read in from SCRATDAT and the possible power variations are calculated. The varying potential power and the demand maxima are then compared, and if at least *one* of the potential power values can meet the demand at the the scheme, the user is allowed to proceed unimpeded. If *none* of the potential power values can meet the demand, then the user is presented with the usual menu scheme displaying the options to proceed or to repeat the previous section. Before either of these options is allowed, the data just calculated is stored in SCRATDAT.

If the repeat option is selected then DEMTRY is re-loaded. If the proceed option is selected then TARIFFS is loaded.

6.5 : Program TARIFFS

Filename:	TARIFFS
Program size:	38400 bytes
Number of rules:	23
Number of commands:	58
Number of variables:	44
Text space:	12kbytes

6.5.1 : General Description of TARIFFS

This program calculates the expected revenue of the scheme, given the demand blocks entered earlier. The data required by this program is read in from the data exchange file SCRATDAT at the beginning of module. All other data is entered by the user, and no calculations are carried out in this module.

6.5.2 : Tariffing in Developing Countries

Demand for power from a micro hydro scheme can usually be classified according to the time scale over which it varies. Diurnal variations are characterised by peaks of demand at specific times during the day, for instance, the peak in demand for domestic lighting in the evening. Seasonal variations show the changes in demand as agro-processing requirements vary with harvest times. Other demand can remain constant over the year, for example, because the hours of daylight vary little with the seasons at that latitude, the demand due to domestic lighting remains fairly constant over a twelve month period.

The subject of electricity tariffs has been treated at great length in chapter 1, so the reader is referred to this if further information is required.

Where the scheme supplies mechanical power for agro-processing, the owner of the scheme is usually the owner of the agro-processing equipment, and charges clients for carrying out processing operations, as they occur, rather than having an agreed regular fee. The way in which income varies with the seasons is usually well known and the mill owner will know what income to expect, given the local rates for carrying out the processing, and the expected catchment area for clients for the scheme.

In this case it is necessary for the user to enter details of how the income can be expected to vary over the year.

6.5.3 : Revenue Calculation in MICADO

In the TARIFFS program the user is first asked to enter details of the expected monthly income for each electrical demand block (e.g. for domestic lighting, low-power cooking), and this is assumed to be constant throughout the year.

Since the demand for motive power is expected to vary seasonally, the income data is entered for each month. The version of MICADO which has been released has data input fields for the Nepali months, and has screens which allow the user

Figure 6.4 : Data Input Screen for Revenue from Supply of Mechanical Power

```
EXPECTED REVENUE FROM MECHANICAL EQUIPMENT

Enter expected revenue from mechanical equipment for each month
of the year:
(Include all revenue from crop-processing, etc. as well as expected
income from workshops etc.)

    Month      : Revenue      Month      : Revenue
                 (Rs)                      (Rs)

    Baishak    : 2000         Kartik     : 3000
    Jestha     : 2000         Marga      : 2700
    Ashdah     : 2500         Poush      : 2400
    Shrawan    : 2700         Magh       : 2200
    Bhadra     : 3000         Palgun     : 1800
    Ashwin     : 3100         Chaitra    : 2100

        Enter values and then press ENTER or RETURN to continue
```

to input any other income data which may not have been covered by the screens dealing with the income from agro-processing. (This screen is shown in figure 6.4)

The total income for each month is then calculated, and as usual, the user is then offered the option of either repeating the revenue evaluation section, or of returning to the main menu, with a view to proceeding with the evaluation.

If the user chooses to proceed, the data generated in this program is stored in SCRATDAT, and the flag column variable relating to this set of programs is updated to indicate that the data is available to subsequent modules.
The menu program is then re-loaded.

Chapter 7

Scheme Layout

There are a number of choices which must be made before the water transport system of a scheme can be designed using the usual techniques of civil engineering. These include specification of the general layout of the scheme and the selection of the design flow rate.

Figure 7.1 : Block Diagram Showing Location of Layout Selection Module in MICADO
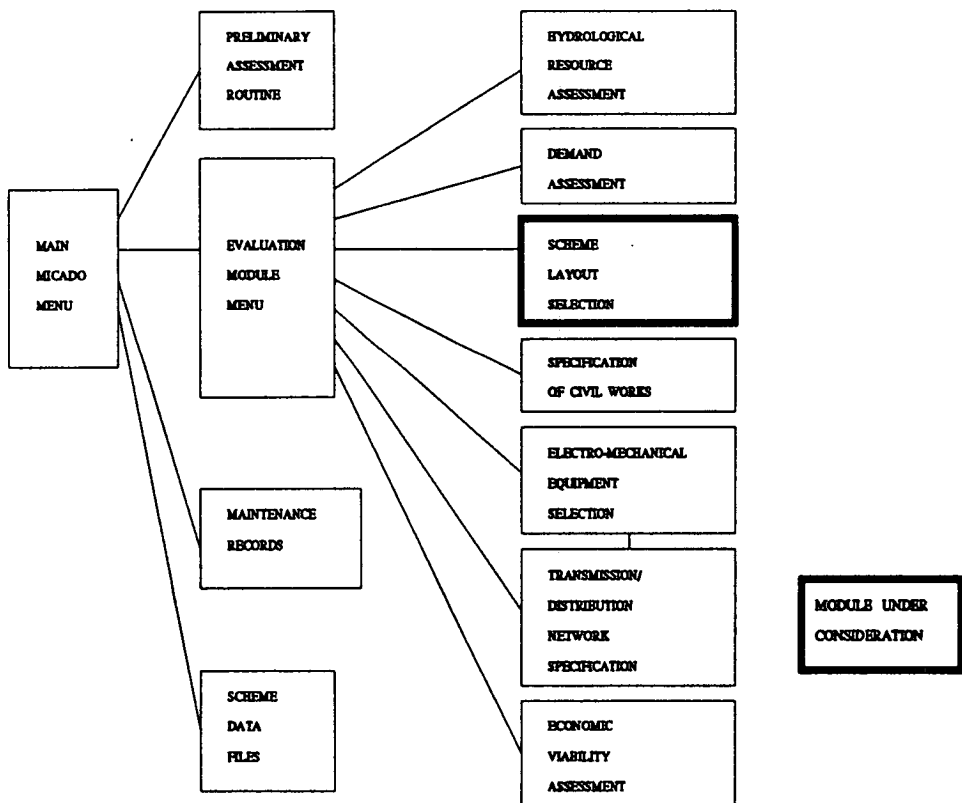
This module of the MICADO system guides the user in these choices.

7.1 : Scheme Layout

It is often the case that a number of configurations can be considered for any scheme. A trade off between factors such as the distance between the scheme and consumers, and the length of the penstock are common [Fraenkel et al]. The length of the penstock must be minimised to reduce costs. This means that it should be positioned as near the vertical as possible, which has a direct impact on the length of the canal bringing water from the intake to its head. The length of transmission line used can have a large impact on the total scheme cost, and although it is typically around 13% of the total scheme cost [Brown], in some cases it can account up to 40 or 50% [DCS].

It is often thought that it is possible to plan the layout of a micro hydro scheme from contour maps, but in fact this is only really possible after a site visit. The case of Salleri/Chialsa is well documented, where the position determined from contour maps was unsuitable due to problems with the construction of the penstock inlet. In the same scheme, the powerhouse had to be sited away from the initially planned position as it was discovered that it was a possible flood point [NRECA]. Floods were also a factor influencing the siting of the powerhouse in Doti [Litscher and Kapali].

Social factors can also have a considerable impact on scheme layout and design, as has become apparent with the emergence of environmental considerations in the developed world. There can also be long-standing issues which must be taken into account. In Nepal, for instance, water rights have been held by families for long periods of time, sometimes for centuries, and are jealously guarded. In the Nepali mid-hills, this has made it impossible for high head turbines such as the Pelton to be used, as the penstock must then take the water *past* agricultural land. In the mountain regions, where there is a more "communal" attitude to water rights, their use is more likely [ITDG].

7.2 : Program LAYOUT

Filename:	LAYOUT
Program size:	68608 bytes
Number of rules:	35
Number of commands:	130
Number of variables:	40
Text space:	17kbytes

7.2.1 : General Description of LAYOUT

The program begins by reading in data from the file SCRATDAT on disk. This includes the variables *usemech* and *useelec* as well as details of the demand maxima, and, depending on the value of the variable *readtime*, the data on the potential power available.

Assigning Flow Rate

The first task of the system is to assign a value to the variable *desflow* which will then be used throughout the evaluation as the design flow of the scheme. If there is no data on power variation throughout the year, the system assigns an upper limit to *desflow* and asks the user to input a design flow which is within this limit.

If data on power variation is available then the user is presented with an exceedance table for the annual flow variation and can then select the design flow from a menu.

Checks are carried out to ensure that the design flow will cover the demand maxima, with the user given the option of overriding any recommendation that the

design flow be increased, if this is necessary. The same checks are carried out for any future demand maxima.

Selecting Components for the Scheme

When the design flow has been specified, the user is then asked to indicate which items from a list of common components of micro hydro schemes will be used. This is done via an "All Data Entered" menu screen.

The menu screen in this case contains the usual list of options available to the user, but next to each option is displayed the value of a variable in a string array which relates to whether or not the user has chosen it. In this case the string either contains the value "SELECTED" or the value "NOT SELECTED". The menu is shown in figure 7.2.

Figure 7.2 : Component Selection Menu

As the user selects an option from the menu, the program tests for the position of the option in the menu list, and switches the value of the corresponding variable in the string array. This process is repeated until the user is satisfied with the components listed. The item list then becomes a checklist for the section of MICADO which deals with the design and configuration of the scheme civil works.

As described above, the data generated by this module is then stored in SCRAT-DAT and the appropriate flag column value is updated before the menu program is loaded.

Chapter 8

Scheme Civil Works

The term "Civil Works" is used throughout the field of micro hydro power to refer to the system of channels, pipes and other objects which are used to transport water from the stream or river to the turbine.

Figure 8.1 : Block Diagram Showing Location of Civil Works Specfication Module in MICADO
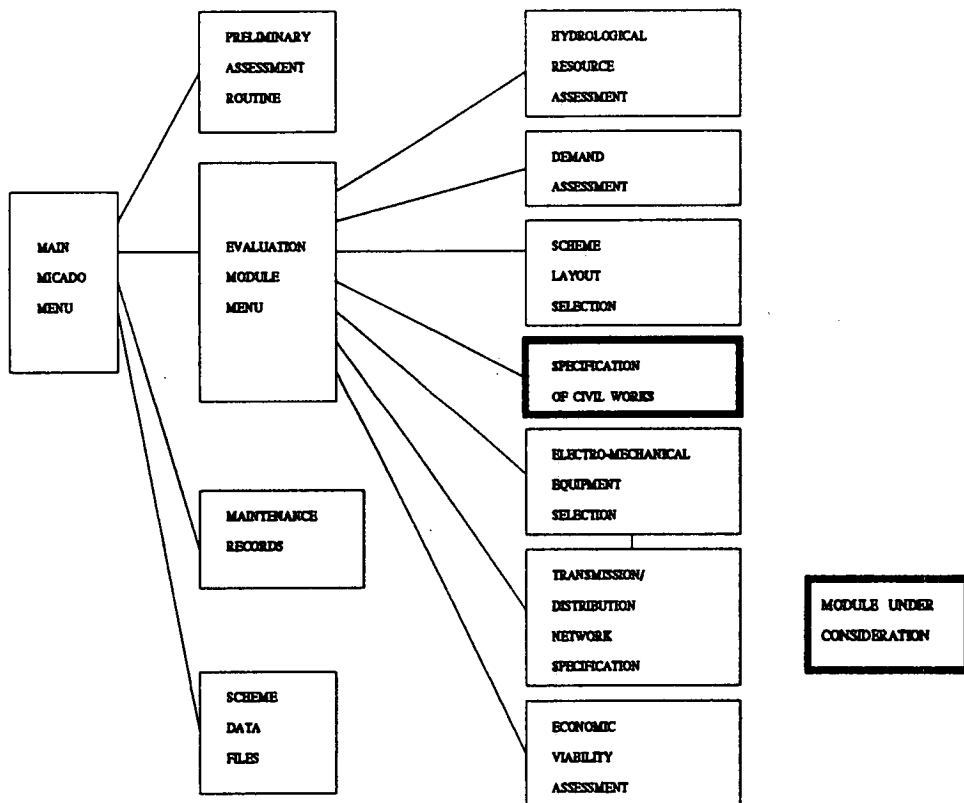
These features are usually designed according to empirically derived rules and frequently have characterstics which are uniquely suited to local conditions. This chapter describes the section of the MICADO system which is concerned with the

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design of these components. Figure 8.1 shows the position of this module within the MICADO system.

8.1 : Scheme Civil Works

While the civil works for a micro hydro scheme can be designed with any one of several priorities in mind, in practice the most important of these is likely to be cost. In Nepal, for instance, where penstocks are very expensive in comparison to earth channels [Fraenkel et al], it is usually sensible to use a short and steeply inclined penstock with a long earth channel from the intake, rather than a longer penstock and a short channel.

Conventionally, designers of micro hydro schemes will experiment with the dimensions of only one of the more costly components and examine the effect that this has on scheme cost. The designers of large hydro power schemes will, of course, have optimised the scheme for all the major components, as they have the resources to do this. The MICADO system is configured so that the user is taken through the design process in a methodical way, and ensures that steps are not missed out due to bad habits or, perhaps, ignorance. It also allows the user to optimise the scheme design for any of the components being considered, as it is possible to reiterate the design procedure from numerous points within the program.

Each component is dealt with in a section which runs through the necessary design calculations and brings other matters which may be relevant to the attention of the user. The program allows for the fact that variations in local conditions may impose particular constraints on the design of the scheme.

Because of memory constraints, the civil works routines have been divided between two programs, DESDATA1 and DESDATA2. These will be described

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below.

8.2 : Program DESDATA1

Filename:	DESDATA1
Program size:	101888 bytes
Number of rules:	209
Number of commands:	525
Number of variables:	82
Text space:	50kbytes

8.2.1 : General Description of DESDATA1

This program deals with the design of the first sections of the civil works, which are concerned with the transport of water from the stream or river to the head of the penstock. The routines for design of the weir and intake structures, the water canal and the settling tank are described below.

8.2.2 : Design of Intake and/or Weir
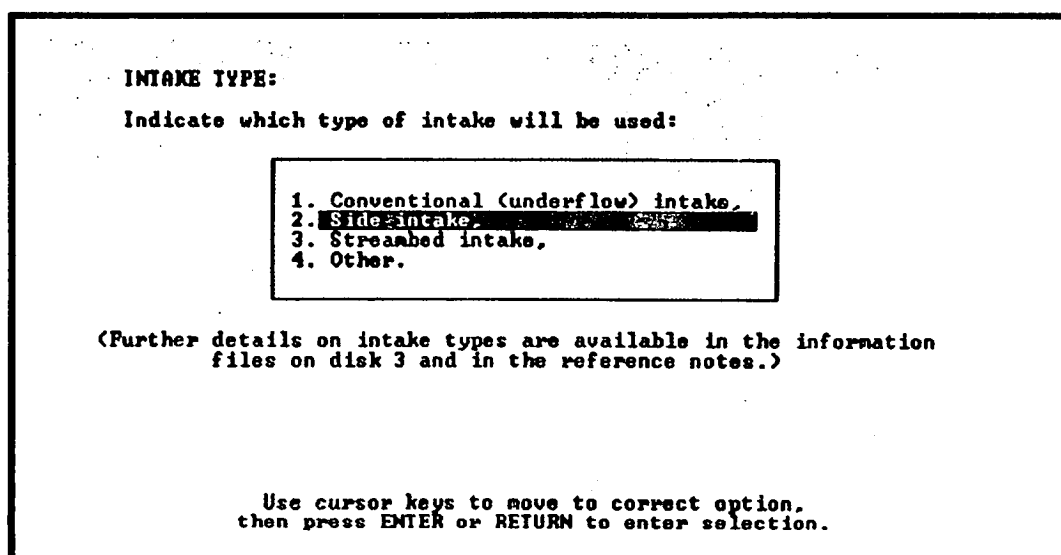
A hydro power scheme is designed to take a constant flow from the stream or river, independent of the flow conditions at the time. A weir is designed to maintain flow rate in times of low flow, whereas an intake ensures that in times of high flow or flood the flow rate does not become too large.

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As with all the components in the civil works of the scheme, this section begins by testing if the component is to be used in the scheme. It is unlikely that a scheme would be designed without an intake or a weir, but to allow for particular local conditions this facility is included.

Intake Design

If an intake is to be used, the user is first presented with a series of menu screens, allowing the selection of variables which specify intake type (variable *intake_type*) and location along the stream or river (variable *intake_locn*). The intake type menu is shown in figure 8.2.

Figure 8.2 : Intake Type Menu

```
  INTAKE TYPE:

  Indicate which type of intake will be used:


              ┌──────────────────────────────────────┐
              │ 1. Conventional (underflow) intake,   │
              │ 2. Side intake,                       │
              │ 3. Streambed intake,                  │
              │ 4. Other.                             │
              └──────────────────────────────────────┘


    (Further details on intake types are available in the information
         files on disk 3 and in the reference notes.)




              Use cursor keys to move to correct option,
           then press ENTER or RETURN to enter selection.
```

The user is then presented with a menu allowing the selection of various subsidiary components, such as spillways, which can make the scheme more efficient and less prone to failure in adverse flow conditions. The design routines for these are not included in the program, as it was judged that a longer program would be more cumbersome, and the majority of users would find it tedious. The user is referred to texts such as "Micro Hydro Power: A Guide for Development Workers" [Fraenkel et al], and the "Micro Hydro Power Source Book" [NRECA], for details on how to calculate the size of these components.

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To conclude this section, the user is asked to enter estimates of costs of materials for construction of the intake and of the labour and transportation costs likely to be incurred. In Nepal, transportation costs can be prohibitively high.

Weir Design

If a weir is to be used, the user is first presented with a menu screen allowing the specification of weir type (variable *weir_type*).

A display of the screen presented to the user is shown in figure 8.3.

Figure 8.3 : Menu Screen for Weir Type

```
WEIR TYPE.  Indicate the type of weir which will be used in this scheme.
(Further information on all types available in information files or in notes)

   ┌─────────────────────────────────────────────────────────┐
   │ Temporary Weirs:      Boulder Weir                       │
   │                       Brush and Boulder Weir             │
   ├─────────────────────────────────────────────────────────┤
   │ Semi-permanent Weirs: Gabion Weir                        │
   │                       Crate Weir                         │
   │                       Timber Weir                        │
   ├─────────────────────────────────────────────────────────┤
   │ Permanent Weirs:      Concrete Sill Weir                 │
   │                       Earth Weir                         │
   │                       Concrete Weir                      │
   │                       Masonry Weir                       │
   │                       Combined Masonry & Concrete Weir   │
   └─────────────────────────────────────────────────────────┘

           Use cursor keys to move to correct option, then
                 press ENTER or RETURN to select
```

This also allows the user to make a distinction between the categories of weir which are available (i.e. permanent, semi-permanent and temporary). Temporary and semi-permanent weirs are widely used in Nepal, and are designed with the expectation that they will be destroyed by flood flows, generally during the monsoon, and that they will require rebuilding. The cost of a temporary weir is usually a fraction of that of a permanent weir, but the cost will be recurring and is therefore considered as part of the annual running costs of the scheme.

As for the intake, the design procedures for weirs are not included in the program and the user is directed elsewhere if these are required. The costs of materials, labour and transport are then requested.

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8.2.3 : Design of Canal from Intake to Penstock

This constitutes by far the largest section of the program DESDATA1. It takes the user through the design of a canal from the intake point to the top of the penstock.

Although all the configurations shown above may be technically feasible, it is unlikely that they will be equally suitable in economic terms. As stated earlier, because of the relatively high cost of penstock pipe in Nepal, it is usual for the penstock to be as short as possible, and for water to be transported from the intake point to the penstock top via as long a canal as possible. If a canal *is* to be used, the user is first presented with an introductory screen and then asked to input the number of distinct sections which will be used to make up the whole canal.

If the water can be taken from intake to penstock without having to cross any obstacles then there will only be one distinct section in the canal. If, however, there is a stream or road to cross or the canal must circumvent some geological formation, then the water may have to be directed through a culvert or viaduct. In such a case, the cross section of the channel is likely to be different, (as the water is carried in, say, a PVC pipe or a wooden aquaduct,) causing changes in the flow regime. This is why different sets of calculations must be made for each section. Data can be entered and calculations made on up to 10 sections.

For each section the program makes detailed calculations of the likelihood of head loss, flow loss and erosion along the length of the section, depending on the data entered by the user. The routine described below is iterated for each section.

Routine for Canal Section Design

The first parameter required is the length of the section (variable *sect_length*), and this is followed by the menu allowing the user to specify whether the section is to be

- open,
- closed or

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• an aquaduct.

This is stored in variable *sect_type*.

Depending on variable *sect_type*, the user is then presented wth one of three menus allowing the selection of the type of lining for this section of the canal.

An example of one of these menus is shown in figure 8.4.

Figure 8.4 : Menu for Canal Lining Material


```
        Select type of lining which channel will have.
                          1.  Soil
                          2.  Concrete
                          3.  Masonry
                          4.  PVC
                          5.  Rock
                          6.  Gravel


                  Use cursor keys then enter to select
```
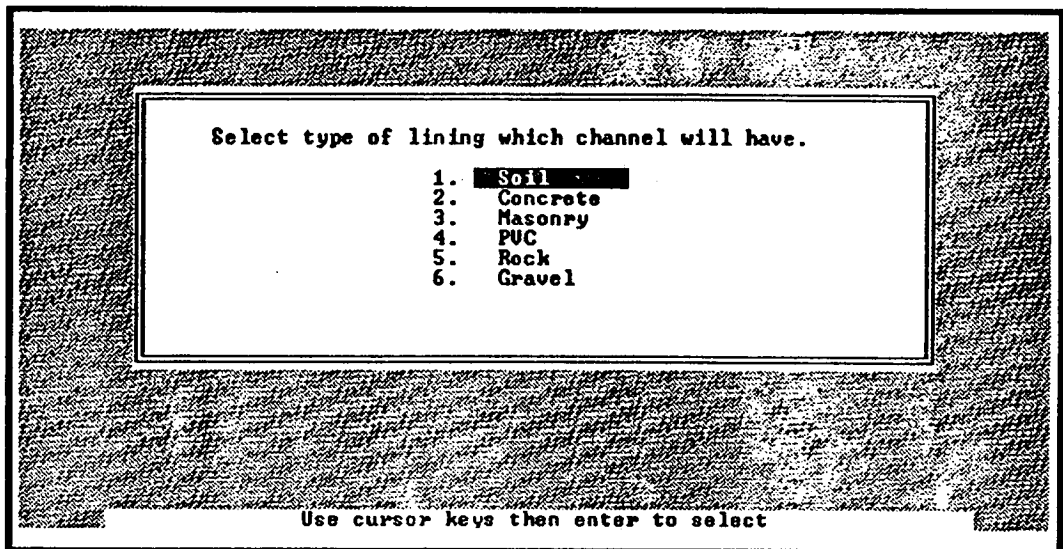
For all values of *sect_type*, the lining type is stored in variable *lining_type*, although the values mean different things for different values of *sect_type*. There are tables within the knowledge base which store this data.

Depending on variable *lining_type*, the user is again presented with a menu allowing the specification of the *form* of the canal. This refers to whether the canal is new, old, clean, has a rough or smooth surface, is clogged with weed, or in the case of water passing through pipes, whether the pipe is new, old, has a smooth or pitted surface, or is corroded. The canal form has an effect on the turbulence of the water flowing in the pipe, and therefore has an impact on head loss. The option selected from the menu is stored in variable *canal_form*, and again, the same value of *canal_form*, can mean different shapes, depending on the values of *sect_type*. and *lining_type*, which have been selected previously.

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Laminar Velocity of Water

The user is then asked to specify the maximum laminar velocity expected for the water in this particular section of the canal, and this is compared with recommended values stored in tables in the program. The user is warned if the laminar velocity exceeds the water velocity above which erosion of the canal surface is likely to occur. In practice, this check routine is only invoked for earth-lined canals. The velocity of the water in the canal as a whole must be set so that it is not so large as to cause damage to the canal, does not change abruptly between sections of the canal, and is not so low that there is excessive siltation of the canal, or growth of weed.

Canal Profile

The canal profile is set to a default shape appropriate to the particular lining type selected, and in order to encourage the user to select this, the default is presented on a YES/NO response screen. If the user specifically rejects the default shape then the menu screen allowing selection from all the options available is shown, and the option selected is encoded in variable *canal_profile*. The options available depend primarily on the type of lining to be used for this section of the canal. If it is then necessary, the user is asked to specify the side slope of the canal (held in variable *side_slope*).

Depending on all the variables assigned above, the program assigns a value of Manning's roughness coefficient (*M*) to the canal section in question. This is done by referring to detailed data sheets which are stored in the knowledge base. The user has no access to these tables. The coefficient is then used, together with the system design flow rate, to calculate hydraulic radius and freeboard flow.

The hydraulic radius of a channel is equal to the cross-sectional area of the water flow divided by the wetted perimeter of the channel. An efficient channel has a high hydraulic radius, reflecting the minimum possible wetted perimeter, i.e. the minimum contact between the body of the water and the surface of the channel,

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and hence the minimum drag at the surface and minimum head losses due to tur-
bulence. As might be expected, the most efficient channel cross section is semi-
circular.

The freeboard flow of a channel is the amount by which the channel is oversized
to allow for   higher flows than the design flow.   . In this particular
design procedure, the canal has been sized to take 1.2 times the design flow of the
system. This is usual for micro hydro schemes [Fraenkel et al].

The program then uses the above information to recommend a canal slope for this
section of the whole canal. At this point the user is allowed either to concur with
the recommended canal slope, or to input some alternative value.

Once the canal slope and the hydraulic radius are known, the canal dimensions
and the total wet wall area can be calculated. From these, the total flow loss due
to seepage through the wall and the head loss due to the slope of the canal can be
assessed. Further details of these methods can be found in [NRECA] and
[Fraenkel].

Interim Checks

The method for designing canals for micro hydro schemes is usually iterative, so
at this point the program carries out two interim checks, the first to make sure that
the head loss is not greater than 100%, and the second to check that it is not above
50%. If the loss is greater than 100%, the system immediately returns to the
beginning of the canal design section, if it lies between 50% and 100% the user is
given the option to continue with the evaluation, if this is considered sensible, but
is advised to return to the beginning of the canal section. An identical routine is
carried out for the flow loss.

When the data for all sections has been entered, the total head and flow losses are
computed, and again checked and displayed to the user, who can decide whether
to proceed to the next set of calculations or to re-iterate the canal design

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procedure. If the program moves on to the next section, then the cost of materials, transportation and labour are entered, allowing an assessment of the costs and giving the user another chance to repeat the whole routine before the program moves on to the section dealing with the settling tank.

8.2.4 : Design of Settling Tank

Water-borne particulates can cause serious problems for micro hydro schemes, either by silting up pipes and canals, or by being carried into the turbine and abrading runner vanes or buckets. Wherever possible, particulates should be removed to minimise such effects. This is usually done by directing the water flow through a settling tank which is wider than the rest of the canal, allowing the water to slow sufficiently to allow the particulates to settle out. It should be borne in mind, however, that cost is a major factor in the design of micro hydro schemes, and that the cost of, say, a replacement runner vane in a crossflow turbine may be a fraction of the cost of the cement needed for the construction of a settling tank.

This section begins by checking whether a settling tank is to be used or not. If not, the user is presented with the usual screen stating that this section of the program will be skipped, and the program moves to the data storage section described below. If a settling tank *is* to be used, the user is first asked to specify the tank location using a menu screen (see figure 8.5).

The option selected is stored in variable *tank_location*. This data is used by the system to deduce the laminar velocity of the water entering the settling tank. Further menus allow the selection of the type of settling tank to be used (stored in *tank_type*) and the size of the water-borne particulate which the tank is to be designed to remove (stored in variable *debris_type*).

This is followed by a routine which compares the variable *debris_type* with a table of values of expected settling velocities in normal streamflow, and the

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Figure 8.5 : Menu for Tank Location

```
                        SETTLING TANK LOCATION

          Select the approximate location of the settling
                    tank from the list below.



        ┌──────────────────────────────────────────────────┐
        │ 1. Between the intake and the rest of the scheme. │
        │ 2. Along the canal between intake and penstock.   │
        │ 3. Directly before the penstock.                  │
        └──────────────────────────────────────────────────┘




             Use cursor keys to move to correct option,
                then press ENTER or RETURN to continue.
```

settling velocity which the tank must be designed to accommodate is stored in variable *settlingv*.

The user is asked to input the preferred flow velocity for water flowing through the settling tank, and this is compared with the stored values of the flow velocity in the canal section preceding the tank. It is recommended that the flow velocity in the tank is less than that in the section preceding it, but the user is, of course, allowed to override this if there is some unforeseen reason, which the system cannot possibly take into account. The user also enters values for the tank depth, width and length, and these are subject to consistency checks. The user is encouraged to interact with the system, accepting or rejecting its recommendations as it carries out the calculations, depending on the information provided by the system on screen, and the user's knowledge of local conditions. When the user is satisfied, the system moves onto the calculation of materials, labour and transport costs, before moving onto data storage routines.

8.2.5 : Data storage and Chaining DESDATA2

At the end of this program, the data generated is stored in SCRATDAT. This includes the working values of head and design flow, which have been updated to take account of any losses calculated so far. The new values of flow rate and head

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will be used in subsequent routines, unless they are changed later.

8.3 : Program DESDATA2

Filename:	DESDATA2
Program size:	83456 bytes
Number of rules:	127
Number of commands:	353
Number of variables:	89
Text space:	32kbytes

8.3.1 : General Description of DESDATA2

This program deals with the design of the remaining sections of the civil works, which are concerned with the transport of water into the powerhouse, the construction of the powerhouse itself and the way in which water is removed after it has passed through the turbine, and, usually, returned to the stream or river.

The program begins by initialising all variables, and then loads in all relevant data from SCRATDAT, including the working values for head and flow rate. The routines dealing with the design of the penstock, the powerhouse, the draft tube and the tailrace are described below.

8.3.2 : Design of Penstock

The penstock is the pipe which carries water, under pressure, from the end of the canal into the powerhouse to the turbine. Penstocks generally account for a large

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fraction of the total scheme cost [Holland].

Head Loss in Penstock

The head losses in the penstock increase as the pipe diameter is decreased, but larger diameter pipe generally costs more, so the designer usually has to trade off initial capital cost against revenue lost in the future because of lowered power output. Head losses are also dependent on factors such as the roughness of the internal surface of the pipe, and the number of joints, bends and valves along the length of the pipe. Penstocks are usually constructed from locally available materials, and although the most common construction material worldwide is mild steel, they can be made from unplasticised PVC, high density polyethylene, asbestos cement [Holland] and even such things as oil drums [Randell], or wooden planks (the author saw wood stave penstocks in rural Nepal).

The routine dealing with penstock design is the largest section of DESDATA2 and constitutes almost 90% of the program code. It begins by asking the user to input the maximum head loss due to turbulence which can be tolerated in the penstock. The user is asked to accept the default value of 5%, or to over-write it with another value. This means that the design loop can be iterated several times to examine the impact which various pipe diameters will have on the cost/losses trade-off.

Following this, the user is presented with a menu of materials which can be used to construct the penstock, (See figure 8.6). The material selected is encoded in variable *penstock_material*.

In case the user wishes to design a penstock using a material which is not included in the menu, the program allows the material specification, including Manning's roughness coefficient, thermal expansion coefficient and elasticity modulus, to be entered on a special screen.

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Figure 8.6 : Menu for Penstock Material

```
   PIPE MATERIAL
   Select the penstock pipe material from the list below:




                         1  Steel
                         2  Pre_stressed concrete
                         3  Concrete
                         4  Asbestos cement
                         5  uPVC
                         6  Wood stave
                         7  Other




           Use the cursor keys to move to the correct option, then
                press RETURN or ENTER to confirm selection.
```

When an option has been selected from the menu, then the program assigns a value for Mannings Coefficient (variable *Manningsc*), to the pipe, and also assigns values for the Elasticity Modulus, the Thermal Expansion Coefficient, and for the turbulence *k* coefficient. These are dependent on the material used for penstock construction, and are drawn from tables held in the system. The user is then asked to enter the basic specifications of the pipe, such as internal diameter (variable *indiam*), pipe wall thickness (variable *wall_thickness*), and the length of the pipe sections (variable *sect_length*).

Data can be entered on up to 100 sections but the program assumes that all sections will have the same specifications.

After the user has entered the number of sections to be combined to form the pipe, the program carries out checks to ensure that it will be long enough to encompass the working value for the design head. If this is suitable, the expected thermal expansion at the normal working temperature is calculated, and displayed to the user, who is asked to accept it, or to override it and return to the start of the section.

Given the number of pipe sections, the default number of joints is computed and the user is asked to confirm this value. The user is referred to the usual design

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handbooks for the most suitable methods for combining pipe sections for the various materials which may be used. For each bend the user is then asked to enter estimates of bend angles and the ratio of bend radius to pipe radius. These are necessary for calculation of the possible head loss in the pipe.

Finally, the user is asked to enter details of numbers of and costs of any anchor blocks, thrust blocks and support piers which may be used. Design routines are not included for these features as they are so site-specific and depend on so many factors that they could not be dealt with effectively within the space allowed for the MICADO system.

When the data has all been entered, the calculations can begin. The first parameter to be evaluated is the speed of the water inside the pipe, given the design flow rate, and the pipe diameter. Once this is known, the head loss due to turbulence is calculated using two methods.

Mannings method is used by some practitioners, although this does not in fact apply to flows in enclosed pipes. This method has been included in the program for completeness, as despite the theoretical limitations some users will inevitably prefer to use it. The so-called Darcy/Colebrook-White method is suitable for calculating the friction losses in enclosed pipes, and is generally used by practitioners where manufacturer's tables of friction losses in their pipes are not available. Details of these methods can be found in [NRECA] and [Fraenkel].

Pressure Surge in Penstock

The water in the penstock is under pressure, especially at the bottom of the pipe, so the pipe must be strong enough to withstand this constant pressure under normal operation. The pipe must also be able to withstand much higher pressures, which may occur in exceptional circumstances, such as accidental closure of the penstock when a valve fails, or debris blocks the pipe. If a sudden change in flow velocity occurs, the energy carried by the water must be dissipated rapidly, and a surge wave is formed which can move up and down the pipe. The pressure of the

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wave adds to the static pressure which already exists in the pipe, due to the head of the water. The pipe must therefore be designed to withstand the sum of the two pressures.

The MICADO system designs for the worst case, when the water velocity changes from the design velocity to zero, and recommends a minimum pipe thickness based on this calculated pressure and the resistance of the pipe, which is tabulated in the knowledge base.

If the user is not satisfied with the recommended thickness or with other aspects of the penstock then the options of either repeating the section, or of proceeding with the evaluation are offered.

If the evaluation is to proceed then a screen is displayed which allows the user to enter details of costs for the pipe, piers, and thrust blocks, including labour and transportation. The trade-off between cost and head loss is then presented, wth the user deciding whether or not to accept the recommended penstock.

8.3.3 : Design of Powerhouse

The program section dealing with the design of the powerhouse is quite small and asks for a minimal amount of data. Power house designs can vary from the conventional, such as the powerhouse at Syangje (see figure 8.7), to the bizarre, (see figure 10.2) and are also a minor part of the actual design of the scheme. The user is therefore asked to enter only the dimensions of the building, as well as its location, owner and the cost of both constructing it and of purchasing the ground on which it stands.

The only other task carried out by the program is to remind the user that the agreed guidelines for micro hydro sites in Nepal (see [Waltham]) recommend that agro-processing equipment should not be housed in the same building as electrical generation equipment, if the electrical rating of the scheme is over 50kW.

Scheme Civil Works 140

Figure 8.7 : Powerhouse at Syangje

Scheme Civil Works 141
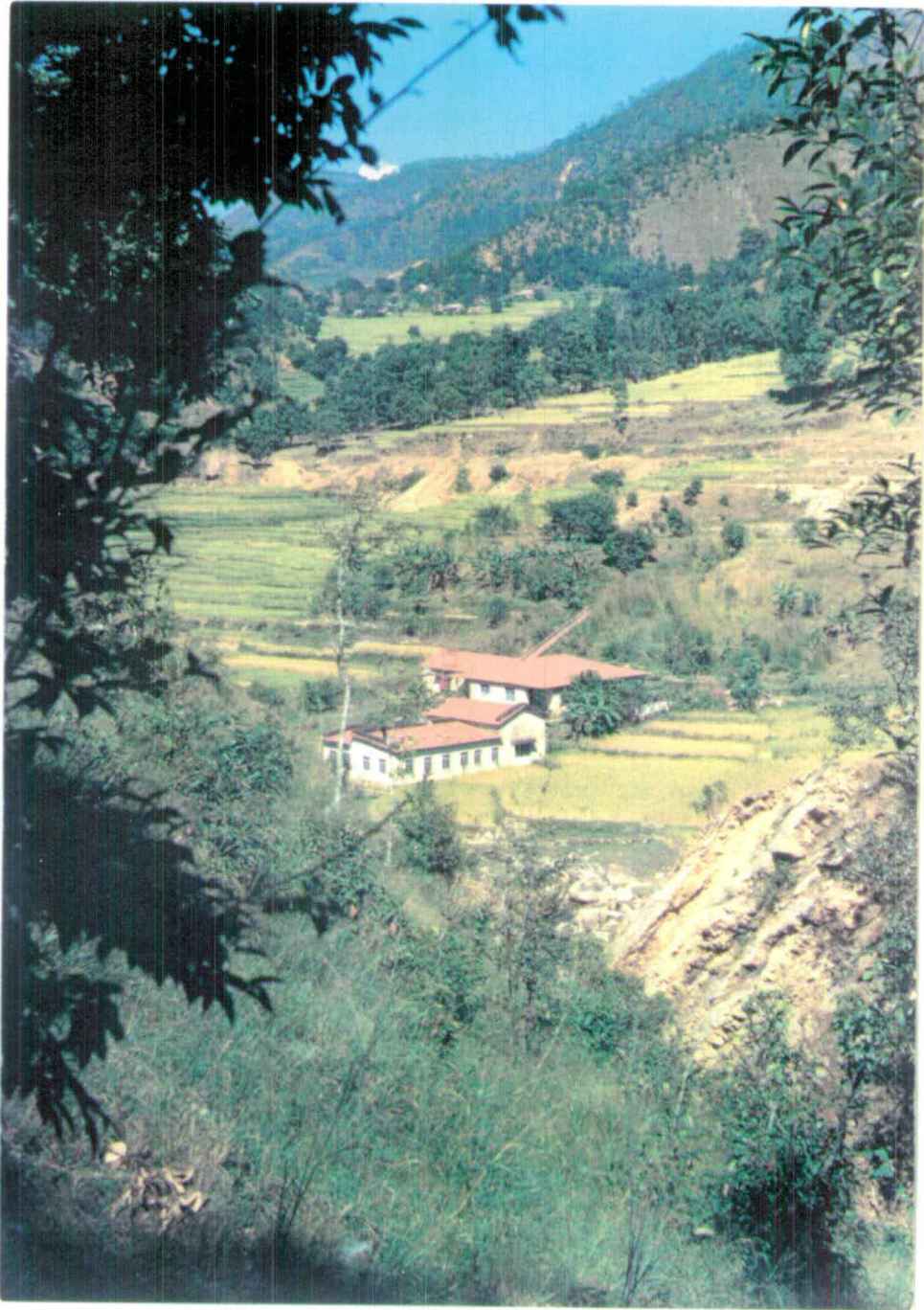
8.3.4 : Design of Draft Tube and Tailrace

A draft tube is a suction pipe connected to the penstock when a reaction turbine
such as a propellor turbine is used.   A reaction turbine is a turbine
which is completely immersed in the water flow, which gains its energy from the
kinetic energy of the water. Reaction turbines are generally used at sites with
high flow rate and low head. The draft tube is necessary to allow the recovery of
the residual kinetic energy of the water after it has passed through the turbine.
This ensures that the water will be carried away from the turbine as quickly as
possible, allowing an efficient flow through the system. Although the user is
allowed to specify a reaction turbine by the MICADO system, in practice they are
rarely used in micro hydro schemes in Nepal.

Reaction turbines and the penstock pipes in which they operate must be con-
structed to higher degrees of accuracy than impulse† turbines and their penstocks.
This higher standard of engineering will usually be too costly for rural communi-
ties. The MICADO system does not, therefore, contain routines for the design of
a draft tube. If the user has indicated that a draft tube is to be used then the nett
head gain due to the suction of the tube is requested, and this is added to the
working value for the head of the scheme.

The tailrace is the canal which carries water away from the power house after it
has passed through the turbine. It is generally not designed to minimise head or
flow loss, except where seepage from the canal would undermine the powerhouse
or any surrounding structures. Construction of the tailrace is often carried out by
local people, such as those who are usually responsible for the construction of irri-
gation canals. The MICADO system does not, therefore, supply a routine for the
design of tailrace canals.

---

† Impulse turbines, such as the pelton and crossflow, extract energy from the water by virtue of
its impact on the runner buckets or vanes. After it has fallen through the turbine, the water is car-
ried away by the force of gravity, and the turbine is therefore not enclosed in a pressure pipe.

Scheme Civil Works 142

The system does, of course, request the costs of constructing these two features, as these must be included in the economic assessment of the scheme.

8.3.5 : Data Storage and Return to Menu

The data storage routine for this program takes a long time (up to 28 seconds) to run as there are 102 variables to be stored, including the final value for the actual head at the site. The flag column variable for the civil works routines is also updated, before the main menu program is reloaded.

Chapter 9

Electro-Mechanical Equipment Selection

This chapter describes the section of MICADO which is concerned with the specification of turbines, agro-processing equipment and alternators, if these are to be used in the scheme.

Figure 9.1 : Block Diagram Showing Location of Electro-Mehcanical Equipment Selection Module in MICADO
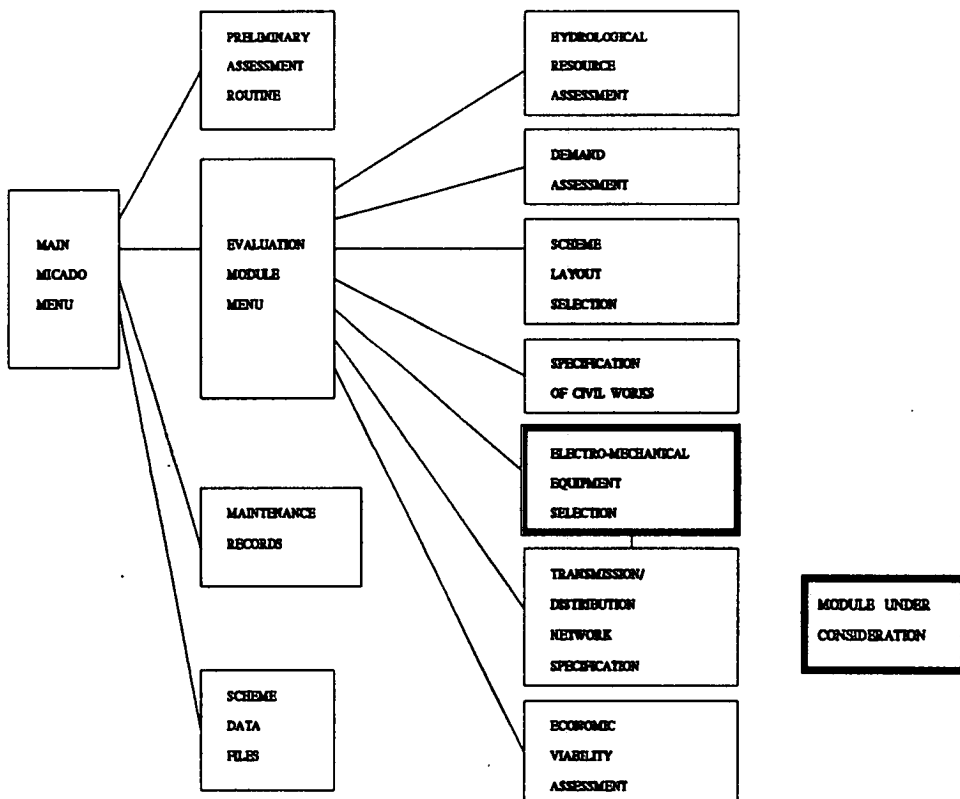
Although the programs dealing with the design of the transmission and/or distribution network for electric power are loaded directly by this module, rather than

from the evaluation menu, these are dealt with separately in the next chapter. Figure 9.1 shows where this module is situated in the MICADO system.

9.1 : Electro-Mechanical Equipment Selection

The *ghatta*, or traditional Nepali water wheel, typically has an output of around 1 horsepower, (0.746kW), and is thus large enough to drive only a single grindstone for milling flour. The increase in agricultural production which began in the 1950s and 1960s, however, precipitated the need for power to drive other agro-processing machinery, as manual processing of crops came to be seen as too arduous [Seddon]. Diesel sets were introduced in the 1960s to drive oil expellers and rice hullers and these were followed, in the early 1970s, by water-driven modified turgo and cross-flow turbines. These water-powered units usually drive several machines at once, via drive belts, and have outputs in the range 7 to 12 kW [Bachmann and Nakarmi]. Over 450 of these were in use in 1986 [AIM], and the manufacturers report that units are still being installed.

The machinery used for agro-processing is usually not used after dark, so many scheme owners disconnect agro-processing equipment from the drive shaft and connect alternators in the evening, as described in chapter 1. It is likely therefore, that a micro hydro scheme which supplies electrical power will also supply motive power for crop processing and in fact it is only in the last decade that micro hydro schemes have been installed to supply electric power alone [Brown]. The MICADO system, therefore, was set up to design schemes to supply:

- electrical power only,
- mechanical power only or
- electrical and mechanical power.

The last of these options is by far the most likely.

This necessitates the selection not only of a turbine and alternator, as in most small hydro power schemes, but also of agro-processing equipment, drive shafts and drive belts. The selection of powerhouse equipment for a small scale hydro scheme in a developing country is constrained by factors which are not generally present in developed countries. For example, a particular turbine or alternator may be selected because it is the only one available for delivery within six months of the order date, or because a higher rating may be too heavy for a porter to carry to an isolated scheme in the mountains.

An expert system or set of DSS which is to be of any use in developing countries must be able to accommodate these constraints.

9.2 : Program MECSELEC

Filename:	MECSELEC
Program size:	100352 bytes
Number of rules:	202
Number of commands:	555
Number of variables:	120
Text space:	65kbytes

9.2.1 : General Description of MECSELEC

The program MECSELEC is split into four sections, the first dealing with turbine selection, the second with the specification of any agro-processing equipment

which may be required, and the third dealing with the specification of the alternator, if this is required.

The fourth section allows the specification of any drive systems which will be used to link the turbine with the load(s), and, if an alternator is to be used, makes sure that the user at least thinks about items such as a powerhouse earth, monitoring and protection systems.

9.2.2 : Specification of Turbine

There are numerous water turbine types, with different origins and differing performances under various site conditions. A review will not be attempted here, and the reader is directed to texts such as "Local Experience with Micro Hydro Technology" [Meier], "The Micro Hydropower Source Book" [NRECA], "Micro-Hydro Power: A Guide for Development Workers" [Fraenkel et al], "Small-Scale Hydro Power Generation" [Wallace], and "Micro Hydroelectric Power Stations" [Monition et al], if further information is required. Suffice it to say that in Nepal, cost is a major constraint on turbine selection, and that much of the work concerning the promotion of micro hydro power in this country has been directed towards the development of a turbine which can be manufactured locally, at minimal cost. The favoured turbine throughout Nepal is the crossflow, which is manufactured by the Butwal Engineering Works (BEW) and Balaju Yantra Shala (BYS), [BYS, undated], [BEW, undated], but there are several other turbines in use, notably the modified turgo used in the so-called Multi-Purpose Power Units (MPPU), and, less commonly, multi-jet pelton wheels at high head sites, [AIM].

There have been several other attempts to devise a solution to the problem of turbine costs and availability, ranging from the Intermediate Technology run-of-river turbine, to several configurations incorporating pumps run backwards as turbines [Williams], [Hline and Wibulswas].

As the MICADO program is not intended as a turbine design package (for details of such programs see [Wallace], for example,) it does not include turbine design

routines.

Figure 9.2 : Turbine Specification Screen

```
                    TURBINE SPECIFICATION
                     <Technical Details>

  ┌─────────────────────────┬──────────────────────────────────┐
  │ Turbine type            │ Crossflow                        │
  ├─────────────────────────┼──────────────────────────────────┤
  │ Rated head: (metres)    │ 60.000                           │
  │ Rated flow:             │ 0.2000                           │
  │ (cubic metres/second)   │                                  │
  │ Specific Speed:         │ 150                              │
  │ Shaft speed at rated    │                                  │
  │ flow and head:(rpm)     │ 1500.00                          │
  ├─────────────────────────┼──────────────────────────────────┤
  │ Turbine diameter        │ 1.50                             │
  │ (metres)                │                                  │
  ├─────────────────────────┼──────────────────────────────────┤
  │ Bucket or Runner        │ 200.00                           │
  │ size (mm)               │                                  │
  ├─────────────────────────┼──────────────────────────────────┤
  │ Weight  (kg)            │ 200.00                           │
  └─────────────────────────┴──────────────────────────────────┘

  Enter data in the spaces provided, then press ENTER or RETURN to move to the
  screen dealing with turbine efficiency under the scheme operating conditions.
```

Rather, the user is asked to input details of particular turbines which are thought to be suitable for the micro hydro scheme under consideration, and these are assessed in the context of the specifications of the rest of the system.

The user is asked first of all to select the type of turbine to be used from a menu, and depending on this, a default value for specific speed (Ns) is created. A display screen then follows, where there are spaces for the user to input the turbine specifications (see figure 9.2). These include rated head and flow, shaft speed, specific speed, and physical dimensions such as weight, diameter, bucket or runner size.

Comparison of the rated head and flow with actual head and flow then allows the user to accommodate any discrepancies by entering the expected efficiency under the actual conditions at the site.

Administrative details such as price, the date on which the price was given, supplier's name and delivery time are also requested, as these can have a crucial impact on the suitability of any turbine selected. At this stage, the program checks only whether the turbine capacity can meet the maximum demand

calculated earlier.

9.2.3 : Specification of Alternator

In Nepal most micro hydro electric schemes use synchronous generators [Williams], which are produced in India, although Balaju Yantra Shala, Nepal's largest engineering firm, imports synchronous machines from the UK. The machines used are of standard sizes, and tend to be of the type mass-produced for diesel generator sets. These are usually four-pole and operate at 1500rpm and although lower speed, machines with a greater number of poles have been used, these are usually much more costly.

There is increased interest in the use of stand-alone induction generators, especially in the light of the development of an Induction Generator Controller (IGC), by Trent Polytechnic and ITDG which can provide an excitation capacitance which varies with load and phase angle [Holland].

Any micro hydro schemes which produce electrical power in Nepal are subject to a set of guidelines, drawn up initially by the UK-based Intermediate Technology Development Group, and agreed by the major organisations involved in micro hydro in Nepal.
(The first edition of these guidelines can be found in [Waltham].)

The MICADO system has been designed to default to the agreed guidelines whereever possible. The selection of the alternator is the first routine the user encounters upon which the guidelines have any bearing. After entering preliminary specifications of kW rating and output frequency, the scheme is categorised as belonging to one of four scheme types, as set out in the guidelines.

From this point the specifications of the alternator are assigned according to the guidelines and according to whether a synchronous or induction generator is to be used. At each point the user can override the system recommendations, and the system takes into account any changes that may have been made before moving to

the next stage of the specification. Although the user may move through this section of the program relatively quickly, it in fact accounts for almost 80% of the total program space as it covers so many different scheme configurations. The user follows the design path for only one configuration among many possibilities.

Following this, the user has to enter administrative data such as prices and the dates on which these are valid, the supplier and the expected delivery date. There is also room for the user to enter details of the controller type to be used, together with any comments which may be relevant. At this point the turbine is checked to ensure that it can actually drive the alternator, and if there is a mismatch then the program returns to the top of the alternator specification section.

Because of the hostile conditions in which generators must often operate in developing countries, the guidelines include a section which refers to the de-rating required because of high ambient temperature, or because of the rarified atmosphere at high altitudes. An example of a derating screen is shown in figure 9.3.

Figure 9.3 : Menu Screen for Altitude Derating Factor


```
                    DERATING DUE TO ALTITUDE
     Indicate the altitude at which the scheme will be situated:



          Altitude in metres:    1000 metres
                                  1500 metres
                                  2000 metres
                                  2500 metres
                                  3000 metres
                                  3500 metres
                                  4000 metres




            Use cursor keys to move to correct option,
            then press ENTER or RETURN to enter selection
```

There is also a derating factor included to accommodate the use of Electronic Load Controllers, which has been pioneered in Nepal by ITDG and DCS, and can introduce high harmonic loading into the generator load pattern because of the high switching frequencies involved in cutting out sections of the output pulse

from the generator. These have all been included in the program module.

At this point the alternator specifications are checked to ensure that the derated alternator can meet the demand specified earlier. As usual the user then has the option to proceed or to repeat the section just completed.

9.2.4 : Specification of Agro-Processing Equipment

Micro hydro power turbines are most likely to be used to drive grain mills, rice hullers and oil expellers. Other loads include saw mills, lathes, power looms, and threshing machines, but these are less common. Rice hullers can typically process between 70 and 250kg of rice per hour, and have ratings of between 1.5 and 7 kW. Oil expellers have ratings which range between 2 and 6 kW and will process between 150 and 450 kg of mustard seed per hour. Grindstones have a variable range of capacities, depending on the material from which they are produced and the method of production. Locally produced stones will have a capacity of between 12 and 16 kg per hour and must be driven by a turbine or water wheel wth a rating of aound 1 kW. Commercially-produced cast "stones" require a much higher power input, typically in the range 2.5 to 4 kW, but are more efficient than locally produced stones, with a capacity for processing around 75 kg of grain per hour [AIM], [Bachmann and Nakarmi].

There are no standard methods for producing agro-processing equipment, and locally manufactured units vary widely. In light of this, it is not possible to construct a menu from which the user can select specfifications of the units to be installed at the site. The specifications for agro-processing equipment are therefore entered on display screens containing large tables of input fields, corresponding to elements of data arrays such as *agrate[#,#]*, *agspeed[#,#]*, *agbelt[#,#]*, *and agcost[#,#]*. The data arrays are cleared and the details of unit types, ratings, costs and optimum shaft speeds are entered. The data arrays, together with string arrays holding variables specifying unit type, supplier and further details are stored in the data exchange file SCRATDAT at the end of this module.

It is usual for several pieces of agro-processing equipment to be run simultaneously, with drive belts linked to a common shaft which is rotated by the turbine. It is possible, therefore that all the equipment specified above will be run at the same time. The maximum possible load is therefore calculated to ensure that the user has not entered a load which cannot be driven by the turbine.

If the sum of the ratings is larger than the turbine output, the user is warned of this and has the option of indicating whether this is due to the fact that the loads will not be run simultaneously or whether there has been a mistake and the turbine and/or the load must be re-specified.

9.2.5 : Specification of Drive Systems and Electrical Powerhouse Accessories

If the drive speed of the alternator or of any of the agro-processing equipment matches the rated speed of the turbine it is possible that the equipment can be driven directly from the turbine shaft. In practice this rarely happens as there are usually problems with aligning the components and even if the alternator is the only load on the turbine, a 1:1 drive belt is often used. (The author has seen two of these schemes in operation in rural Nepal).

Nevertheless, because MICADO is designed to be as flexible as possible, if the rotational speeds of any of the loads are within 10% of the rated rotational speed of the turbine, the user is allowed to specify a direct drive system for that component. If this is not selected, or the speeds are outside this range, then the user is asked to specify drive belt type, size and cost for each load. The ratio of the drive speed of each component to the rated speed of the turbine is displayed so that the user is supplied with sufficient information to make the specification.

Rather than entering details of all the powerhouse accessories, the user is faced with screens of recommendations from the guidelines for micro hydro schemes, (See [Waltham]), with spaces left on them for entering costs of complying with these. This covers cables, connectors, switching systems and main cable protection.

The earthing system is specified separately with the user being faced with a list of recommended earthing methods to choose from. When the method has been selected the user is asked to specify earth cable gauge etc, as well as costs. It is intended that this approach should encourage the user to comply with the guidelines.

9.2.6 : Data Storage and Return to Menu

At the end of this module the data generated throughout is saved in SCRATDAT. This program produces a large amount of data, so while the user is kept waiting the system displays a sequence of dot screens.

Then, if there is no electrical power produced by the scheme, the menu program SMFT is reloaded. If, however, electrical power is to be generated, the first program dealing with the design and configuration of the transmission and distribution network (TRANSDST) is loaded.

Chapter 10

Transmission and Distribution Network

The MICADO module dealing with the design of the transmission and/or distribution network of the micro hydro scheme is loaded by the MECSELEC program and not by the evaluation menu. (See figure 10.1 for the system block diagram.)

Figure 10.1 : Block Diagram Showing Location of Transmission/ Distribution Network Specification Module in MICADO
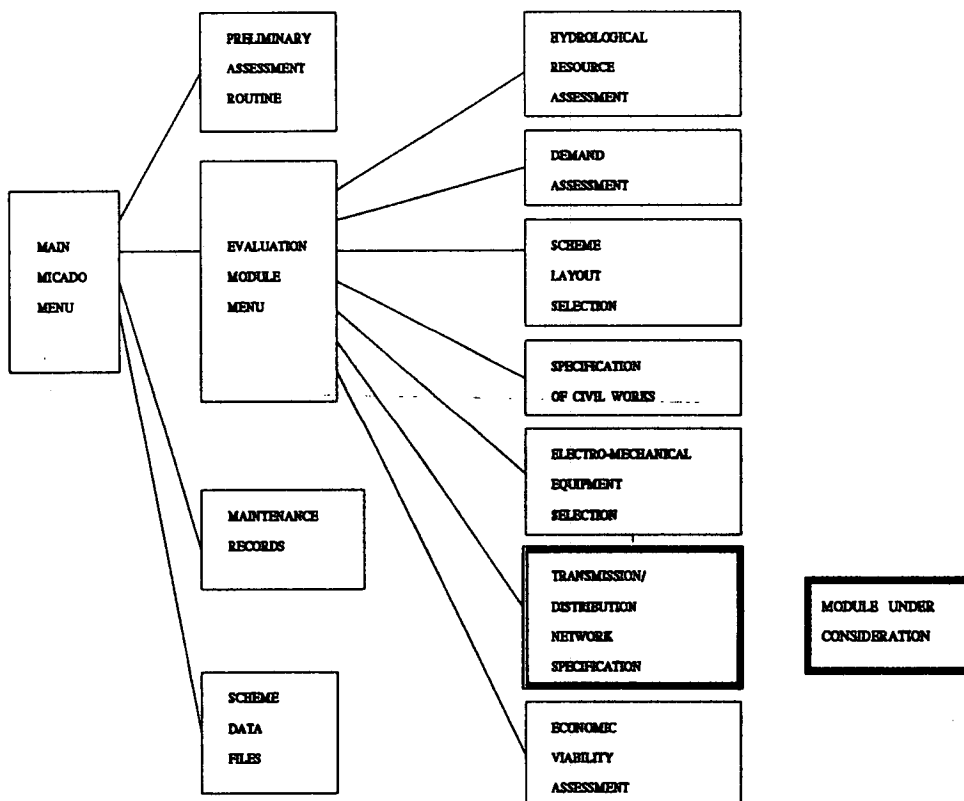
However, as it contains routines concerned with a completely different set of tasks, it is described separately in this chapter.

10.1 : Transmission and Distribution Network Specification

Transmission and distribution networks for electrical power schemes are designed to bring electricity to the consumer with the minimum power loss and acceptable voltage regulation, given the economic constraints. Micro hydro schemes installed solely for the provision of electricity tend to be similar to rural electrification networks elsewhere in the world. Schemes which are designed primarily for agro-processing and which supply lighting only in the evening are characterised by non-standard designs with installers using any materials which readily come to hand. The author saw several such schemes in Nepal, including one in the Annapurna region, where domestic service wire was used to carry the power for a kilometre (see figure 10.2), and a scheme on the outskirts of Kathmandu where a scheme housed in a shack at the bottom of a paddy field supplied power via an electronic load controller to a small group of houses.

This section of MICADO is similar to the previously described sections, in that it draws on a variety of sources, ranging from the usual documentation and interviews with micro hydro engineers to interviews with academics at the University of Edinburgh and with personnel at the (then) Scottish Hydro-Electric Board. It contains a necessary mixture of the conventional and the pragmatic.

The program for network design is split into three separate modules because of the space limitations of the CRYSTAL environment, which is limited to loading and running programs which are of size 104 kbytes and smaller. The first program, TRANSTR1, deals with the selection of transmission voltages and transformers, if required. It also treats the selection of line layout and line type and calculates expected losses along the line length. The second, TRANSTR2, deals with the layout of the transmission poles for the network, and the third, TRANSTR3, contains code for the design of the distribution network. All three

Figure 10.2 : Photograph of Purang Village Micro Hydro Scheme, 1988

modules are structured on the guidelines for micro hydro electric schemes agreed for Nepal.

10.2 : Program TRANSTR1

Filename:	TRANSTR1
Program size:	102400 bytes
Number of rules:	145
Number of commands:	475
Number of variables:	69
Text space:	50kbytes

10.2.1 : General Description of TRANSTR1

This program deals with the transmission of electrical power from the power-house at the site to the load centre. It examines transmission voltages and the use of transformers. The line current, and hence the expected voltage regulation along the line are calculated for a range of lines, and the voltage losses are checked against a previously set acceptable level.

In rural Scotland overhead lines are generally overrated by 100% because of the possible temperature rise due to ohmic heating [Brass, 1988], but this could make scheme economics too marginal in developing countries.

10.2.2 : Calculation of Line Length

To assess the length of wire required for a transmission line it is necessary to make a series of calculations of the "sag" of the line, i.e. the length of the catenary curves in which the line hangs when it is suspended between poles. The catenary occurs naturally and is necessary because of the contraction of lines in cold temperatures. In developed countries, the pole configuration is decided upon before the line calculations are carried out, and a surveyor's chart of the line is used to calculate the dip in each span of the transmission line. For micro hydro schemes in developing countries, the method for calculating line length is generally less rigorous, as the lines tend to cross a shorter distance, and it may not be possible to survey the terrain between the powerhouse and the consumers. To carry out such a survey would usually be regarded as a waste of resources, and pole spacing is generally not decided until the engineers and the poles are on site.

There are several methods used to calculate the length of wire required for the network. One of the most commonly used involves taking the linear distance of the transmission route, and multiplying it by a factor which allows for the sag in an average span [Brass, 1988]. This method is incorporated in the MICADO system, with a factor of $\sqrt{2}$ being used, in conjunction with an average span of 40m, as recommended in the agreed guidelines for micro hydro in Nepal (see [Waltham]). This assumes that the wire hangs in a line approximating to the hypotenuses of two right angled triangles when it is suspended between two poles. It ignores the difference in the catenary curves due to transmission poles placed at different heights but adds a safety factor of 15% to account for this [Brass, 1988].

This method was known to most practitioners, although other methods, such as the *Return Wave Method* (see [Waltham]), are also used.

10.2.3 : Specification of Transmission Voltage

The first decision in this process is whether or not to use transformers. If it is economically sensible to use lines at a lower voltage, this is usually preferred, as the transformer represents extra capital cost, extra transportation costs and extra maintenance costs. It also represents another component which may fail. In practice, a transformer must be used to avoid unacceptably high voltage losses, (up to 40% in some cases). Engineers designing micro hydro schemes will usually consider their use at any transmission distance of 1 km and over. Other criteria do exist for deciding on their use. One method, for instance, is to multiply voltage and distance in km: transformers are used if the product is greater than 40 [Pandey, 1987]. The MICADO system uses the more familiar test for transmission distances greater than 1km.

The MICADO system, therefore, tests first of all for the transmission distance, and on the basis of this makes a first recommendation to the program user, (which the user can then ignore), on whether or not transformers should be incorporated into the design.

If transformers are not required, the user is asked to confirm the transmission voltage displayed, which has been drawn from the voltages recommended in the draft standards for micro hydro electric power in Nepal. The specified transmission voltage depends on variables *schemetype, phi* and *stardelta*.

The user can override the program's suggestions, if this is thought to be necessary. For three phase systems, the selection of recommended transmission voltage also includes a check that *stardelta*, the variable which signifies whether the transmission network is star or delta connected, is appropriate to the scheme rating. Again, the user can override this.

If transformers are necessary, the transmission voltages recommended by the agreed standards depend on *schemetype* and *phi*, and the system again uses a menu to encourage the user to design using these values.

Whether transformers are to be used or not, the system then checks that the output voltage of the alternator (*opvolts*) and the transmission voltage (*transv*) are equal. If they are not equal then there is a menu which allows the user to select to:

1. re-specify the transmission voltage,
2. specify a transformer,
3. set transmission voltage equal to alternator output voltage or
4. proceed with the voltages chosen.

10.2.4 : Specification of Line Number

At the beginning of this section, the user is asked to give an indication of exactly how many lines will be used in the transmission system (including the number of lines which will be used as earth lines and lightning shields). This depends on *phi* and *stardelta* first of all, and this leads the user into specific menu screens, from which line number can be selected. The data is stored in variable *lineno*.

In some cases, the transmission network has consisted of a single line between two transformers, with the neutral of the transformer plugged straight into earth at the supply and consumer ends of the line. This "earth return" line configuration has the advantage of being very cheap (the cost of the transformers being offset by the reduced line costs), but is generally not used, since earthing systems will be useless, earth leakage breakers will not work and circulating earth currents can cause hazard to animals and people.

The most commonly used line configuration, for single phase systems, consists of a supply line plus a neutral line. Three phase systems, if they are delta connected, can use three lines and if they are star connected can use four lines. In regions of high lightning incidence extra conductors, installed as a lightning shield, must be used.

10.2.5 : Specification of Transformer(s)

The same program code is used at the beginning and at the end of this module to select step-up and step-down transformers. The routine will therefore be described only once.

If the network is transmitting single phase power, then only one transformer is to be selected and the selection process is relatively simple. If, however, the network is transmitting three phase power, the user has the option of installing either one three-phase transformer or three single-phase transformers. It is often recommended that three single phase transformers be installed, as they are generally cheaper and easier to transport. It is also cheaper and easier to replace a single phase transformer than a three phase transformer.

For each transformer, regardless of its place in the network, the program runs through a series of design screens. The program keeps track of which particular transformer is being treated, and stores the data entered in the appropriate elements of array structures. The user is reminded which transformer is being dealt with at each stage. The data entered on each transformer includes: input voltage, output voltage, power rating, type (i.e. oil-filled or dry), weight and price.

10.2.6 : Calculation of Line Current and Regulation

At this point the system carries out calculations of the expected line current, for whatever line configuration has been selected. Data from databases in MICADO relating to the line type selected from an initial menu, is loaded into the array *lspex[#,#]*. If, for instance the user wishes to use Aluminium Conductor Steel Reinforced (ACSR) lines, then data on ACSR lines is loaded into *lspex[#,#]* from the appropriate table in the knowledge base. (See figure 10.3 for a display of the MICADO menu screen.)

Voltage regulation calcuations are carried out for all cables which are specified in the *lspex[#,#]* array, and the results of the calculations for this particular network

Figure 10.3 : Menu Used to Specify Transmission Line Type

SELECTION OF TRANSMISSION CABLE				
Option	Cable type	Cost/km (Rs)	Regulation (x)	Acceptiblity of voltage losses
1	Squirrel	7650	7.926	Losses acceptable
2	Gopher	9000	6.306	Losses acceptable
3	Weasel	10900	5.236	Losses acceptable
4	Rabbit	18200	3.124	Losses acceptable
5	Dog	33500	1.574	Losses acceptable
6		0	0.000	Losses acceptable
7		0	0.000	Losses acceptable
8		0	0.000	Losses acceptable

The table above shows the calculated regulation for the cable types
indicated, and whether or not this is within the limit for percentage
voltage loss entered earlier in the evaluation.
You can now use the cursor keys to move to the cable type which you would
like to use in designing the transmission network for this scheme.
When you reach the correct option, press ENTER or RETURN to
confirm your selection.

are then added to a section set aside within the array itself.

10.2.7 : Transmission Line Selection and Specification of Distribution Voltage

The user, having specified a line type earlier in the program, is now presented with data on the voltage losses and on the costs of using each particular gauge or size of the line type specified.

In addition, the program carries out a routine which assigns the value "Acceptable" or "Unacceptable" to the elements of the variable array *voltage_loss$[#,#]*, which are displayed beside the data elements from *lspex[#,#]* referring to the appropriate line size. Despite the fact that some line sizes will have a voltage loss which is "unacceptable", i.e. greater than the level entered at the start of the program, the user is allowed to select any of the lines displayed from the screen.

The program contains no information on any mechanical problems which might be encountered for each line type. For instance, ACSR lines are very strong, and can be stretched over longer spans than copper conductors. However, if ACSR lines fracture or collapse, the poles are often damaged or even broken. This is less likely with copper conductors [Brass, 1988].

If an earth line is to be used in the network, the user is then required to select an earth line size. The program is biassed towards the use of the same gauge line for transmission and earth lines as there are often cost savings due to bulk orders. If this is not the case, the user can override the system suggestions.

At this point the system moves into the section dealing with the specification of the second transformer, if this is required. In order to test whether or not a transformer will be required at the distribution end of the network, the system asks the user for the distribution voltage. This is also done with reference to the guidelines agreed for micro hydro in Nepal. This section uses the same code as the initial transformer selection routine.

10.2.8 : Repeat Option and Data Storage

At this point a menu screen is presented to displaying all the decisions on transmission network design. The user may either proceed with the evaluation or repeat all or some of the routines carried out so far. Finally, the data generated is written to the data exchange file SCRATDAT. The system then chains the next module dealing with the design of the transmission network, TRANSTR2.

10.3 : Program TRANSTR2

Filename:	TRANSTR2
Program size:	75264 bytes
Number of rules:	117
Number of commands:	314
Number of variables:	51
Text space:	24kbytes

10.3.1 : General Description of TRANSTR2.

This section deals with the layout of the poles required to support the transmission lines. The agreed guidelines for micro hydro electric schemes in Nepal contain recommendations for the clearance of wires passing over various features. This module contains tables of data on these clearances, together with the recommended dimensions of poles for the various scheme sizes, and for the transmission voltages used for these.

10.3.2 : Transmission Pole Layout

Data required from previous modules is first of all loaded from the data exchange file SCRADAT. The user inputs the expected number of poles and the maximum span between the poles. Checks are carried out to ensure that there are at least enough poles to cover the transmission distance, with the usual option of repeating the section or overriding system recommendations being offered to the user if there are not enough.

The user is then asked to separate the number of spans into the three categories outlined in the agreed electrification guidelines. Namely,

- over open ground,

- beside a motorable (sic) road,

- over a motorable road.

Then, depending on the value of the transmission voltage variable *transv*, and on the value of the variable *schemetype*, the clearance distances are assigned for the three categories of poles. The dimensions of the poles are assigned on the basis of the value of transmission voltage variable *transv*, the value of the clearance distance variable *clrdst*, and on whether the transmitted power is single phase or three phase.

At this point the recommended pole dimensions are displayed to the user, who is at liberty to override them completely when entering the actual dimensions of the poles to be used. In all cases the user can recommend the use of convenient trees rather than actual poles. This section finishes with a screen for entering the costs of the pole network.

10.3.3 : Insulators, Stay Wires, Lightning Protection

Depending on the voltage of the transmission lines, the insulator prescribed by the electrification guidelines is displayed to the user for confirmation or rejection. Further specifications, including costs, are then requested. The number entered is checked against the number required, given the number of lines and poles.

It has been reported [Brown, 1989] that most of the problems concering loss of lines in mountain regions are due to lightning. As the majority of schemes in Nepal are in the mountains, installers are encouraged, by the agreed guidelines, to use lightning protection along the length of the whole line. Cover from lightning is assumed to be given by lightning protectors or by spark gaps, and the user is asked to enter the numbers of these with a certain minimum recommended.

Stay wires should be installed at each bend along the line, and at the ends. In addition, the user is encouraged to install stay wires where the line may cross soft

ground or where there may be strong cross winds.

10.3.4 : Repeat Option/ Data storage

The user then has the option of repeating any of the routines, before moving to the end of the program. At the end of TRANSTR2, the data generated is written to the data exchange file SCRATDAT.

10.4 : Program TRANSTR3

Filename:	TRANSTR3
Program size:	80896 bytes
Number of rules:	54
Number of commands:	272
Number of variables:	47
Text space:	29kbytes

10.4.1 : General Description of TRANSTR3

This section of the MICADO system deals with the design and configuration of the distribution system. It can be run separately from the previous two programs, and can deal with data on up to five branches of the network.

The design procedure set out in this program is carried out for each of the branches of the distribution network. The procedure is repeated, decrementing the branch counter each time, until each branch has been designed.

Before the procedure is set underway the user is given the opportunity to select the type of wire to be used, and data on the various gauges of the wire type selected is loaded into the *lspex[#,#]* array which is used to store wire data in all of the three TRANSTR programs.

10.4.2 : Design Procedure for Branches of Distribution System

The first parameter required is the length of the branch. This stored in variable *linelength*. The expected load in watts along this branch is then entered (a power factor of 0.85 is assumed [Waltham]), and the user then specifies the location of the load (i.e. at the end of the line, or evenly distibuted along its length) using a menu which stores the choice made in variable *loadlocn*.

The maximum permitted regulation voltage along the branch is entered. The calculated regulation depends on whether the supply is single or three phase.

The regulation expected for all the sizes of the wire type entered are displayed and the user selects the most appropriate size from a menu, (which also displays the cost of the line), depending on the expected regulation and/or other factors. At this point the user is presented with full data on the choice of wire and can opt either to proceed with the gauge of wire selected, or to return to the menu and select another. If the user wants to continue with the evaluation, the system checks that the maximum regulation is not exceeded. If it is, then the user can either proceed, overriding the system recommendations, or can return to the wire gauge selection menu.

The end of the design routine is concerned with assessment of the costs of each branch, and asks the user to enter data on costs of wires, poles, pole furniture, and consumer connection on data entry screens. The program assumes that the scheme will use positive thermal coefficient resisitors (PTCs) and/or other current limiting devices (see chapter 1) and asks the user to enter data on these.

10.4.3 : Data Storage and Return to Menu

At the end of TRANSTR3, the data generated by this program is written to the data exchange file SCRATDAT, and the appropriate variable in the flag column is updated, indicating that the routines for the design of the transmission system have been carried out completely.

The program concludes by chaining the menu program SMFT.

Chapter 11

Assessment of Economic Viability

This chapter describes the program which is used in the MICADO system to assess the economic viability of the proposed scheme.

Figure 11.1 : Block Diagram showing Location of Economic Assessment Module in MICADO
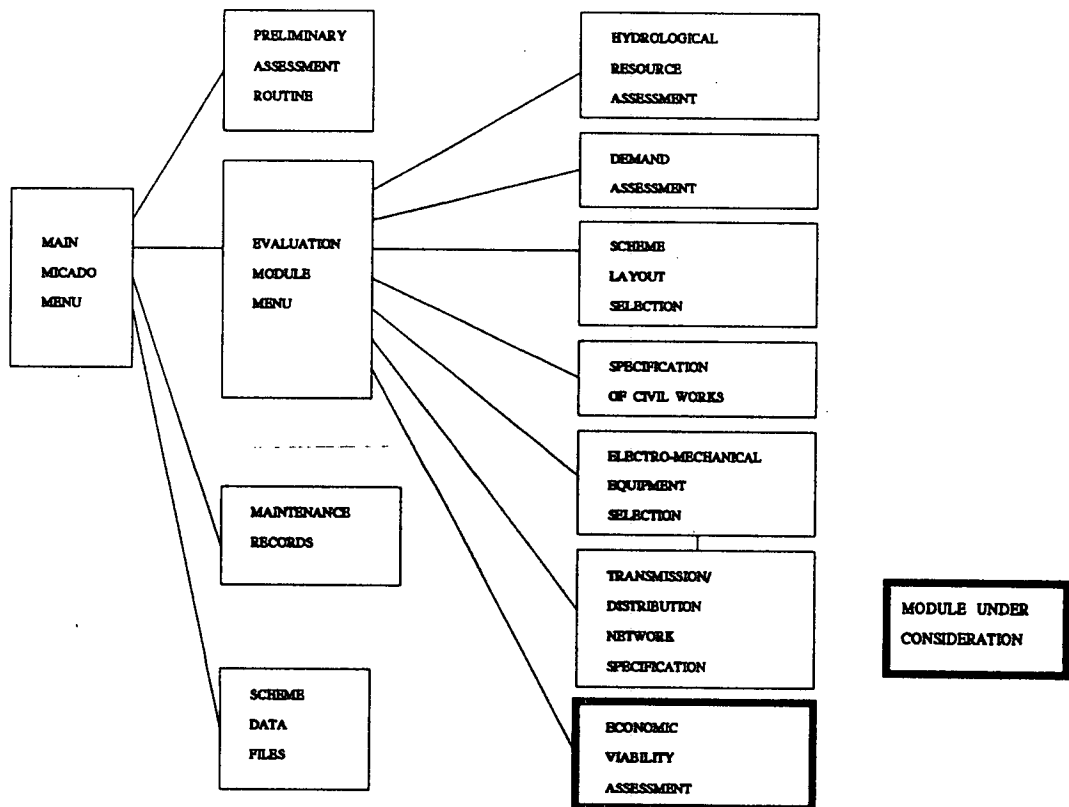
Figure 11.1 shows the relation between this module and the rest of the MICADO software.

11.1 : Assessment of Economic Viability

It is rare, in developing countries, for the installer of a micro hydro scheme to be able to meet the initial capital cost of the scheme. Loans are often sought to enable scheme construction, and in some countries grants and subsidies are avaiable to installers, as governments try to promote micro hydro power. In Nepal, for instance, there was funding available from UNICEF in the early 1980s [AIM] for the installation of Multi-Purpose Processing Units, and the government has made funding available via loans from the Agricultural Development Bank (ADB) which have very favourable repayment conditions attached [NCST].

It is customary, when considering whether or not to install a micro hydro scheme:

1. ' to consider whether the money to be invested in the scheme could give a better return if put to another use,

2. to consider whether the scheme will be financially viable and

3. to consider whether another fuel will meet the energy requirements of the consumer group at less cost within a set period of time.

There may be other factors which are particular to the scheme, to the provider of the loan or even to the country under consideration.

In the case of the MICADO system, it has been assumed that the user has already decided that the micro hydro scheme represents the best source of power for the consumers and that the financing institution is prepared to invest funds in micro hydro power if viability is shown. (This is often the case in Nepal, where the financing institution is almost invariably the country's Agricultural Development Bank (ADB).) Although there are numerous frameworks which may be used to judge the viability of a micro hydro scheme, in the MICADO system scheme viability is assessed on the basis of financial criteria.

Discussions with officials at the ADB revealed that they carried out calculations of financial viability for all the proposals they received for loans for micro hydro schemes. The calculations, without exception, centred on an assessment of whether or not the loan would be repaid within the forseeable lifetime of the scheme. This was adopted as the format for the economic assessment module of the MICADO system. The program which carries out the economic assessment, ECASSESS, is described below.

11.2 : Program ECASSESS

Filename:	ECASSESS	
Program size:	84992 bytes	
Number of rules:	84	
Number of commands:	361	
Number of variables:	85	
Text space:	33kbytes	

11.2.1 : General Description of ECASSESS

Before the economic viability of a scheme can be assessed, financial data from all the other modules must be collated and processed so that the relevant information can be used in the calculations. Consequently, the program ECASSESS begins with routines which scan through the data exchage file SCRATDAT, loading in all data on the expected cost of installing the scheme, and on the expected revenue which will be generated by it when it is in operation. Once this data has been collected, the program requests information from the user on subsidies and grants

which may be available to facilitate the project, and only then carries out the calculations.

11.2.2 : Cost and Revenue Data

After initialising all arrays to be used, the SCRATDAT file is opened, and cost and revenue data from all relevant modules is loaded into arrays. The information is collated and displayed to the user on a series of screens.

When the total cost of the scheme has been calculated, an estimate of the annual running costs of the scheme must be entered. This screen is shown in figure 11.2.

Figure 11.2 : Screen Requesting Data on Annual Running Costs of Scheme


```
RUNNING COSTS
For the purposes of this evaluation it will be
assumed that the annual running costs for the
micro hydro scheme will be approximately equal
to 3% of the total capital cost of the scheme.

  Is this acceptable ?    Yes      No

  (You can enter an alternative value if the
   value above is not acceptable)

         Use cursor keys then enter to select
```
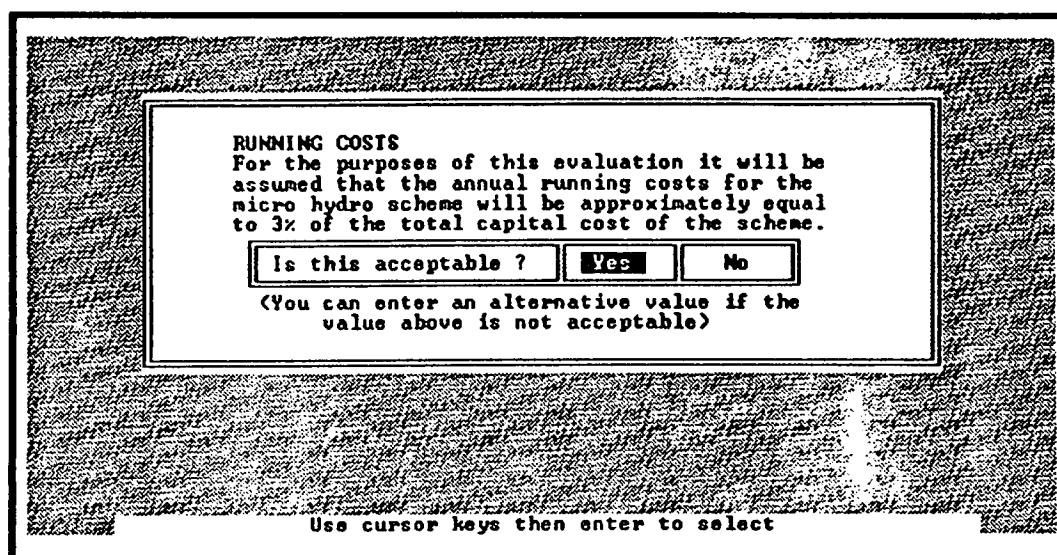
As a default, a fraction of 3% of the total cost is presented to the user for confirmation or correction. A screen showing total costs and running costs is then displayed.

11.2.3 : Subsidies and Grants

The types of and methods for calculating subsidies and grants may vary from country to country and even from scheme to scheme within the same country, depending on the source of the money.

A grant is assumed to be an amount of money which is specifically given to enable the scheme to proceed, and which does not have to be paid back. The

amount of the grant can be subtracted directly from the capital cost of the scheme. Subsidies are specified first of all by type, using a menu screen with "All data entered" box. There can be more than one subsidy type, and more than one of each type of subsidy can be specified if necessary. The amount of each subsidy is entered, and the user is asked to provide details of who supplied it and why. When the data on subsidies has been entered, the system can then calculate the outstanding amount required for scheme installation.

11.2.4 : Loan Constraints and Loan Selection

The user must first indicate the type of loan, i.e.:

    1. fixed interest rate

    2. fixed payback period or

    3. fixed interest rate and payback period.

For each type of loan, the system calculates the annual cost (which can be a single value or an array of values), and displays this to the user.

Depending on the loan type, a menu is offered so that the user can select the loan conditions which make the scheme seem most attractive in economic terms. Only then is the economic viability checked, with the user then being offered a series of menus allowing the program either to proceed or to loop back so that alternative conditions may be tried. Lastly, the loan conditions are stored in an array which will be written to SCRATDAT.

11.2.5 : Data Storage and Return to Menu

This, the last evaluation module in the MICADO system, also writes data to the data exchange file SCRATDAT, including the flag variable which indicates that the module was completed successfully. Although this is not required for subsequent programs in the evaluation, it is necessary if the data is reloaded, either for viewing at a later date, or for re-entry.

Although this is the last module in the evalution, the program finishes by chaining the menu program SMFT, as the user may wish to rerun other modules, to save the data stored in SCRATDAT throughout the evaluation, or simply to exit from the system.

Chapter 12

Preliminary Assessment Routine

This chapter is concerned with the MICADO preliminary assessment routine PRELIM. In effect the PRELIM program carries out a condensed version of the whole DSS system. Figure 12.1 shows how this program is linked to the rest of MICADO.

Figure 12.1 : Block Diagram Showing Location of Preliminary Assessment Routine in MICADO
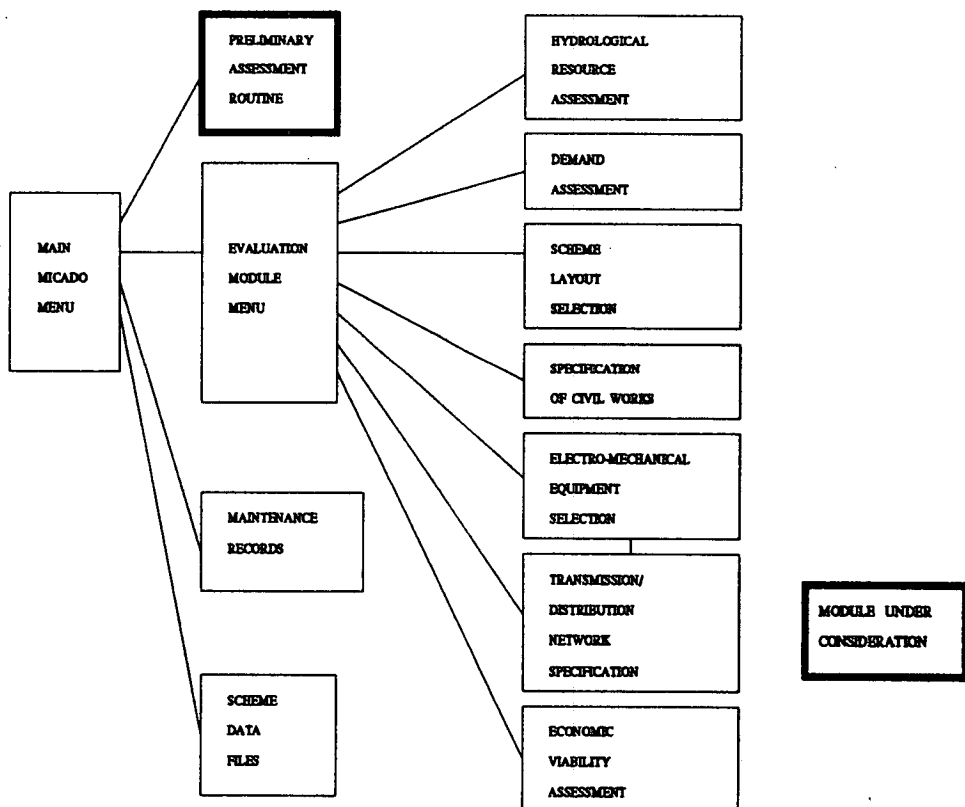
Each of the tasks included in the program is described with reference to the MICADO module which carries out the longer version.

12.1 : Preliminary Assessment of Scheme Viability

Before carrying out a full-scale assessment of the viability of a proposed scheme, it is often preferrable to compare a few configurations of the scheme to see which parameters should be varied in order to optimise scheme layout. There may be several configurations possible which are vastly different (topologically speaking), but which are not dissimilar in price. Conversely, the variation on the length of a penstock or of a transmission line can have an impact on the viability of the scheme which is far from obvious at first sight. In order that the user does not have to carry out the full evaluation of each configuration, the MICADO system contains a program (PRELIM) which allows comparison of three configurations at the same time. This can indicate which configuration should be evaluated more fully by a complete pass through the design procedure.

12.2 : Program PRELIM

Filename:	PRELIM
Program size:	102912 bytes
Number of rules:	216
Number of commands:	622
Number of variables:	141
Text space:	73kbytes

12.2.1 : General Description of PRELIM

As stated above, this program carries out a shortened version of the whole MICADO evaluation for three separate options at the same time, allowing the user to choose between them on the basis of economic advantage, or otherwise. Because this version of the evaluation takes a fraction of the time taken to run the whole of MICADO, the user can try out several options, without becoming involved in a long process. The PRELIM program, like the rest of MICADO can also be used as a training aid, leading an inexperienced user through the design process, step by step.

The program deals first of all with:

• Demand assessment

• Assessment of the potential power available at the site

• Comparison of various civil works configurations

The specifications of up to three turbines can then be entered. These are checked to see if they meet the demand entered earlier and also to see if they match the flow regimes at the site. This is followed by a routine which deals with the specification of agro-processing equipment and/or alternators.

Rough details of any transmission and/or distribution network are then requested. These are very important, as the cost of transmission lines can account for up to 50% of the total scheme cost [DCS, undated]. The economic assessment then concludes the program, allowing the user to select the most financially attractive scheme configuration from a menu.

12.3 : Demand Assessment

This rudimentary procedure begins by asking the user to enter details of the demand in up to eight blocks, specifying each with four parameters:

- rating,

- start time,

- end time and

- whether the demand is for motive or electrical power.

These are stored in an array called *ARRAY[#,#]*.

The next screen asks the user to enter the estimated percentage increase in demand over the first ten years of the scheme lifetime. This is shown in figure 12.2.

Figure 12.2 : Screen Used to Enter Percentage Increase in Demand Over Scheme Lifetime

The percentages are compounded and the resulting figures displayed to the user who can then elect either to return to the beginning of the routine or to proceed with the data entered so far. Iterative loops using the *CRYSTAL* MAX command then calculate the maximum demand for electrical and mechanical power.

12.4 : Hydrological Resource Assessment

Because this program is designed as a first "rough cut", the user inputs estimates of flow rate and head and calculates potential power from these rather than from large sets of hydrological data. The screen used to request this data is shown in figure 12.3.

Figure 12.3 : Hydraulic Data Screen in PRELIM

```
┌───────────────────────────────────────────────────────────────────────┐
│                                                                         │
│   ESTIMATED HYDRAULIC DATA                                              │
│                                                                         │
│   For the preliminary assessment of the scheme, you will be required to │
│   enter figures for head and flow rate which you think may be suitable  │
│   for the flow regime at the site in question.                         │
│   (Remember to enter zero values if you do not wish to consider any option) │
│                                                                         │
│   ┌─────────────────┐  ┌─────────────────┐  ┌─────────────────┐        │
│   │    Option 1     │  │    Option 2     │  │    Option 3     │        │
│   │                 │  │                 │  │                 │        │
│   │ Estimated Flow Rate│ Estimated Flow Rate│ Estimated Flow Rate│      │
│   │  (litres/second)│  │  (litres/second)│  │  (litres/second)│        │
│   │      8.15       │  │      8.25       │  │     ▊▊▊▊        │        │
│   │                 │  │                 │  │                 │        │
│   │ Estimated Head  │  │ Estimated Head  │  │ Estimated Head  │        │
│   │   (metres)      │  │   (metres)      │  │   (metres)      │        │
│   │     50.00       │  │     50.00       │  │     49.00       │        │
│   └─────────────────┘  └─────────────────┘  └─────────────────┘        │
│                                                                         │
│       Enter values and then press RETURN or ENTER to continue          │
│                                                                         │
└───────────────────────────────────────────────────────────────────────┘
```

The data entered here is stored in the array *hydres[#,#]*.

The estimated efficiency for each configuration is then read in and is used, together with data on the potential power available, to check if the site can supply the demand entered in the first routine.

The usual checking routines follow, with the user having the last word on whether or not the evaluation should proceed.

12.5 : Civil Works Design

This subroutine allows entry of data on the length of the canal and the penstock, together with the materials to be used in their construction and the cost per unit length of each of these. This screen is shown in figure 12.4.

Figure 12.4 : Civil Works Specification Screen in PRELIM

ESTIMATED DIMENSIONS AND SPECIFICATIONS OF CIVIL WORKS AND PENSTOCK	Option 1	Option 2	Option 3
Flow rate (litres/second)	0.15	0.25	0.22
Estimated head (metres)	50.00	50.00	49.00
Length of canal from intake to top of penstock (metres)	100.0	100.0	100.0
Length of penstock (metres) (NOTE: Penstock length should be equal to or greater than estimated head.)	52.0	55.0	50.0
Penstock material (s=steel, p=HDPE, o=other)	s	s	s

Enter values in the spaces provided and press ENTER or RETURN to continue

There is a checking loop which ensures that the dimensions are sensible, e.g. the penstock length is at least equal to the head available for each option. The cost of each configuration is computed at the end of the subroutine.

12.6 : Electro-Mechanical Equipment Selection

12.6.1 : Turbine

A turbine is selected from a menu for each configuration being considered, and for each turbine a default value is assigned for the specific speed *(Ns)*. For all three turbines the user is then asked to specify:

- design head,
- design flow rate,

- rotational speed,

- specific speed,

- power output and

- cost.   .

This screen is displayed in figure 12.5.

Figure 12.5 : Turbine Specification Screen in PRELIM

```
TURBINE SPECIFICATIONS FOR MAXIMUM DEMAND     11 kW

                              Option      Option      Option
                                1           2           3

 HYDROLOGICAL RESOURCE

 Head (metres)                50.00       50.00       49.00
 Flow rate (litres/sec)        0.15        0.25        0.22
 Potential Power (kW)         40.47       67.44       58.16

 TURBINE SPECIFICATIONS

 Type                        Crossflow   Pelton      Crossflow
 Design Head (metres)         50.00       55.00       50.00
 Design Flow Rate(l/sec)       0.15        0.20        0.15
 Design Speed (rpm)           750        1500         750
 Specific Speed              150.00       20.00      150.00
 Rated Power Output (kW)      35.00       40.00       35.00
 Cost (Rs)                   35000       37000       35000

 Enter the data for the turbines for each option in the spaces in the
         the table above. Press ENTER or RETURN to continue.
```

As the site conditions may not be the same as the conditions under which rated output is expected, the user is also asked to enter the expected efficiency and rotational speed at the site for each unit.

There is the usual menu screen for the user to decide whether or not to proceed with the data entered thus far.

12.6.2 : Agro-processing Equipment

The user is allowed to enter specifications for up to six different types of agro-processing equipment, including rating quantity, cost, name, etc. The ratings of the machines are summed, and the program tests if the demand for motive power entered earlier in this module has been exceeded. The user can decide whether to proceed with the data entered up to this point or to enter alternative data.

12.6.3 : Alternator

The alternator is specified using the parameters shown on the display of the screen shown in figure 12.6.

Figure 12.6 : Screen Used to Enter Data on Alternator

```
SYNCHRONOUS GENERATOR SPECIFICATION     CONFIGURATION   1

Input the specifications of the scheme generator in the spaces below:

         Rating (kVA)               35
         Number of phases (1 or 3)  3
         Rated generator rpm (rpm)  1500
         Voltage (V)                250
         Output frequency (Hz)      50
         Power factor               0.80
         Efficiency (%)             95
         Cost (Rs)                  95000

Type data in the spaces provided, then press ENTER or RETURN to continue.
```

The system then calculates whether or not the output of the alternator will meet the demand for electrical power. Details of drive systems are then entered, followed by data on power house accessories, and other items which are usually included on any quote which may be sent out to a potential scheme installer in Nepal.

12.7 : Transmission and Distribution Networks

For all three options the following data are requested:

- Distance from powerhouse to load centre,
- Number of wires in system,
- Line length required
- Line type and

• Line cost.

No calculations are carried out on the potential voltage losses along the line, as at this stage the aim of the program is to select the best scheme configuration for evaluation by the rest of the MICADO system.

The user is then asked to enter details of the poles required for the transmission and distribution system, together with details of any transformers and pole furniture, such as insulators and lightning arrestors. The costs are added to the total cost of the scheme so far.

12.8 : Economics

At the beginning of this section the user is asked to enter data on the expected revenue to be generated by the scheme. As explained earlier, it is assumed that the demand for electrical power will not be subject to seasonal variation, and that the monthly income from this source can be assumed to be constant throughout the year.

The income from agro-processing, is, however, expected to vary quite considerably, depending on when crops are harvested, so the income from this source is entered separately according to the Nepali calendar. The expected revenue and costs, stored in arrays throughout this program, are combined in the section which calculates the economic viability of the project.

Running costs are assumed to be a fraction (with a default value of 3%) of the total capital cost of the project, and the user is also asked if there will be any grants or other injections of cash to offset the initial costs before financial viability is assessed. The user enters the amount of any loan, together with its interest rate and payback period, and the system then calculates nett annual income and

assigns a positive or negative viability to the scheme depending on this.

12.9 : Selection of Configuration and Data Storage

The salient details of each configuration are then displayed on a menu screen and the user can then select the one which appears to give the best economic return. The details of this configuration are then displayed in greater detail, with the user being presented with the choice of either proceeding with the selection already made, repeating the selection, or returning to the beginning of the whole program.

If the program proceeds, it then carries out the data storage routine, where the data for the routine selected are stored in the file SCRATDAT on disk.

It should be noted at this point that the data stored by this module is not used subsequently in the main body of the MICADO evaluation routines. It is interrogated later by the file viewing program. The appropriate flag column variable is updated before the main menu program OPT is chained.

Chapter 13

Record Viewing

This chapter describes the record-keeping routines devised for micro hydro schemes in Nepal. Figure 13.1 shows the relation between this module and the rest of the MICADO system.

Figure 13.1 : Block Diagram Showing Location of Record Viewing Routine in MICADO
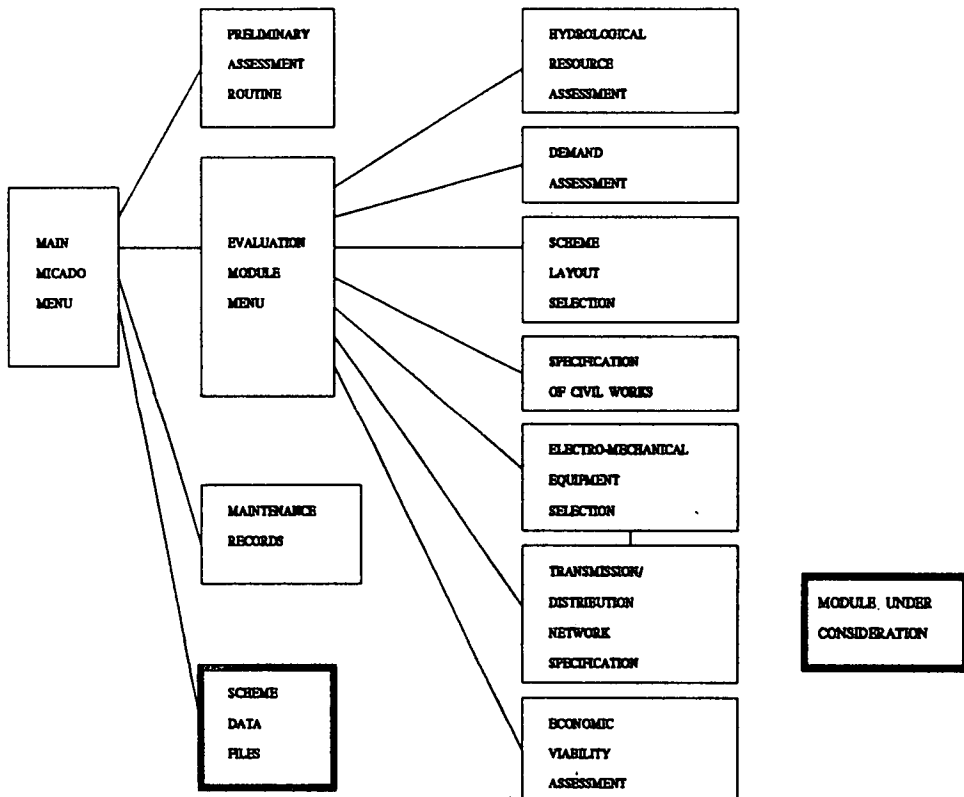
13.1 : Scheme Records

This module allows the user to view the data records for any scheme which has been evaluated using the MICADO system. Record keeping for micro hydro systems in rural areas is usually inadequate. The author was present, for instance, when an engineer returned to a micro hydro organisation in Nepal from a site situated at four days' walk from the nearest road. Because the engineer had been unable to find a record of a turbine nozzle size for that particular site, he had guessed at the component size, and on his arrival at the site found that he had made a mistake. This resulted in the waste of a week of his time.

Any records which do exist generally relate to components specially ordered for the scheme and to quotes sent out to the potential scheme owners, rather than to any systematic list made while the scheme was being constructed.

As explained in chapter 1, the lack of knowledge of the micro-hydrology of Nepal hampers the promotion of micro hydro power in general, and the need for logging hydrological estimates has been expressed [MHTAP], [Wesselink]. A system of logging the whole evaluation procedure is one way in which such a system of records can be developed.

Where surveys have been carried out at scheme sites, the information gained from them is often discarded once the scheme goes ahead. On occasion it has been discovered that alternative, and sometimes more economically viable, scheme configurations should have been considered at the early stages of a project [DCS, 1986]. In addition, where the original surveys at a site are recorded in detail, it is easier for any modifications of the scheme to be considered at a later date. It will be relatively easy to consider whether it is possible to eke another 10kW of power out of a site if the original survey data is readily available.

13.2 : Program RECORDS

Filename:	RECORDS
Program size:	95232 bytes
Number of rules:	209
Number of commands:	508
Number of variables:	84
Text space:	64kbytes

13.2.1 : General Description of RECORDS

The RECORDS program begins by using *dos* commands to change directory to the data subdirectory *subrecdir*. The user can then choose either to enter the name of a particular file or to select a file name from a menu list. If the first option is chosen then the file name must be matched with one of the files on the disk. If the second option is chosen then the list of available files must be read in from the disk.

It is then loaded into the text array *scheme$[#,#]* and displayed on a menu screen. The menu option is stored in variable *scheme* and the program then loads the correct name into the *getfile$* variable using the command line:

$$getfile\$ = scheme\$[scheme - 1]$$

The correct file is copied onto the SCRATDAT file, and the system loads in and displays the basic scheme details before moving onto the main menu of the program. This is displayed in figure 13.2.

Figure 13.2 : Menu Screen for RECORDS Program

```
  ┌─────────────────────────────────────────────────┐
  │ SCHEME FILE NAME: SCHAIDAT                       │
  └─────────────────────────────────────────────────┘

    ┌──────────────────────────────────────────────────┐
    │    MENU                                            │
    │    Preliminary assessment of site                 │
    │    Hydrology of site                              │
    │    Demand estimation (including projected increase)│
    │ ■4■ Tarriff and monthly income estimates          │
    │    General data on civil works                    │
    │    Mechanical equipment specifications (if applicable)│
    │    Electrical equipment specifications (if applicable)│
    │    Electrical transmission/distribution system (if applicable)│
    │    Economic assessment of scheme                  │
    │                                                    │
    │    Leave Menu                                      │
    └──────────────────────────────────────────────────┘
    You may now view any data screens from the list of options above.
          Use cursor keys to move to correct option,
```

13.3 : Record Viewing Screens

As can be seen from the menu displayed at the end of the previous section, the program displays information to the user according to which module of the MICADO system was used to collect the data. Selecting the majority of the options in the menu shown in figure 13.2 will result in the user viewing a series of information screens, and then being returned to the menu. All the options which concern electrification are only available to the user if electric power is actually produced at the scheme under examination. The program tests for this by reading the variable *useelec*. The exception to the procedure described above is the option to view the information on the transmission and distribution network for a micro hydro-electric scheme. This is accessed via a secondary menu, which is displayed in figure 13.3.

For each of the options displayed in this menu, the user is taken through a series of data screens such as that displayed in figure 13.4.

Figure 13.3 : Menu Used to Access data on Transmission Network of Scheme

```
┌─────────────────────────────────────────────────────────────┐
│  ╔═══════════════════════════════╗                           │
│  ║ SCHEME FILE NAME: DEMO1       ║                           │
│  ╚═══════════════════════════════╝                           │
│                                                               │
│        DATA ON TRANSMISSION AND DISTRIBUTION NETWORKS         │
│                                                               │
│   There is a large amount of data on the transmission/distribution│
│   network. You may or may not wish to view all of it at one time.│
│   Select the data screen you wish to view from the list below:│
│     ┌─────────────────────────────────────────────────────┐ │
│     │ 1    Basic parameters of transmission network        │ │
│     │ 2    Line specfications for transmission network     │ │
│     │ 3    Transformer specifications (if applicable)      │ │
│     │ 4    Transmission pole specifications                │ │
│     │ 5    Basic parameters of distribution network        │ │
│     │ ■6■  Line specifications for distribution network    │ │
│     └─────────────────────────────────────────────────────┘ │
│                                                               │
│        ╔═══════════════════════════════╗                     │
│        ║ 7    Return to main menu      ║                     │
│        ╚═══════════════════════════════╝                     │
│                                                               │
│        Use cursor keys to move to the option you require,     │
│         then press ENTER or RETURN to enter your selection.   │
│        You will be returned to this menu after each data screen.│
│   (Select Option 7 to return to the menu dealing with the whole scheme.)│
└─────────────────────────────────────────────────────────────┘
```

Figure 13.4 : Information Screen from Transmission/Distribution Section of RECORDS

```
┌─────────────────────────────────────────────────────────────┐
│  ╔═══════════════════════════════╗                           │
│  ║ SCHEME FILE NAME: A           ║                           │
│  ╚═══════════════════════════════╝                           │
│   TRANSMISSION/DISTRIBUTION DATA SCREEN 4: GENERAL DATA ON TRANSMISSION POLES│
│                                                               │
│   ┌POLES─────────────────────────────────────────────────┐  │
│   │Pole supply : Poles supplied locally                   │  │
│   │Number of transmission poles:              16          │  │
│   │Number of trees used as transmission poles: 3          │  │
│   │Total cost of poles (Rs) :                   8         │  │
│   └───────────────────────────────────────────────────────┘  │
│                                                               │
│   ┌SPANS─────────────────────────────────────────────────┐  │
│   │Number of spans crossing open ground:       12         │  │
│   │Number of spans running beside motorable road: 2       │  │
│   │Number of spans crossing motorable road:    2          │  │
│   └───────────────────────────────────────────────────────┘  │
│                                                               │
│                                                               │
│                  PRESS ANY KEY TO CONTINUE                    │
└─────────────────────────────────────────────────────────────┘
```

13.4 : Return to main MICADO menu

At the end of this module the user selects EXIT from the program menu. This returns the user to the main MICADO menu, by chaining the SMFT program.

Chapter 14

Maintenance Logging

In addition to the lack of records on the state of the original scheme at the commissioning date, micro hydro organisations in Nepal rarely have systematic methods for logging maintenance and upgrading activities which can be carried out subsequently.

Figure 14.1 : Block Diagram Showing Location of Maintenance Record Routine in MICADO
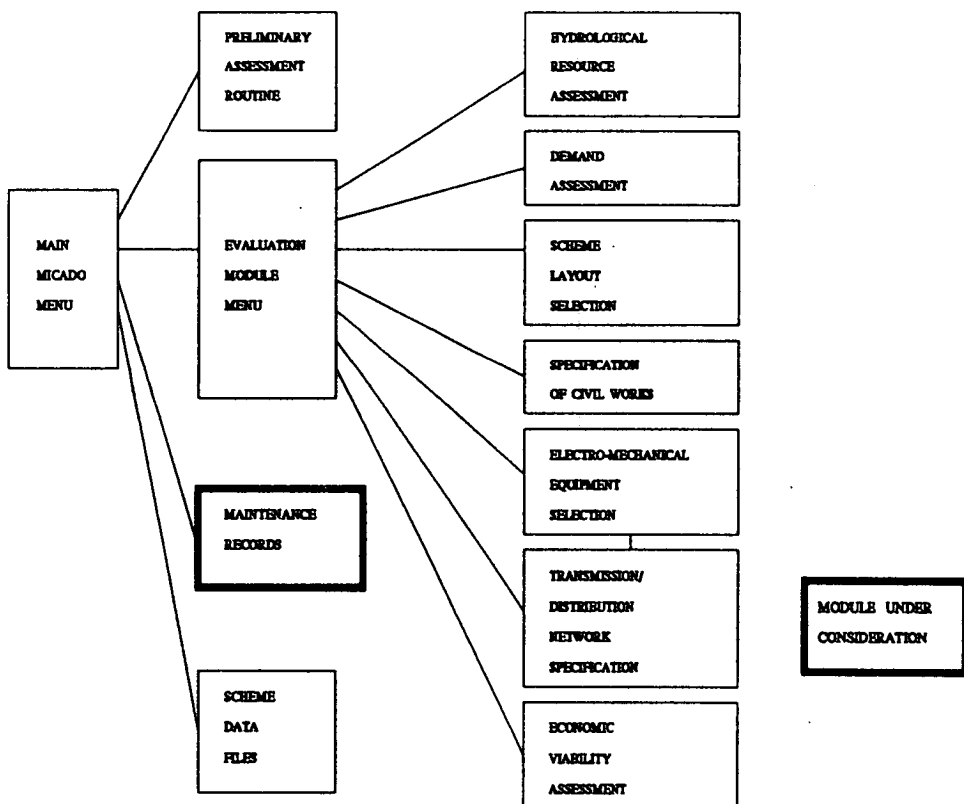
This chapter describes the MAINTAIN module of MICADO, which has been designed to facilitate the preparation of maintenance reports. (See figure 14.1 for

a block diagram showing the location of MAINTAIN within the MICADO system.)

14.1 : Maintenance Logging

This module enables the user to write, read and ammend maintenance records for a scheme on which the system already holds a data file. Maintenance problems account for a large proportion of the time during which micro hydro schemes are inoperable [Meier]. Because of the remote location of most of the schemes in Nepal, and because of the low level of expertise among scheme operators, simple faults often cannot be repaired by local labour and the scheme installers will be asked to send trained personnel to the site.

Other problems can be introduced at this stage, especially if the message from the scheme operator is vague, or records of the scheme design and component lists are unavailable. Most of the personnel interviewed by the author in Nepal stated that the lack of maintenance records was a major hindrance to the promotion of micro hydro in the country. They requested that a routine for creating, viewing and updating maintenance records be included in the MICADO system.

14.2 : Program MAINTAIN

Filename:	MAINTAIN
Program size:	57344 bytes
Number of rules:	75
Number of commands:	232
Number of variables:	35
Text space:	33kbytes

14.2.1 : General Description of MAINTAIN

Data from each scheme evaluation which has been carried out is stored in the data exchange file SCRATDAT as the evaluation proceeds. At the end of the evaluation the data exchange file is written to another file, with the same format, which is assigned a name particular to the scheme. This module operates by manipulating data which is stored in columns in a designated area of the scheme data files held on disk.

The program MAINTAIN begins by operating *dos* command which changes the directory to the records subdirectory *subrecdir*. The names of the data files stored there are then called in from the disk and displayed on a menu screen, as in the RECORDS module. When a particular scheme is selected, the system loads in basic data on the scheme (including scheme name and location and owner's name). Included in this is the variable *vcount*, which is used as a counter for the number of maintenance records stored for the scheme. The variable *vcount* is incremented every time a new entry is made.

The basic data is displayed to the user, and the program then loads in data from the "noticeboard" area of the scheme file. This is an area where users can leave short messages, either to themselves or to any other user who may access the maintenance records. Having read the noticeboard, the user is then taken to the main menu of the program as a whole. This is shown in figure 14.2.

Figure 14.2 : Menu for MAINTAIN program

```
 ┌─────────────────────────────────────────────────────────────┐
 │  ╔══════════════════════════════════════════╗                │
 │  ║ SCHEME FILE NAME: DEMO1                   ║                │
 │  ╚══════════════════════════════════════════╝                │
 │                                                               │
 │  ┌─────────────────────────────────────────────────────────┐ │
 │  │       MENU                                               │ │
 │  │  1.  View records of previous maintenance visits/operations│ │
 │  │ ■2■  Make record of new visit/operation                  │ │
 │  │  3.  Ammend record of previous visit/operation           │ │
 │  │  4.  Update noticeboard file                             │ │
 │  │  5.  View records for another scheme                     │ │
 │  │  6.  Exit                                                │ │
 │  └─────────────────────────────────────────────────────────┘ │
 │       You may now carry out any of the operations displayed above. │
 │            Use cursor keys to move to correct option,         │
 │             then press ENTER or RETURN to continue.           │
 └─────────────────────────────────────────────────────────────┘
```

The main menu contains the six options listed below:

1. View maintenance records,

2. Make new record,

3. Ammend record,

4. Update noticeboard,

5. View records for another scheme and

6. Exit.

These are described below.

14.3 : View Maintenance Records

The program uses the *vcount* variable as an offset to determine the area of the data file which should be read into the memory of the machine. The area holding the dates of the entries and the names of the personnel who entered the data is loaded first, and displayed on two menu screens. Each data file can hold up to 33 entries in the maintenance section and the user can choose to view any entry on the list. The menu variable *view* is used as an offset in the data loading routine so that the correct maintenance record is entered.

The entry is then displayed to the user on another menu screen, which offers three options:

    1. View another record for this scheme,

    2. Return to main menu or

    3. Restart whole program.

14.4 : Make New Record

This option allows the user to make a new entry in the maintenance section of the data file. The first screen presented to the user requests the date of the entry and the name of the person making the entry. The data is stored in the text array *maint$[#,#]*. The second screen contains a large area for text entry, where the user can type details of any maintenance action carried out or make any nots on the scheme components. repair of a scheme component. This data is stored in the text array *detail$[#,#]*.

The next screen is a menu and displays the data entered so far, together with three options:

1. Save data entered,

2. Enter different data or

3. Return to main menu without saving data.

14.4.1 : Save Data Entered

This particular routine stores the arrays *maint$[#,#]* and *detail$[#,#]* in the scheme data file. Before it can do this, the user must enter the current system password and the password is checked using the routine described in the previous chapter.

The program then increments the counter *vcount* and uses this as an offset to identify the column of the data file to which the array should be written, up to column 31. If the counter is greater than 31, the user can choose to overwrite a previous entry or to return to the main menu without saving the data.

14.4.2 : Enter Different Data

This subroutine returns the user to the original data entry screens, with the exception that the arrays *maint$[#,#]* and *detail$[#,#]* are not cleared before the screens are called up. The user can then overwrite the data entered previously.

14.5 : Ammend Record

The first part of this routine loads in and displays data for the maintenance entry selected in the same way as the "View Maintenance Records" option. The screen menu then allows the user either to view another record, to ammend the record shown or to return to the menu. The first and last options are as described above, the second involves the data being loaded into a text array and dislayed on the screen so that the user can overwrite the particular array elements which must be changed.

When the overwriting is complete the entry is displayed on a menu screen allowing the user to:
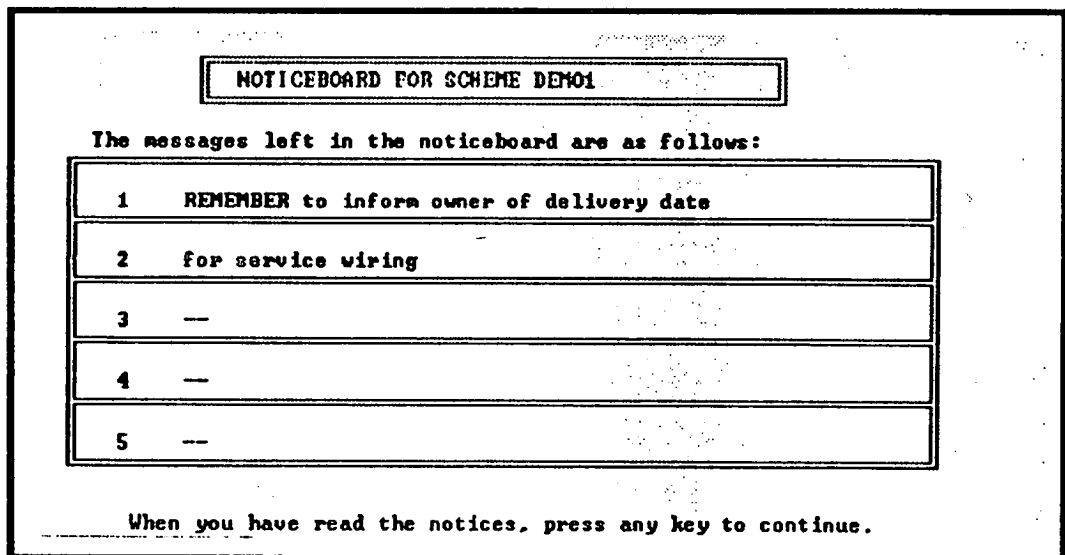
1. Save the data shown,

2. Enter different data or

3. Return to main menu.

These three options call on program code which has been described previously.

14.6 : Update Noticeboard

This particular option allows the user to leave messages and notes on the system noticeboard. An example of a noticeboard entry is given in figure 14.3.

Figure 14.3 : Example of a noticeboard screen in MAINTAIN

```
┌─────────────────────────────────────────────────────────────┐
│        ┌──────────────────────────────────────────┐          │
│        │  NOTICEBOARD FOR SCHEME DEMO1            │          │
│        └──────────────────────────────────────────┘          │
│    The messages left in the noticeboard are as follows:      │
│   ┌──────────────────────────────────────────────────────┐   │
│   │  1    REMEMBER to inform owner of delivery date      │   │
│   │  2    for service wiring                             │   │
│   │  3    —                                              │   │
│   │  4    —                                              │   │
│   │  5    —                                              │   │
│   └──────────────────────────────────────────────────────┘   │
│      When you have read the notices, press any key to continue. │
└─────────────────────────────────────────────────────────────┘
```

The user is first presented with a **YES/NO/MORE INFORMATION** question, where the **MORE INFORMATION** option takes the user through a series of information screen and then reiterates the menu, and the **NO** option returns the user to the main menu for the whole module.

The **YES** option displays the current noticeboard messages in a format in which the user can overwrite them with any other text. This is followed by the usual menu routine which allows the user to save the entries, if required.

14.7 : View Records For Another Scheme

At the beginning of this routine the program calls on code which was used at the very beginning of the module. The dates of the maintenance record entries, together with the names of the people who made the entries are displayed to the user, and the program moves back to the top of the whole program.

14.8 : Exit

The program concludes by returning to the main MICADO menu module, as described in the chapter on the RECORDS module.

Chapter 15

Feedback, Recommendations and Conclusions

This chapter is concerned with the reception which MICADO received from its intended user group and suggests ways in which the feedback from the user group could affect future work in this field. The chapter concludes the thesis with an assessment of how far this project has succeeded in fulfilling its initial aims.

15.1 : Feedback

Various versions of the MICADO software have been tested by personnel in the following organisations.

- Overseas Development Administration, R & D Section (UK)

- Overseas Development Administration, Power Section (UK)

- Intermediate Technology Development Group (UK)

- Intermediate Technology Development Group (Nepal)

- Fachstelle Fur Kontextegerechte Technik (Germany)

- German Appropriate Technology Exchange (Germany)

- Developing and Consulting Services (Nepal)

- Agricultural Development Bank of Nepal (Nepal)

- Balaju Yantra Shala (Nepal)

- Scottish Hydro-Electric (Scotland)

- University of Edinburgh (Scotland)

- Napier University (Scotland)

- Queens University of Belfast (Northern Ireland)

The feedback from academics and workers in mainstream engineering organisations in the UK is useful in that it validates the expertise included in the system. The responses of primary interest to this project, however, are those of the user group in the field of micro hydro power in Nepal.

As observed in chapter 3, many of the people to whom the system was demonstrated were initially sceptical about the idea of using AI techniques in micro hydro scheme design. However, on the whole, their initial trepidation was replaced by growing interest and even enthusiasm, once they realised that the software could be designed to their own specifications, or that it carried out tasks which they recognised as time-consuming or error-prone.

Despite the self-explanatory screens used throughout the system, and the clear and non-technical manual, users were still unsure as to whether they were running the system "correctly". Observations revealed that they were in fact running the system exactly as it had been designed to run, but that the users were not confident of their ability to use the technology. It should be noted here that younger workers, who are perhaps more familiar with computers, had less trouble in this area.

In all cases the users expressed an interest in tutorial sessions, either lasting a full day or a few hours, to "introduce" them to the system. This is being pursued as a method of establishing confidence in the user group, rather than a way of actually teaching them how to use a system which they can already operate without mishap.

Users who were experienced in micro hydro scheme design, or who had expertise in one of the specialisms included in the system found it quite chafing that the software would not allow them to "skip through" sections so that they could quickly look at the topic which they thought they would find particularly interesting. Although they made requests that they should be allowed to do this, it was considered imprudent to install an "override" facility in future versions of the software. One of the main concerns in the initial stages of constructing the MICADO system was that it should take a first step towards standardisation of the methods by which micro hydro power schemes are designed. It is unlikely to do this if it allows engineers to cut out sections of the design path which they find irksome or boring.

All the experienced workers who tested the system were very keen to use the preliminary assessment routine. They found that the "What-If" facility this provided gave them time to experiment with more scheme configurations than usual.

They were also keen to use the record keeping and maintenance logging routines. The maintenance logging program was especially popular because it allows notes and observations on any scheme to be entered in natural language.

There is no data yet available on how the MICADO system has actually supported the design or installation of micro hydro schemes in Nepal. This is because, as stated previously, it is usual for a period of three to five years to elapse between the initial survey and the commissioning of the scheme.

15.2 : Recommendations

15.2.1 : The MICADO System

In the field of using AI techniques to support the design and installation of micro hydro schemes, there are several approaches which could be used to improve the performance of MICADO, or perhaps to re-specify the system to some extent.

The first of these concerns the hardware constraint on the software. The initial aim of maximum portability resulted in the software being made available to as many users as possible. However, the wisdom of taking the lowest common denominator in the hardware in order to ensure maximum portability should now be questioned. The MICADO system will run on a wide range of machines, including some which are virtually obsolete. Running the software on these machines takes considerably longer than it does on more up-to-date hardware, and the programs are therefore hardly the design tool they were intended to be in the first instance.

Future versions of the MICADO system should therefore be implemented to run on a more restricted range of machines. While the aim of keeping the user group as wide as possible should be maintained, this should be balanced with the need to streamline the programs. It should also be ensured that the machines have a more sophisticated level of graphical representation available to them, which would allow the inclusion of routines with the ability to sketch site layout, the lay-out of powerhouses, and the configuration of any transmission and/or distribution networks which may be included in the system. These would be an asset for any organisation where staff turnover means that workers making site visits for maintenance and repair work are unlikely to be the ones who installed and commissioned the system.

Using the Nepali calendar and Nepali Rupees throughout the system served the intial purpose of making the software user-friendly in one particular country. However, it also served to make it less applicable in other countries. Future versions of the system should be standardised so that they have a wider range of application worldwide. Country variations should either be removed altogether, or, preferrably, version of the software should be tailored to suit the particular country of application. Some steps towards this are already being taken, as discussions are underway with workers at the Intermediate Technology Development Group on the possibility of translating the system screens into Spanish to support their micro hydro work in Latin America.

The possibility of including a "bolt-on" routine should also be considered, where users can enter calls to programs they have written themselves. The system can then be tailored to suit specific individuals and organisations.

15.2.2 : Computing and Development

There is a need for communication between the world of mainstream engineering and organisations concerned with technology and development. These organisations can provide the link between technologically advanced nations and regions of the world which do not have access to the benefits of modern society. They are also, to some extent, a pressure group which can raise awareness of the needs of the developing world in the developed world, and in fact they often need to do so to raise funds to ensure their own survival.

It is ironic, therefore, that in some of these organisations, there is an intellectually un-rigorous approach to technology in general. The same individuals who are incensed at the under-utilisation of a resource such as hydro power, solar power, or the technological wisdom of rural people will think nothing of using a laptop as a word-processor, with little regard for the use to which their computing resource might be put. While in some cases this will be hidden by luddite invective against technology in general, in most cases, the individuals who work in these

organsiations do not have the time to consider whether their own use of technology is itself "appropriate".

Personnel in aid organisations in developing countries are bombarded daily with human misery and need. Usually they are working in such organisations because they wish to alleviate such distress. In the face of this distress it is often common to find workers remain in the organisation for only a few years, during which time they struggle to achieve as much as they can before they suffer "burn-out". It remains to the workers who stay long enough to achieve managerial positions within such organisations to ensure that the indulgence of dismissing new technologies (such as Expert Systems) because they are intimidating or unfamiliar is not allowed, especially when such developments could be precisely what is required to alleviate the suffering of their target group.

Conversely, there is also a need for education within mainstream engineering organisations. If it is the task of engineering to improve the lot of humanity, in differing cultures this can have vastly different meanings. In the developed world the consumers' and the share-holders' needs are paramount, and engineering is directed towards generating capital for further investment and stimulation of our growth economies. In our society, millions can be spent on developing cars which are faster, safer and kinder to the environment, or an exotic tasting yoghurt with just the right "mouth feel". In the rural areas of developing nations, however, the lot of humanity is improved by technological advances as basic as the use of a length of rubber hose to provide a gravity-feed water supply which by-passes a village latrine area. The disparity in the resources available at such levels could be off-set, to some extent, by the more efficient application of expertise from mainstream engineering in developing countries.

15.3 : Conclusions

This project set out to examine the appropriateness of using AI techniques in developing countries, with specific reference to micro hydro power schemes in Nepal. It has ranged without prejudice through the full spectrum of the uses of technology in society. It has involved investigation of applications as far apart as wooden water wheels and AI, with the view that each of these applications is appropriate to vastly different sets of human experiences. Unlike the majority of engineering research projects, which are narrow in their field of enquiry, this project has been eclectic in scope. This is in fact its main strength.

In each of the subjects which have been drawn together to synthesise this application, much more information and expertise exists than could be incorporated into the DSS. The restrictions applied by the user group were taken to be paramount at all times throughout the project. This meant that the indulgence of producing a system which was interesting and intriguing in a laboratory situation, but which was too fragile to operate in the real world, on a laptop at an altitude of 14 000 feet, could not be taken.

To attempt such a task it was absolutely essential to carry out a period of field-work. Living conditions in the developing world must be experienced before it is possible to begin to understand the restrictions these impose on even the most simple everyday tasks. Equally, it is only after visiting sites at five days walk from the nearest jeep track, or visiting engineering workshops where mild steel cannot be obtained because of trade problems with India, that the constraints on design specifications can be understood. If a person or a mule cannot carry components such as a turbine or a coil of transmission line to a remote site, then even the most appropriate design cannot be realised in practice.

Perhaps more interestingly, this project has shown that AI techniques can be used in hostile conditions in developing countries, and that they are not restricted to

the ivory tower of academia, or to the laboratories of leading technological giants for their field of application. It has demonstrated that it is possible to use these techniques, probably to great effect, elsewhere in the "aid business", but that this will only take place on any significant scale if the gulf between mainstream engineering and the pragmatic world of technology transfer in developing countries is bridged. It has shown that "Appropriate Technology" is a term that can cover far more than the "bamboo-and-string" approach to engineering, and that Artificial Intelligence can be an appropriate technology in a developing country.

As a computer system which will go some way to improving the lot of the rural poor in one of the poorest countries of the world, MICADO demonstrates that this is the case.

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APPENDIX 1

MICADO Manual

MICADO

VERSION 2.2

DRAFT MANUAL

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MICADO
is available without charge to organisations
concerned with the promotion of Micro Hydro power
in developing countries who are in possession
of a CRYSTAL runtime system.

1. Introduction

This manual is designed to help you to use the MICADO system.
It will

- Introduce the MICADO software,

- Tell you what MICADO can do,

- Explain the set of disks which comes with this manual,

- Specify which computers MICADO will run on,

- Tell you how to get MICADO started.

When you have read this, you will then be able to run through the sections of the manual dealing with the way in which MICADO communicates with you, the user, the way in which it asks for information, and the ways in which you can enter data.

Finally, the manual will describe the ways in which data entered by the user is stored, and how it can be used in the future.

You should note that MICADO is designed to communicate effectively with you as it is running, and full instructions on how to proceed are given on each screen, so once you are familiar with the system, you probably will not need this manual at all.

2. About MICADO

2.1. What can MICADO do for you ?

You have just received a system of Decision Support Software which is designed to help you in your evaluation and design of Micro Hydro schemes in developing countries.

The version which you have received has been specified with Nepal in mind, although it can be used for other countries, with care.

The software is NOT designed to replace an experienced engineer with much of the expertise required to specify Micro Hydro schemes, but aims primarily to provide technical and administrative support to just such an engineer, who may be working without the support of a large organisation of fellow engineers and adminstrative assistants.

The software can also be used to evaluate the financial feasibility of proposals for Micro Hydro installations, and therefore is of use to officials of agencies who may be considering the relative merits of several of such proposals, with a view to granting funding or loans for the development of the proposed sites.

2.2. What does the software do ?

MICADO communicates with you, the user, throughout any evaluation, and will demand a lot of data from you as it carries out the engineering and economic calculations required to assess Micro Hydro site feasibility.

The program is split into separate sections, which are distributed between the disks you have received according to convenience for the user.

2.3. The disks and the machines.

To run this software you will need an IBM-compatible Personal Computer (PC), running DOS version 2.0 or later. You will need a VDU, preferrably with an EGA graphics adapter. (CHECK!!). Although this is not essential, it will make it easier for you to read the information screens which the program will display from time to time.

You have been supplied with three 3.5 inch microfloppy diskettes which hold the program code.

You will need a PC-compatible machine with at least one 3.5 inch drive and a hard disk.

If you want to use a printer to make paper copies of any of the information which MICADO stores, you will have to configure your printer before you begin to use the program.

3. Starting up.

3.1. PC-compatible with hard disk and at least one 3.5 inch disk drive.

The best way to run the program, if you have a hard disk available, is to load the system onto the disk and run it from there, rather than from the 3.5 inch drive.

To do this, you should first copy the system over onto the hard disk.

The program is written to run from a directory called "MICADO", so if you do not copy the programs into a directory with this name, you will find that it will not run.

The MICADO system prefers to store data in a directory called "DATA", although this is not absolutely necessary. If you wish to store data in a directory with this name (or any other name), you should remember to create this directory, or check that it exists before you try to run the system.

NOTE that the directory "MICADO" and the data directory (regardless of its name) should BOTH be in the ROOT DIRECTORY of your hard disk.

When your system is copied over, you should change directory to the "MICADO" directory, then type

                    "LTCR /XRUN"

and press the ENTER or RETURN key.

After this, you can proceed through the program by following the instructions which are displayed on the screen.

3.2. PC-compatible with two 3.5 inch drives.

NOT APPLICABLE TO VERSION 2.2 OR EARLIER.

You should begin with your computer switched off, and program disk number 1 in the boot drive for the system (usually drive A).
Switch the machine on and wait for the prompt >.
Type "RUN" and press ENTER or RETURN key.
After this, you can proceed through the program by following the instructions which are displayed on the screen.

3.3. Other disk configurations.

NOT APPLICABLE TO VERSION 2.2 OR EARLIER.

Although every care has been taken to ensure that the programs will run on any PC-compatible, you should note that when you are running the programs on any non-standard disk drive configurations you may have to exchange floppy disks while the system is in operation.
After this, you can proceed through the program by following the instructions which are displayed on the screen.

4. Preliminary Points.

4.1. First Screens.

At the beginning of the program you will see the MICADO logo and a picture (if you have a suitable graphics adapter) of a "typical" Micro Hydro scheme. You should press any key to move from these screens to the rest of the program.

4.2. New or Old Data.

At the beginning of the program you will be asked if you want to look at totally new data, e.g. consider a scheme for which you have no data in a record file, or whether you want to look at data which is already stored in a data file ("old" data).

You can choose to look at "new" data files if you wish to consider a scheme for which you have no data file, or if you wish to consider a scheme for which you wish to create a new data file.

NOTE that if you want to *view* record files and/or maintenance records, then you should select the "new" data option at this point, (i.e. you should select the option which doesn't load a data file into the system).

When you have selected this option, the system will then take you into the Main Menu.

You can choose to look at "old" data if you intend to finish an

evaluation which wasn't completed on a previous run, or you wish to change data in a file which already exists.

The system will then load in a list of the data files available, and you can select the appropriate file from the list.

When you have chosen this data type, the system will take you straight into the Subsidiary Menu.

4.3. Displayed Values.

When you are running the program you will come across spaces for data entry which have values already in them. These are values which have been entered on previous runs of the program. You can type over these if you wish to enter alternative values, or you can press ENTER or RETURN if you wish to enter the value displayed.

5. The Menu System.

5.1. The Main Menu.

The whole program is managed by a central menu system (known as the Main Menu), which allows you to move between different sections of the evaluation process.
To choose any of the options on the Main Menu, you should use the cursor keys until the highlight bar shows the option you wish to select. You should then press the ENTER or RETURN key.

5.2. The Subsidiary Menu.

From the Main Menu, you will find that you can move either to a preliminary evaluation programme, to Data file or Maintenance file viewing, or into a Subsidiary Menu which will ask you to select further options. The menu system has this structure so that is easy to see on the screen, and also because it is then easy to move between tasks of equal priority.

6. Interacting with the program.

6.1. "Press any key to continue"

When you see an instruction like this on a screen (it will usually be written along the bottom of the screen), you should press any key when you have FINISHED looking at the screen being displayed at that time.

6.2. "Press ENTER or RETURN to continue"

When you see an instruction like this on a screen (it will usually be written along the bottom of the screen), you should press the ENTER or RETURN key when you have FINISHED looking at the screen being displayed at that time.

6.3. Yes/No Questions.

When you see a question which requires a Yes/No answer, you should either move the cursor to the YES or NO box displayed on the screen, and then press the ENTER or RETURN key to enter your selection, or you should press the "Y" or the "N" key, depending on which option you are selecting.

6.4. Menu Screens.

When you are presented with a menu screen, it will offer you a list of options, and you will have to select the one which most closely matches the answer you want to give to the question on the screen. Where the options do not match your

answer exactly you should choose the nearest answer available. To make your selection, move the highlight bar with the cursor keys until it indicates the correct option. Then press ENTER or RETURN to enter your selection.

6.5. "Enter a value/letter"

When you see an instruction like this on a screen (it will usually be written along the bottom of the screen), you should type the answer(s) to the question(s) in the space(s) provided.

If one variable is required, type the data in to the answer box and then press ENTER or RETURN to continue.

Where more than one variable is required, you can move around the answer boxes using the "UP" and "DOWN" cursor keys. To move to the next screen, you should press the ENTER or RETURN key when the highlight bar is indicating the LOWEST data entry space at the most RIGHT HAND position on the screen.

6.6. Indicate relative value on a gradual scale.

This occurs infrequently in the program, and because of the way the program leads you through a "Tree" structure, you may never actually come across the particular screens which use this method of data entry.
If you do need to enter a data value in this way you should first of all think carefully about the question being posed and assess how you would place the answer on a scale of 1 to 10,

or 1 to 20, or whatever the particular scale being displayed allows you to choose.

You should then move the cursor in the left to right direction across the screen, until it reaches the position on the scale which best reflects your answer. (If you overshoot, you can move back until you reach the correct position). You should then press ENTER or RETURN to enter your selection.

6.7. Entering data in tables.

To enter data into tables, you should use the "UP" and "DOWN" cursor keys to move around the screen. Enter data in the boxes provided, in response to the questions posed at the beginning of the screen. To move to the next screen, you should press the ENTER or RETURN key when the highlight bar is indicating the LOWEST data entry space at the most RIGHT HAND position on the screen.

7. Finishing the program.

7.1. Data Storage.

When you decide to leave the program, go to the menu which is controlling the section of the program you are running and select the "EXIT" option displayed there. (This will usually be at the bottom of the menu list.)

If you are in the Subsidiary Menu, this will return you to the Main Menu, where you should again select the "EXIT" option. The EXIT option of the Main Menu will then ask you if you want to save the data from the scheme evaluation you have been running.

You can save complete files, for future reference, or you can save files for partially completed evaluations, if you wish to complete the process at a later date.

If you wish to write over files which have already been saved, the system will ask you for a password.

The system password is "hello".

If you wish to change this password, you should follow the instructions provided by the program.

8. And Finally....

MICADO is a new piece of software, and as such will be prone to the inevitable bugs and teething troubles which plague such systems.
If you come across *any* problems with the program, you can contact Teresa Anderson at the University of Edinburgh, (see address details on front page) and she will try to help.

Additionally, if you have any comments or suggestions for subsequent versions of the system please send them to Teresa Anderson via the same channels.
The could help to make MICADO more useful for you and for other people.

If you would like information on or copies of any subsequent versions of the system, please include your name, affiliation and full contact details.

APPENDIX 2

Questionnaire

MICROHYDRO DESIGN QUESTIONNAIRE.

SECTION 1: SITE VISIT.

1/.   In which order do you make your scheme assessment ? i.e. head/flow survey followed by demand estimation, or vice versa.

2/.   How would you set about making your estimate of domestic demand for electricity ?

3/.   What would you expect the lighting demand to be per household (in Watts or kW) ?

4/.   Would you expect cooking to form a major fraction of the total domestic demand ?

5/.   If so, what would you expect the cooking load to be per household (in Watts or kW)?

6/.   How would you estimate any other demand, either for electrical or mechanical power ?

7/.   Would your survey usually include some estimate of the increase in demand which is likely to occur over the lifetime of the scheme ?

8/.   How would you go about estimating this increase ?

9/.   How would you estimate the lifetime of any scheme ?

10/.   When estimating the load on a scheme, are you likely to use a method which plans the load pattern for 24 hours ? If so, which method are you likely to use ?

11/. Which method(s) would you use for measuring/estimating the head ?

12/. What confidence limits would you give the method(s) ? e.g. +/- 10%, 20%.

13/. Which method(s) would you use for measuring flow rate ?

14/. Again, what confidence limits would you give the method(s) ?

15/. Would you use the same methods for measuring dry season flow ?

16/. How would you correlate the values obtained from your measurements with the flow regime of the river/stream in previous years ?

17/. Would you refer to any hydrological/climatic tables for the region/river in question ?

18/. Would you estimate the amount of siltation likely to occur during the operation of the scheme?

19/. How would you go about this, and what criteria would you use to judge the size of silt particles, etc. ?

20/. If you do not think this is necessary, could you explain why not ?

21/. Would you select materials/suitable components during the site visit ?

22/. Would you expect the design of the penstock/civil works configuration to be largely ,or in part, determined by materials locally available ?

23/. How would you estimate the suitability of locally available materials for canal lining, powerhouse construction, penstock construction, transmission poles, etc. ?

24/. Would you expect local workers to carry out all or some of the civil construction work?

25/. Would you expect local workers to carry out wiring and installation work ?

26/. How would you estimate the ability of local workers to carry out work ?

27/. Would you expect transportation costs to be a constraint on choice of materials/components ?

28/. Would you investigate land/water rights and their possible effect on the scheme during the site visit, or would you ask a local person to fill you in later ?

29/. Do you have a systematic way of inquiring about land/water rights ?

30/. Do you make any decision about transmission/distribution system configuration on-site, or is this done solely wth the aid of cost sheets/specification lists etc ?

SECTION 2: CALCULATIONS.

31/. What method(s) do you use for calculating the variation in the power available from the river/stream ?

32/. What confidence limit would you give to the method(s) of calculation ?

33/. How would you select the design flow/exceedance for the scheme ? (does this take into account water/land rights, how tolerant local folks will be of dim lights during seasons of low flow , etc. ?)

34/. How do you calculate the dimensions of the power canal ? (Does your method rely on tables of maximum velocity allowed to avoid erosion, limiting values for side slopes, etc. or do you use a more intuitive method ?)

35/. How do you calculate power/head losses along the power canal ? (Alternatives to using Mannings Coefficient calculations etc. or do you use a more intuitive method for this too?)

36/. Do you make any allowance for flow losses due to seepage from the canal etc. ?

37/. Would you include a settling basin/trashrack, etc. in most schemes ? Why ? or Why not ?

38/. How would you select the dimensions of any settling basin which would be included: (do you use mathematical formulae or guesswork) ?

39/. How would you calculate the number of bags of cement and amounts of sand, rubble etc. required for the construction of the power canal, settling bay, spillways, etc. ?

40/. How would you calculate the number of mandays required for each section of the civil works construction ?

41/. What factors affect your choice of penstock material ?

42/. How would you calculate the dimensions of the penstock pipe ?

43/. What error margin do you expect for your method of selection/calculation ?

44/. How would you assess the maximum pressure surge which the pipe can be economically designed to withstand and how would you select pipe thickness on the basis of your assessment ?

45/. What is your confidence limit for this method ?

46/. What method would you use to specify the flange sizes for the penstock ?

47/. How would you assesss the number and position of any anchor blocks which may be required?

48/. Would you expect the penstock to be constructed exactly or approximately to your specifications ?

49/. How would you calculate losses in the penstock ?

50/. What is your confidence limit for this method ?

51/. On what basis would you include spillways/ sluice gates/ in your scheme design ?

52/. Would you use the same methods for assessing the quantity of materials/ number of mandays required for their construction as you did for the rest of the civil works ?

53/. What are the main factors you take into account when selecting a turbine for a scheme?

54/. What are the main factors you take into account when selecting an alternator for a scheme ?

55/. How do you select the drive method for the scheme ?

56/. How would you select/design the governing system for the scheme ?

57/. What are the main factors you take into account when designing the protection system for a scheme?

58/. How do you make allowances for sag/thermal expansion/contraction when assessing the length of conductor required for transmission ?

59/. What would you regard as an "acceptable loss" in the transmission/distribution system?

60/. How would you assess the amount of service wire required for domestic installations?

61/. How would you assess the number of mandays required for domestic wiring/installation ?

62/. How would you calculate the overall efficiency of a scheme ?

63/. What, in your opinion, are the best methods for reducing/eliminating illegal loading on the scheme?

64/. What, in your opinion, are the best strategies for improving the load factor of any scheme ?

65/. What, in your opinion, are the main benefits of rural electrification, and microhydro in particular?

66/. What are the most likely methods for setting tariff rates ?

67/. How are monies usually collected ?

68/. In the case of communal schemes, is a local representative usually selected to liase between the loan body and the local community ?

69/. In your experience, do microhydro schemes usually pay back loans within the required period ?

70/. How do the legal implications of scheme ownership and operation affect the way in which a site may be exploited ?

71/. Which forms of tariffing appear to you to be most effective in promoting the efficiency of the scheme?

72/. Can you think of *anything* else ?

APPENDIX 3

Original Publications

MICROCOMPUTERS FOR MICROHYDRO: THE CASE OF NEPAL.

TM Anderson, HW Whittington.

University of Edinburgh, UK.

1: INTRODUCTION.

The electrification of rural areas of developing countries is generally regarded as an important key to their development, Flavin (1). Countries such as Pakistan, Indonesia, Papua New Guinea, Nepal, Peru, India and, of course, China, are amongst those which have adopted ambitious programmes of rural electrification, Finnigan (2). Extension of urban grid systems to remote areas of these countries is, however, prohibitively expensive, United Mission to Nepal (3), and the isolation of rural communities makes maintenance of grid transmission equipment virtually impossible.

Stand-alone power plants are therefore installed in rural areas almost as a matter of course. Although diesel sets are frequently used in these situations, the escalation of oil prices in the 1970's, coupled with the fact that many countries without a national oil or coal resource are trying to reduce their dependence on imported fossil fuels, has prompted a re-evaluation of the economic viability of such systems on a national and local level, Flavin (4).

It is in this context that small de-centralised power plants have gained credibility as a low-cost solution to the rural electrification problem, Meier (5).

It has been estimated that the world-wide potential for small hydro system is in excess of 100 000MW (1). There was an estimated capacity of 10 000MW of non-grid-connected small hydro projects constructed in the Third World by 1983; this figure is expected to treble by the early 1990's (1).

The development of microhydro in Nepal began as early as the 1960's, when a nationally-owned engineering company fabricated and installed a small number of propeller turbines in mills. The installation programme has increased in size and sophistication since then, and in the last few years over 400 new turbines have been installed, Inversin (6).

Funding from bodies such as the Asian Development Bank, UNCTAD (7), and UNICEF, AIM (8), has ensured that the programme has maintained its initial momentum.

2: MICROHYDRO IN NEPAL.

Microhydro schemes provide many villages in Nepal with a cheap and renewable supply of electricity and motive power. In remote areas the installation of such schemes stimulates the local economy by making rural industries possible and increases the availability of off-farm employment. Added benefits which cannot be measured in economic terms include:

(i) electric lighting (which people are prepared to pay for at rates sometimes more than double that of the U.K.), (9), and the resulting possibility of improved literacy,

(ii) better health care and the possibility of storing vaccines etc. in cold boxes or refrigerators in village health centres, Integrated Development Systems (10),

(iii) increased awareness of more advanced technology levels, and introduction of the skills required to maintain a scheme efficiently into the local work force, Hislop (11),

(iv) increased confidence in employment opportunities in the local community, and a reduction in the rate at which migration to urban centres occurs, Hislop (12),

3: CURRENT ASSESSMENT PROCEDURE.

In Nepal, microhydro plants are either installed from scratch, or are "add-on" schemes, where an alternator is linked by a drive belt to one of the hundreds of suitable mechanical water mills already in use in hilly and mountainous regions (8).

Small hydro schemes characteristically require high initial capital input, but relatively low upkeep (as compared, for instance, with diesel generators), Holland (13), so successful schemes can generate income as soon as they are in operation. Schemes which do not begin to pay for themselves immediately, or suffer long periods of downtime can, however, become a financial drain on the owner or local community, especially where interest payments are due on loans taken out to finance the scheme.

3-1: Operational Experience.

In practice, breakdowns of micro hydro plants occur for a variety of reasons which can be divided into three broad general categories, viz

(i) Faulty or sub-optimal design.
At present, design engineers working in microhydro employ some optimisation routines, making a few passes through an iterative process, say, to improve efficiency of civil works by a few percent. Few, however, have either the time or resources required for an overall optimisation routine, where the economic and engineering implications of each aspect of the design are balanced together with more practical details, such as the implications of using materials which are scarce in a particular region, or which will introduce a high transport factor into the final cost of the scheme, National Rural Electric Cooperative Association (14).

(ii) Inefficient Installation and Operation Procedures.
At present there is no national installation and safety standard applied to microhydro installations in Nepal, and this has been identified as a major weakness of the microhydro programme, East Consult & IDS (15). Designs drawn up in engineers' offices are rarely adhered to rigorously in the field, and often design parameters as critical as penstock length, or powerhouse siting are altered by the installation team. In some cases, poor installation standards result in schemes which never operate at above 50% of their design capacity (16).

The efficient operation of any plant is as crucial to its success as is the design of its various components. This may include ensuring that voltage and frequency levels are maintained, and illegal loading is prevented, that civil works are free from debris, or that trashracks and siltation basins are cleared at regular intervals. Failure to satisfy any one of these conditions can and does frequently result in breakdown of either the whole plant or of associated equipment.

(iii) Poor or Non-existent Maintenance Routines.
As well as promoting the installation of new schemes, organisations involved in rural electrification projects are also concerned with maintaining present installed capacity.

Current maintenance programmes in Nepal are minimal, and no routine refurbishment of electro-mechanical equipment is carried out (17). Schemes are repaired only when they break down, with an ensuing lack of power while the repair group is contacted and makes its way to the site.

Lack of proper documentation can exacerbate maintenance difficulties. For example, the author was present in Nepal last October when an engineer returned from an abortive site visit in the mountains. He had travelled to the site, three days walk from the nearest road, only to find that he had taken the wrong size turbine nozzle and tools with him. Because of poor site records, the scheme was operating below capacity for some time, with attendant financial losses for the owners.

4: RATIONALISED APPROACH.

This situation would benefit greatly from some form of standardised design and operation procedure, which optimised schemes according to local requirements, and generated clear and concise records of the

specifications of every installed and proposed scheme. Nepal Electricity Authority (18).
This can be achieved for each of the three main categories above.

(i) Design Practice.
In order that design faults are reduced to a minimum, it is essential that competent assessments of new sites are made, and that specifications of any sites surveyed (either for electrification or mechanical milling alone) are stored in an efficient and readily accessible manner (18)
It is also essential that validated standard design practices are used, and that the design is streamlined by the use of overall optimisation routines. Such routines should take into account:
● trade-offs between economic and engineering considerations,
● availability of construction materials and electro-mechanical components,
● local engineering practices,
● the quality of workmanship which can be expected, and
● any specific local considerations.

(ii) Installation and Operation Practice.
Experience has shown that installation and safety guidelines laid down in an engineer's office are not adhered to in the field any more rigourously than the specifications of, say, penstock length and canal length, which are frequently altered during the installation process.
It is, however, advisable that plant designers use what engineering methods are available to them locally to achieve the safest and most reliable installations possible.
Codes of practice must be developed and validated to improve operation from the design stage.

(iii) Maintenance Routines.
The practice of repair on demand results in unnecessary loss of operation time. Interviews with engineers with several years experience in the field indicate that where schemes are unreliable, local communities often lose confidence in the power supply, and revert to kerosene lights and batteries, reducing the long-term income generated by the plant, and hence the motivation for its upkeep (10).
Routine maintenance scheduling, where equipment and civil works are checked for problems at regular intervals, can significantly reduce the number of occasions on which total shutdown of a scheme is required. Engineers in Nepal have already expressed their need for such a schedule, and some organisations are trying to develop one at the moment, Micro Hydro Technical Assistance Project (19).
Effective operation of such a maintenance schedule is possible only if details of system components (e.g. component sizes, contents of site tool box, etc.) are readily available to the engineer before the site visit. Details of previous system faults and breakdowns should be logged, so that a clear and concise record of plant faults can be built up, and weak points in design and operation can be identified.

5: EXPERT SYSTEM/DATABASE DECISION SUPPORT SOFTWARE (DSS).

The current state of the art of microhydro design comprises a body of theoretical information and practical experience, combined together to form almost a "Black Art". It is to situations of this type that Decision Support Software (DSS) has been applied in the past (e.g. design of Switched Mode Power Supplies).
Microhydro design has been already identified by Nepali organisations as an area which would benefit greatly from the application of computer systems. The Nepal Electricity Authority (NEA) MicroHydro Technical Assistance Project (MHTAP) and the Agricultural Development Bank of Nepal (ADBN) have already set up their own preliminary assessment systems on PC's, a basic form of DSS.
DSS suited to microhydro would consist of the knowledge and skills of many experts structured into programs which provide a standardised assessment method for scheme feasibility. The program would interact with the user clearly and concisely, in natural language, prompting the user for the information required, a good way of ensuring that none of the details are left out by accident.
To answer the problems set out above:
(i) The DSS should include optimisation procedures involving both economic and engineering criteria. These procedures should take into account the availability of construction materials and scheme components, specifications of which should be stored on a database, and be referred to by the evaluation routines throughout the

program. The system's recommendations for scheme layout and design should be flexible enough to allow an experienced designer to override them because of his or her knowledge of particular local conditions or unusual circumstances.
(ii) The DSS should promote safe and standardised installation practices which are appropriate to local conditions and engineering expertise. The use of devices which improve plant efficiency and reduce the likelihood of breakdowns and power losses should also be recommended where these are appropriate.
(iii) In order that site data be readily available, the DSS should include a database of scheme specifications which can be updated as the scheme is upgraded, repaired, suffers faults or breaks down.
The data base should include a facility whereby "sketches" of powerhouse layout, transmission system configuration etc. can also be stored as part of the data entry for each scheme. This would be a great aid in calculating whether there is room in the power house for a new alternator, or in estimating the sizes of new drive belts or distribution lines. In situations where an investigative site visit may entail up to ten days walk from the nearest vehicle track, this feature would obviously save considerable time and effort on the part of any maintenance team.

It is essential that the interaction between the user and the microhydro DSS is via clear and unambiguous language, and uses graphics and tables where these are required.

6: USERS OF DSS IN NEPAL.

Recent discussions and meetings with some of the major organisations involved in the field of microhydro in Nepal revealed that they are very familiar with the use of microcomputers, although at the moment these are employed primarily for word-processing and accounting tasks.
Their application to engineering problems is now gaining importance, and as noted above, some of the agencies are at present experimenting with the idea of applying decision support software to microhydro:

(i) The Nepal Electricity Authority have begun development of basic DSS systems on PC's.

(ii) The Agricultural Development Bank of Nepal provides loans for the majority of microhydro installations in Nepal, and would benefit greatly from having a fast and efficient method of assessing scheme proposals prior to granting these loans.

(iii) Development and Consulting Services (DCS) of Butwal runs the Small Turbines and Mills Project (STMP) which is responsible for the installation of over 200 water mills in hilly and mountainous regions, some of which include electrification projects. They have already discussed their plans for a computerised database of these schemes, and are at present looking towards this particular software configuration to meet their requirement.

(iv) Balaju Yantra Shala (BYS) of Kathmandu, another of Nepal's major microhydro installers, have also indicated that they would be very interested to use such a system of DSS, as it would speed up the more mundane iterative routines required for design optimisation.

7: FINANCIAL BENEFITS OF USING DSS.

With typical costs for microhydro installations in the range of $US 1000 - 4000 per kW, the failure of even a small percentage of sites can cost hundreds of thousands of ill-afforded dollars
Decision Support Software can make significant reductions to these losses in the following ways:
(i) Identification of economically unfeasible schemes. If the development of one unfeasible 30kW scheme is prevented, the saving is a minimum of $US30 000.

(ii) Optimisation of designs. It is difficult to quantify the saving resulting from optimising any design, but it is anticipated that an average of about 10% of the capital cost would be achieved,

disregarding any savings in the engineer's time which would result from using a computer. For an installation program of 100 schemes per annum, each averaging at 10kW installed capacity, this would represent an annual saving of $US100 000.

(iii) Better sourcing of materials through a database of suppliers. This, again, is difficult to quantify, but can mean the difference between, say, selection of a 4-pole, or a slower-running 6-pole alternator, which is likely to last longer in the conditions encountered in rural electrification sites (20).

(iv) Improved installation procedures and codes of safety practice. Such considerations cannot be quantified in financial terms, other than in the cases where schemes would have been shut down due to accident, or due to damage caused to property by, for instance, fires caused by faulty wiring. However, it is correct engineering procedure to install to the highest practical safety standards.

(v) Planned maintenance scheduling and improved maintenance procedures. These practices have been widely adopted throughout the power industry, and are regarded as being ideally suited to the application of software systems. More importantly, engineers in Nepal have already expressed their need for such a system, as long periods of downtime have a drastic effect on the income generated by a scheme. Typical savings are claimed as high as 10% per annum of running costs.

(vi) Identification of common modes of failure. Over several years of operation, a database of common faults in certain equipment types will be built up. By using only those plant items with proven reliability in new scheme designs, improved economic running will be achieved.

8: DSS HARDWARE AND SOFTWARE REQUIREMENTS.

8-1: Hardware Requirements.

DSS hardware requirements are dictated by the type and range of machines available within the country. In Nepal itself, IBM PC's and compatibles are widely available, and some versions are manufactured in-country.

8-2: Software Requirements.

The software components of the sytem are also restricted to what is readily available, so the industry standard Expert System builder CRYSTAL, and the LOTUS 1-2-3, spreadsheet package were selected as the system environment.
An enabling software interface between these two is being developed and so far this has been structured to allow any expert system program to consult databases of equipment and materials available on a national and local basis.

9: FIELD VERIFICATION OF DSS.

A demonstration of DSS was carried out during a visit to Nepal in October & November of 1988.
The preliminary system stepped through a range of modules, interrogating the user and consulting databases of equipment and materials available in Nepal, which were stored on disk.
The development of the system is now proceeding, based on extensive research carried out in Nepal and the UK.

10: ACKNOWLEDGEMENTS.

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