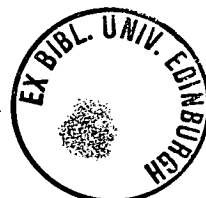


MICRO AND MINI HYDRO-POWER
IN PAPUA NEW GUINEA

by

Keith Duncan Whittaker, B.Sc.

Doctor of Philosophy
University of Edinburgh
1988



Abstract

The initial section of this thesis discusses the need to encourage rural development, in many areas of the developing world, if the standard of living of the majority of the population is to be significantly improved. This is followed by a discussion of the role of energy in development. It is noted that the provision of electricity in rural areas is unlikely to have a major impact unless other developmental factors are also present.

Micro and mini hydro-power are then introduced. There is a brief description of the technical function of the individual component parts of a micro hydro-power project. The advantages and disadvantages of micro and mini hydro-power as a power source are discussed with particular reference to the rural areas of developing countries. It is suggested that, if micro and mini hydro-power resources are to be widely developed, positive financial, technical and managerial support will often be needed.

The remaining sections of the thesis concentrate on Papua New Guinea, using it as a case study to examine the role of micro and mini hydro-power in the rural development process. A brief geographical, political and economic history of the country is given which is followed by a description of the country's energy consumption patterns. Electricity production within the country is examined. It is noted that the Papua New Guinea Electricity Commission is profit orientated and, as a result, has undertaken little rural electrification work. As a result, electricity supplies at over 100 rural centres remain the responsibility of the national government. These supplies are highly subsidized and the various initiatives aimed at reducing costs by replacing diesel generators with micro and mini hydro-power projects are discussed.

The majority of micro and mini hydro-power projects developed in Papua New Guinea to date have been developed by various mission organizations. The performance of these, a commercial project and a number of projects implemented to serve villages is discussed. There

follows a discussion of factors affecting the development of the nation's micro and mini hydro-power resources. Finally, a number of conclusions are drawn and recommendations made.

Declaration

I declare that this thesis has been composed by myself and that the work contained in it is my own.

Acknowledgements

I would like to express my gratitude to Dr. H. W. Whittington and to Dr. D. E. Macpherson for the help and encouragement they have given me in completing this thesis. Their suggestions and criticisms have been invaluable throughout.

The second year of my studies was spent in Papua New Guinea and I am deeply indebted to a great many people at the Papua New Guinea University of Technology and throughout the country for making my work in the country possible and for ensuring that my time there was enjoyable. At the University of Technology, I would, in particular, like to express my gratitude to Professor D. Harris, Head of the Department of Electrical and Communication Engineering, for making me welcome and for providing an environment conducive to my work. I would also like to thank Mr. C. Kiewiet for allowing me to become involved in his work on micro hydro-power projects and for the encouragement that he provided to my own investigations. Similar thanks are due to Mr. A. R. Yadav from the Department of Civil Engineering and to Dr. R. Burton, Director of the Appropriate Technology Development Institute.

My work in Papua New Guinea would not have been possible without the assistance of the Papua New Guinea Electricity Commission, the Department of Minerals and Energy, and the Morobe Provincial Government. In particular I would like to express my gratitude to the following staff who provided me with access to information and made themselves available for interview a) Mr. Tey, Hydro Engineer with the Electricity Commission, b) Mr. C. Cheatham, Power Systems Planner with the Energy Planning Unit of the Department of Minerals and Energy, c) the Honourable Tingnau Mandan, Minister for Forests in the Morobe Provincial Government and d) Mr B. Nablu, Mr. A Sesiguo and Ms. V. Toloube of the Policy Planning and Co-ordination Research Section of the Morobe Provincial Government.

Many other individuals provided me with valuable information or in others way contributed to my work in Papua New Guinea. They are too

numerous to list in full, but in particular, I would like to thank Kaye Bowman for introducing me to the people of Uimbang and Baidoang and Mursalin New, Lukis Romaso and Paul Unwin for providing me with information on rural industry in Papua New Guinea. Other people to whom I owe particular thanks are Professor J. L. Woodward, Dr. Whittle and Messrs J. Beraro, R. Hothersall, L. Jajing, B. Kavi, S. Lattimer, R. MacLachlan, N. Mohiba, P. Robinson, and Yang.

For assisting with the final editing of this thesis would I like to again thank Dr. Whittington and Dr. Macpherson. Thanks are also due to Sarah Villeneuve for the help and encouragement offered in the final stages of this work.

List of Contents

Title Page	1
Abstract	ii
Declaration	iv
Acknowledgements	v
List of Contents	vii
List of Tables	xiv
List of Figures	xv
List of Terms and Abbreviations	xvi
1. <u>Rural Development</u>	1
1.1. The Concept of Development	1
1.2. Colonial History	3
1.3. Independence and the Dual Economy Model	4
1.4. Industrialization	5
1.5. Regional and Rural Development	7
1.6. Conclusions	12
2. <u>The Role of Energy in Development</u>	14
2.1. Energy as an Aid to Productivity	14
2.2. The Case for Rural Electrification	15
2.3. The Impact of Rural Electrification	18
2.4. Implications for Future Rural Electrification Programmes	21
2.5. The Role of National Power Utilities in Implementing Rural Electrification Programmes	24
2.6. Appropriate Organizational Structure	25
2.7. Conclusions	26

3.	<u>Power Sources for Electricity Generation</u>	28
3. 1.	The Scale of Generating Facilities	28
3. 2.	The Cheap Oil Era	28
3. 3	Hydro-Power	29
3. 4	Small-Scale Plant	30
3. 5	Micro and Mini Hydro-Power	31
3. 6	The Physical Components of a Micro Hydro-Power Project	32
3. 7.	The Costs of Micro and Mini Hydro-Power Projects	40
3. 8	The Role of Micro Hydro-Power in the Rural Areas of Developing Countries	41
3. 9	The Rationale for Establishing a Micro Hydro-Power Support Agency	44
3. 10.	The Functions of a Micro Hydro Support Agency	45
3. 11.	Conclusions	48
4.	<u>Papua New Guinea</u>	50
4. 1.	Introduction	50
4. 2.	The Geology and Topography of Papua New Guinea	50
4. 3.	The Climate of Papua New Guinea	52
4. 4.	The Vegetation of Papua New Guinea	53
4. 5.	The Culture and People of Papua New Guinea	53
4. 6.	The Colonial History of Papua New Guinea	54
4. 7.	Development Strategies Since Independence	59
4. 8.	The Current Situation	61
4. 9.	The Hydro-Power Potential of Papua New Guinea	72
4. 10.	Conclusions	74

5.	<u>Energy Consumption and Electricity Generation in Papua New Guinea</u>	75
5.1.	Introduction	75
5.2.	Domestic Energy Consumption	78
5.3.	Electricity Production	78
5.4.	Energy Consumption by the Transport Sector	80
5.5.	The Energy Consumption of Mining and Other Industry	81
5.6.	The Papua New Guinea Electricity Commission	82
5.7.	Official Electricity Supplies at Non-Elcom Centres	89
5.8.	Conclusions	93
6.	<u>Official Rural Electrification Activity in Papua New Guinea</u>	95
6.1.	Introduction	95
6.2.	The Rural Electrification Debate	95
6.3.	Subsequent Rural Electrification from Elcom's Grid System	106
6.4.	Official Rural Electrification Activity Based upon Micro and Mini Hydro-Power Projects	109
6.5.	Kabwum and Simbai Micro Hydro-Power Projects	109
6.6.	The Provincial Mini Hydro-Power Programme	115
6.7.	Elcom Response	122
6.8.	The Hydro-Power Development Study of Papua New Guinea	125
6.9.	Subsequent Government Response	126
6.10.	The Mini Hydro Resource Inventory and Diesel Power Replacement Programme	126
6.11.	Conclusions	134

7.	<u>Other Micro and Mini Hydro-Power Developments</u>	136
7.1.	Introduction	136
7.2.	The Activity of Mission Organizations	136
7.3.	Village Schemes	139
7.4.	Private and Commercial Developments	153
7.5.	Conclusions	153
8.	<u>A Discussion and Summary of Factors Affecting the Development of Micro and Mini Hydro-Power Resources in Papua New Guinea</u>	156
8.1.	Introduction	156
8.2.	The Diesel Power Replacement Programme	156
8.3.	Village Micro Hydro-Power Projects	157
8.4.	Conclusions and Recommendations	166
Appendix A.	<u>Further Information on Elcom Systems</u>	169
A.1.	The Ramu System	169
A.2.	The Port Moresby System	169
A.3.	The Gazelle System	170
A.4.	Other Elcom Systems	170
Appendix B.	<u>The Simbai Micro Hydro-Power Project</u>	172
Appendix C.	<u>The Kabwum Micro Hydro-Power Project</u>	173
Appendix D.	<u>The Sohun Mini Hydro-Power Project</u>	174
Appendix E.	<u>The Ru Creek Mini Hydro-Power Project</u>	175
Appendix F.	<u>The Lake Hargy and Tinputz Hydro-Power Projects</u>	176
F.1.	Background to the Bialla Area	176
F.2.	Lake Hargy Hydro-Power Scheme Design	176

F. 3.	Background to the Tinputz Area	177
F. 4.	Tinputz Hydro-Power Scheme Design	177
Appendix G.	<u>The Tari Mini Hydro-Power Project</u>	178
Appendix H.	<u>The Highlands Christian Mission Mini Hydro-Power Project</u>	180
H. 1.	Introduction	180
H. 2.	Background to the Hydro-Power Project	180
H. 3.	Civil Works	181
H. 4.	Power House and Electro-Mechanical Equipment	183
H. 5.	Project Costs	183
H. 6.	System Operation and Problems	184
H. 7.	Mission Power Use	186
H. 8.	Project Economics	186
Appendix I.	<u>The Umbang-Baindoang Micro Hydro-Power Project</u>	189
I. 1.	Introduction	189
I. 2.	Project Motivation	189
I. 3.	Details of the Design of Stage One of the Umbang Project	190
I. 4.	Project Implementation	192
I. 5.	A Proposal to Expand the Micro Hydro-Power Project	193
I. 6.	Implementation of Stage Two of the Micro Hydro-Power Project	195
I. 7.	The Performance of the Umbang-Baindoang Project	196
I. 8.	Recent Project Re-Habilitation	199
I. 9.	Conclusions	200

Appendix J.	<u>The Ogeranang Micro Hydro-Power Project</u>	202
J. 1.	Background Information on Ogeranang	202
J. 2.	Micro Hydro-Power Investigations	203
J. 3.	Project Implementation	204
J. 4.	Details of the Completed Project	206
J. 5.	Project Operation	207
J. 6.	Conclusions	209
Appendix K.	<u>The Anga Region: Micro and Mini Hydro-Power Projects and Investigations</u>	211
K. 1.	Background to the Anga Region	211
K. 2.	Micro and Mini Hydro-Power within the Region	213
K. 3.	Conclusions	221
Appendix L.	<u>The Nawong Micro Hydro-Power Project</u>	223
L. 1.	Introduction	223
L. 2.	Project Details	223
L. 3.	Scheme Operation	224
L. 4.	Conclusions	226
Appendix M.	<u>Faseu Village Micro Hydro-Power Project</u>	228
M. 1.	Introduction	228
M. 2.	Hydro-Power Project Details	229
M. 3.	Project Feasibility	230
M. 4.	An Alternative Proposal	231
M. 5.	Conclusions	233

Appendix N.	<u>The Ambua Lodge Micro Hydro-Power Project</u>	235
N. 1.	Introduction	235
N. 2.	Hydro-Power Scheme Details	235
N. 3.	Scheme Operation and Problems	236
N. 4.	System Loads	236
N. 5.	Project Economics	237
Appendix O.	<u>Basic Information on Other Micro and Mini Hydro-Power Projects</u>	239
References		243

List of Tables

Table 1.1.	The Per Capita Gross National Product of Selected Nations in 1985	2
Table 4.1.	Major Items Exported from Papua New Guinea in 1985	65
Table 4.2.	The Population of Papua New Guinea's Eight Major Urban Centres in 1980	70
Table 5.1.	Sources of Primary Energy for 1981	77
Table 5.2.	Major Primary Energy Consuming Sectors	79
Table 5.3.	Elcom's Uniform National Tariff as of 1st June 1983	87
Table 5.4.	Hours of Operation at Selected 'C' Centres	90
Table 6.1.	A Comparison Between Forecast Costs of Hydro-Power and Diesel Generation at Simbai	112
Table 6.2.	A Modified Comparison Between Costs of Hydro-Power and Diesel Generation at Simbai	113
Table 6.3.	Proposed Mini Hydro-Power Project Capacities	116
Table 6.4.	Estimated Costs of the Four Mini Hydro-Power Schemes	117
Table 6.5.	Estimated Completion Costs for the Lake Hargy and Tinputz Mini Hydro-Power Projects, March 1985	124
Table 7.1.	Types and Numbers of Micro and Mini Hydro-Power Projects	136
Table A.1.	Information on Elcom's Isolated Power Systems	171
Table I.1.	Electrical Load Forecast for Umbang Regional Centre	191
Table I.2.	A Breakdown of Material and Equipment Costs for Stage One of the Umbang-Baindoang Project	194
Table K.1.	A Cost Comparison of Two Potential Mini Hydro-Power Projects to Supply Menyamya	219
Table K.2.	A Net Present Value Analysis of the Proposed Government Mini Hydro-Power Project	220

List of Figures

Figure 3.1.	Schematic Representation of a Micro Hydro-Power Installation	33
Figure 4.1.	The Major Landforms of Papua New Guinea	51
Figure 4.2.	The Mean Annual Rainfall of Papua New Guinea	54
Figure 4.3.	The Provinces of Papua New Guinea	62
Figure 4.4.	Map Showing the Road Network and Major Urban Centres of Papua New Guinea	69
Figure 5.1.	Fuel Imports: Quantities and Values	76
Figure 5.2.	Elcom's Existing Transmission Systems and Supply Centres	84
Figure 5.3.	Elcom Generation 1973-1995	85
Figure 5.4.	Elcom Electricity Production Costs by System	88
Figure 6.1.	Official Rural Electrification Initiatives and Proposals	97
Figure 7.1.	Locations of the Case Study Hydro-Power Projects	137
Figure 7.2.	Organizational Structure of the Morobe Provincial Mini Hydro Programme	143
Figure G.1.	Schematic Layout of the Tari Hydro-Power Project	179
Figure H.1.	Schematic Layout of the Highland Christian Mission Project	182

List of Terms and Abbreviations

ADA	Anga Development Authority
ADB	Asian Development Bank
AEC	Administrator's Executive Council
ATDI	Appropriate Technology Development Institute, formerly the Appropriate Technology Development Unit
BCL	Bougainville Copper Limited
BDO	Business Development Office
CAVI	Community and Village Industries Programme
DASF	Department of Agriculture, Stock and Fisheries now known as the Department of Primary Industry
DECE	Department of Electrical and Communication Engineering, Papua New Guinea University of Technology
DES	Development Engineering Service
DME	Department of Minerals and Energy
DPI	Department of Primary Industry, formerly the Department of Agriculture, Stock and Fisheries
DPRP	Diesel Power Replacement Programme
EEC	European Economic Community
Elcom	Papua New Guinea Electricity Commission
EPU	Energy Planning Unit, Department of Minerals and Energy
FIRR	Financial Internal Rate of Return
fob	freight on board
GDP	Gross Domestic Product
GNP	Gross National Product

GPEE	Gazelle Peninsula Electric Energy (Corporation)
IRR	Internal Rate of Return
K	Kina, the national currency of Papua New Guinea
LGSDWS	Local Government Section of the Department of Works and Supply
MHRI	Mini Hydro Resource Inventory
NEC	National Executive Council
NEPC	National Energy Planning Council
NPEP	National Public Expenditure Plan
NPO	National Planning Office
NPV	Net Present Value
NRECA	National Rural Electric Co-operative Association
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of Oil Exporting Countries
PDG	Power Development Group
PIDO	Provincial Industrial Development Officer
PMV	Public Motor Vehicle
PNG	Papua New Guinea
RIP	Rural Improvement Programme
SPATF	South Pacific Appropriate Technology Foundation
TOE	Tonnes of Oil Equivalent
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization

UNIDO United Nations Industrial Development Organization
Unitech Papua New Guinea University of Tehnology
USA United States of America
USAID United States Agency for International Development
USSR Union of Soviet Socialist Republics
VEDF Village Economic Development Fund
VES Village Equipment Supplies
VSO Voluntary Service Overseas

1. Rural Development

1.1. The Concept of Development

Over one hundred countries are generally considered as being 'developing nations'. Collectively, they contain three quarters of the world's population. Individually, they exhibit a huge diversity in their size, population, population density, resource endowment, political and economic history, climate, topography and many other characteristics. But, for all of them, there is a significant gap in the 'quality of life' of their citizens when compared with that of those countries considered as developed. However, both 'quality of life' and 'development' are terms that defy explicit definition since they are affected by personal view point and political ideology. Nevertheless, a number of factors are generally accepted as indicating a country's level of development (1.1). These include:

- a) the political independence of the nation,
- b) the per capita Gross National Product (GNP) of the nation,
- c) the extent to which the national economy is independent of foreign aid,
- d) the level of diversification of the nation's economy,
- e) the level of infrastructure development within the country,
- f) the values of various health and education indicators,
- g) the extent of absolute poverty among the population,
- h) the degree to which income is evenly distributed through the population.

Many of these indicators are hard, if not impossible, to quantify and there is a tendency to treat 'development' in purely economic

terms. There are dangers in this since increased economic activity at a national level does not necessarily lead to increased 'quality of life' for the majority of the population. Per capita GNP is perhaps the indicator most commonly used and Table 1.1. indicates the per capita GNP of selected nations for the year 1985.

Table 1.1. The Per Capita Gross National Product of Selected Nations in 1985

<u>Low Income Countries</u>	<u>Per Capita GNP in US\$</u>
Ethiopia	110
Mozambique	160
India	230
<u>Lower Middle Income Countries</u>	
Morocco	470
Papua New Guinea	680
Botswana	840
Costa Rica	1,300
<u>Upper Middle Income Countries</u>	
Brazil	1,640
Argentina	2,130
Singapore	7,420
<u>High Income Oil Exporting Countries</u>	
Libya	7,170
Kuwait	14,480
<u>Industrial Market Economies</u>	
United Kingdom	8,460
Denmark	11,200
U. S. A.	16,690

Source: World Bank Development Report, Oxford University Press, 1987.

Many developing countries were, in the past, colonies of European nations. They were largely seen by the colonizing powers as sources of cheap labour and raw materials such as agricultural produce, timber and minerals. This pattern of resource exploitation affected the settlement pattern and transport network development in many countries and can be seen in a number of stages (1.2). Thus:

- a) initially a number of small ports and trading posts were established by colonizing settlers. These were scattered along the coast, largely unlinked, each trading with its own small inland hinterland.
- b) a few major lines of penetration were opened up and inland trading centres established. This resulted in the more rapid growth of those ports with such connections.
- c) from the main penetration routes, lateral connections and feeder routes began to develop. The main ports continued to expand, capturing the trade of lagging ports. Along the main inland routes, intermediate centres developed.
- d) growth in the number of centres and transport routes continued.

Countries in which this type of development is plain include Ghana, Nigeria, Brazil, Malaysia, Kenya, Australia, New Zealand and Papua New Guinea. As settlement and resource exploitation proceeded the economies of the colonies became more diverse. Processing operations were established and the cash incomes of local producers and employees began to transform the domestic market, encouraging local production of goods. Increasingly the colonies became markets for manufactures produced in the colonizing nation.

Although some countries gained independence earlier, it was not until after World War Two that major moves were made towards establishing the various colonies as independent nations. By this stage an urban elite had developed in most of these countries and it was from this group that the majority of future rulers were drawn. They had often received a western education and acquired many of the tastes and aspirations associated with European culture. At independence they inherited 'dual economies' a term that refers to the pronounced contrast found between the modern, enclave sector and the traditional/informal sector of their economies.

The modern enclave sector comprises large scale operations in manufacturing, trading, services, extractive industries and primary production. It also includes the central government public services. The sector is characterized by the complexity and size of its organization, by its high skill requirements, by a preference for capital intensive production techniques, by a bias towards export and/or the urban market and by high levels of overseas investment and control. The modern sector tends to have significant political influence and so benefits from a high level of state support in the form of legal and financial protection, infrastructure investments and investments in education to serve its manpower needs (1.3).

The traditional/informal sector comprises small-scale agricultural production and processing operations and small-scale trading, manufacturing and service operations. It is characterized by the use of largely traditional skills and techniques, low productivity and under-utilization of labour, use of locally available materials, a lack of formal training and qualifications, lack of capital and high level of self-employment. Although most people are likely to earn their living in the traditional/informal sector, its political influence is limited because it tends to be disorganized (1.4).

1. 4. Industrialization

After independence many countries encouraged large-scale industrial developments as a means of pursuing their development goals. It was argued that investments in industry, by creating employment, would enlarge the domestic market and hence create opportunities for further investment and economic growth. Industries encouraging backward and forward linkages would offer maximum benefits, through increased diversification of the economy. The expansion of the modern sector would result in a 'trickle down' of benefits to the traditional/informal sector (1.5). It was argued that countries could pursue industrialization through production aimed at either the export market or at import substitution.

1. 4. 1. Import Substitution

Import substitution policies aim to encourage the manufacture of goods that would otherwise be imported. It is accepted that initially it may be necessary to protect 'infant industries' from imported competition while they develop and 'learn by doing'. Import substitution policies are most likely to be successful in countries where a large domestic market means that both economies of scale and inter-firm competition encourage efficiency. Import substitution programmes have been undertaken in many developing countries.

1. 4. 2. Export Orientated Production

Export orientated programmes attempt to develop industries in which the nation is likely to show a comparative advantage. For most developing countries this is likely to mean either resource based products or products requiring a high level of labour input such as textiles, footwear and 'foot loose' production. However, it is difficult to break into the international market for manufactured goods. Thus, it is initially necessary to offer export subsidies and marketing assistance. Developed nations have also resorted to protectionist measures to limit the erosion of their own threatened industrial bases (1.6).

1. 4. 3. The Effects of Industrialization

There have been several examples of countries having marked success with industrialization policies, particularly export orientated policies eg. Taiwan, Singapore and South Korea. However, developing countries' attempts at industrialization have often met with limited success, especially when programmes have been import substitution orientated. Many operations are run at well below capacity and the original investment loans from overseas have become a burden to national governments. Factors contributing to this poor performance may include a lack of competent investment planning, lack of capital, materials, manpower skills and/or market. A common result is that high levels of protection are needed to subsidize inefficient and badly chosen industries. This protection itself reduces incentives to improve efficiency and lower costs. It also tends to induce an artificially high foreign exchange rate, inhibiting exports and encouraging capital intensive projects. Further, it distorts the domestic market and often inhibits the growth of backward linked industries such as agriculture (1.7). In addition, national governments may control or subsidize staple food prices since low food prices benefit the urban population who are most visible to politicians, but this tends to disadvantage rural areas as food prices are held in check while the price of manufactures continues to rise (1.8).

1. 4. 4. The Dominance of Cities

Investment in large-scale industrial development tends to be concentrated in the major urban centres. A common result of industrialization policies and the earlier colonial settlement and transport network patterns has been the emergence of a few (or only one) major urban centres that tend to dominate the national economy.

"We find for example in the case of the recently decolonized African states that often only the capital city (which may also be the chief port) can offer infrastructure and services that European type manufacturing industry and commercial undertakings require, and can supply the amenities and activities that would be attractive to European ex-patriates.

Thus, modernization does not spread its effects throughout the urban fields." (1.9)

In comparison with most western countries, the urban hierarchy is characterized by a lack of smaller cities and market towns between the extremes of the major cities and the many rural villages (1.10). The lack of a well developed urban hierarchy tends to inhibit the level of interaction between the modern and traditional/informal sectors resulting in exacerbation of the dual economy system and increasing regional disparities in well being. The benefits of industrialization are 'trickling down' far too slowly to be acceptable and the contrast between sectors is seen as increasing with relative stagnation of the traditional/informal sector.

The lack of opportunities in the rural and small town environment has led to high rates of migration with large shanty towns developing on the periphery of the major urban centres. Industrialization has not led to sufficient levels of job creation to absorb an expanding workforce and the resulting high levels of unemployment and under-employment are causing social and political unrest.

1.5. Regional and Rural Development

The above factors have led to increasing interest over recent years in regional and/or rural development programmes aimed at reducing the disproportion in economic and social welfare between the urban and rural populations.

Agriculture and industry, particularly small-scale localized industry, can be mutually supportive. A prosperous agricultural sector increases rural prosperity and hence the market for industrial goods. It also provides inputs to food processing activities; if these are located in the rural environment then the value added in such processing operations is largely retained locally. Increased agricultural production can either displace imports or be exported. In either case there is a net foreign

exchange benefit to the nation and the potential for increased investment. Similarly agricultural productivity can benefit from industrial development, for example through the development of a firmer market for produce if processing activities are developed and from the use locally produced inputs such as tools, machinery, fertilizers, building materials etc. (1.11).

1.5.1. The Benefits of Small-Scale Production

In discussing small-scale industry, a distinction must be made between decentralized and rural industries. Decentralized industry is essentially derived from the modern sector but located in rural areas or small towns to utilize some advantage such as low labour costs, tax concessions or locally available materials. Rural industry is based on the small-scale industrial sector of craft and cottage enterprises utilizing local skills to serve largely local needs. Unless otherwise stated, throughout this thesis, small-scale industry refers to both decentralized and rural industry (1.12).

In attempting to stimulate regional/rural development the best results are likely to come from a programme that is designed to stimulate the productivity of the small-scale farmer and encourage the establishment of small-scale industrial, commercial and service operations. Such operations generally require lower levels of investment per work place than large-scale projects so that there is scope for significant increases in employment and self-employment. As improved opportunities are perceived by the rural population there is likely to be a reduction in the levels of migration to the major urban centres (1.13).

However, if the agricultural and small-scale industrial and commercial sectors are to prosper, there are a number of obstacles that must often be tackled (1.14). These include:

- a) control of much agricultural land by a wealthy minority.
- b) lack of political power in the hands of the rural poor.

- c) migration of many of the most promising individuals to the urban centres.
- d) the low level of integration of much of the rural population into the cash economy.
- e) a lack of education and skills, particularly technical and managerial.
- f) restrictive social and cultural traditions.
- g) a lack of savings.
- h) investment of rural profits outside the sector.
- i) poor infrastructure, ie. lack of roads, power, communications, etc.
- j) poor access to markets.
- k) the lack of a well developed urban hierarchy.

1.5.2. The Advantages of Urban Centres

Large towns and cities offer a range of advantages to industry and commerce which tends to mean that incentives need to be offered to persuade industrial projects to locate outside the major urban centres. These advantages include (1.15):

- a) a large, concentrated and more affluent market for output.
- b) a large workforce with a wide range of skills.
- c) better access to credit and financial facilities, technical assistance, political contacts etc.
- d) better access to raw materials, spare parts etc.
- e) inter-trading between enterprises.

- f) attractive social amenities for employees, especially important in attracting and holding senior grade management and technical personnel.

1.5.3. Stimulating Central Places and Growth Poles

In many countries a lack of infrastructure at village and small town level means that efforts need to be made to develop the urban hierarchy and improve the rural transport network if rural productivity is to be improved. A good case can be made for encouraging a range of central places by diverting investment to them. The main function of these centres is to increase the rural populations' participation in the cash economy by offering markets and marketing facilities for agricultural produce and by offering a range of goods and services as incentives to increased production. These central places need not be large, and processing, manufacturing and service enterprises are likely to be of a traditional/informal rather than decentralized nature (1.16).

It is also important that larger growth poles be encouraged to act as focal points for regional development. There is some evidence to suggest that a minimum population requirement for potential growth poles is approximately 30,000. These centres will be large enough to offer some of the benefits of the larger urban centres and are likely to attract both decentralizing and small-scale informal enterprises. If a 'critical mass' of complementary industries, infrastructure and services can be achieved with vertical and horizontal integration, it becomes largely self-sustaining. The resulting inter-dependence and inter-trading of enterprises is one of the main advantages of industrial estates and large towns (1.17). Thus, regional growth poles can be seen as a means of ameliorating some of the worst side effects of large-scale industrialization under the dual economy system.

In selecting population centres at which investment is to be directed it is important that the centres and areas chosen have good productive potential. At regional level indicators of such potential

are likely to include a relatively high population density, good natural resource endowment in the form of fertile agricultural land, mineral resources or timber reserves, a relatively well developed transport infrastructure, and a population that is extensively involved in cash cropping and cottage industries. Looking at specific population centres factors to be considered include its accessibility both at inter- and intra-regional level, the size of the workforce and the range of skills available, the level of service and infrastructure provision, the extent of spare capacity in these, and the centre's past economic growth performance (1.18).

1.5.4. Programme Planning and Implementation

Rural development initiatives are most likely to be effective when efforts are part of an integrated programme addressing itself to a broad range of initiatives. Such programmes tend to fall across the areas of responsibility of several government departments so that high levels of inter-departmental co-operation are required. Such co-operation is often notable by its absence.

The linkages and relationships between the different aspects of integrated rural development programmes are complex and little understood. It is extremely difficult to assess the social and economic impact of specific programme initiatives and the interactions between them. Thus, for example, improved road access to an area allows greater access for its products to the national market. It may also mean greater penetration of the area by urban products and influences which can damage the integrity of such areas and lead to greater urban migration. Such damage is likely to be greatest in relatively undeveloped areas and this leads to an argument for establishing regional road networks before improving access to the national system (1.19).

Although the inter-action between elements of regional/rural development programmes remains unclear, a broad range of problems needs to be tackled. A successful programme is likely to include many of the following (1.20, 1.21):

- a) land reform.
- b) reducing levels of industrial protection to encourage competition and reduce bias against agriculture and small-scale enterprises.
- c) improving access to markets for agriculture and small-scale industry, possibly through the establishment of co-operatives to supply inputs and market outputs.
- d) devaluation of the currency to encourage produce export.
- e) improving agricultural extension and research services.
- f) increasing technical and managerial extension services to small-scale industry.
- g) improving access to credit.
- h) removing restrictions that control the development of informal industrial/commercial enterprises.
- i) improving regional infrastructure, especially transport.
- j) investing in infrastructure and amenity improvements at selected centres.
- k) establishing industrial estates at selected centres.
- l) offering locational incentives, such as tax concessions, to industrial projects establishing in selected centres.

1.6. Conclusions

In most developing countries rural development initiatives still attract only a small proportion of overall government expenditure. In part this reflects the complexity of the issues involved in developing integrated rural development programmes. Nevertheless, if the rural populations of many developing countries are to see significant improvements in their lifestyles, increased efforts are

needed to address the problems that affect this section of the population.

It is clear that for many countries a poorly developed urban hierarchy is one of the factors constraining rural development and production. A programme of encouraging the development of a range of selected population centres is therefore likely to be an important element in many integrated rural development programmes. This theme is developed further in later sections of this thesis.

2. The Role of Energy in Development

2.1. Energy as an Aid to Productivity

In those countries now considered developed, industrialization was largely associated with a move from predominantly animate sources of mechanical energy to wind-power, water-power, at a later date steam-power and later still electrical power. Fossil fuels also provided energy in more concentrated forms for heating, both for domestic and industrial purposes, than the earlier fuels of fire-wood and charcoal. The greater availability of energy that resulted made it possible to increase the productivity of many operations (2.1, 2.2). As industrialization proceeded the levels of energy use continued to increase and on a global scale there is a close correlation between a nation's per capita Gross National Product and its per capita energy use. Thus, although the developing nations account for 75% of the world's population they are only responsible for an estimated 25% of total energy consumption (2.3).

In the post-war rush to decolonize and industrialize the Third World, development planners considered power supplies, in particular electricity supplies, as being an infrastructure investment essential to economic development. There was a major expansion in investment in electricity supplies with the World Bank and the regional development banks devoting about 20% of their total lending to electricity development. Commercial banks were also encouraged to invest heavily in Third World power systems and there was a rapid growth in electricity supplies (2.4).

Over 90% of this investment was targeted at major urban centres and industrial developments and large sections of the rural population in most developing countries remain without access to electricity. Thus, in Bangladesh, out of a total of 65,000 villages, less than 2,000 have been electrified. In Latin America less than 33% of the rural population has access to electricity, whilst for Africa's rural population the figure is just 5% (2.5).

For these people, energy requirements for heating/cooking and to a lesser extent lighting are met from various bio-mass sources, in particular fire-wood. Animal and human effort remain their principal sources of mechanical power. In many of these countries, an expanding population is increasing pressure on land resources. Fire-wood and other bio-mass fuels are becoming increasingly scarce and over-exploited. In some areas this has resulted in extensive deforestation and serious deterioration in the environment (2.6, 2.7).

2.2. The Case for Rural Electrification

In an attempt to alleviate bio-mass fuel shortages and to increase the productivity of agriculture and small-scale industry a good case can be put forward for increasing the availability of energy supplies to rural areas. Electricity is a high grade energy source applicable to a wide range of industrial and commercial processes and is a convenient energy source for many domestic appliances. Rural electrification programmes have therefore been seen as having the potential to contribute significantly to regional/rural development in developing countries by increasing productivity in existing agricultural, industrial and commercial enterprises, by acting as a stimulus to the establishment of further enterprises and by providing a broad range of social benefits to rural households and communities (2.8, 2.9). This view-point is supported by the major role played by rural electrification in both the USA and the USSR in integrating vast rural areas into the modern economy (2.10). China also has made considerable use of rural electrification to increase productivity in both agriculture and small-scale rural industries and 500,000 of its 710,000 villages are now electrified (2.11).

Many developing countries have initiated ambitious rural electrification programmes. On a global level, millions more people are provided with access to electricity supplies each year. Among developing countries, the highest rates of rural electrification are found in South Korea and Taiwan. Virtually all of Taiwan has electricity and its rural power system is one of the most well

managed in the world, reflecting the general level of affluence and education in the country. In India over 55% of villages are now connected to an electricity grid. In some parts of the country the share is much higher and in the states of Kerala, Punjab, Haryana and Tamil Nadu all villages now have electricity. However, even in electrified villages, often over 50% of households are not connected to the supply (2.12). The Philippines is another country pursuing an aggressive rural electrification policy and it aims to have all areas electrified by the end of 1987 (2.13).

Proponents of rural electrification suggest that it offers a wide range of economic and social benefits (2.14) which may include:

- a) pure and safe drinking water due to electrified pumping with a subsequent reduction in the levels of gastro-intestinal disease.
- b) improved diet and reduced incidence of gastro-intestinal disease as the result of improved food storage facilities through refrigeration.
- c) better services at health clinics due to improved lighting, refrigeration, more efficient sterilization procedures and possibly the ability to operate new equipment such as X-ray machines.
- d) convenience and lower cost of house lighting,
- e) increased quality of life due to electrical household appliances such as radios, cookers and sewing machines.
- f) generally increased evening activities.
- g) new entertainment activities such as movies and videos.
- h) increased use of educational facilities at night.
- i) improved literacy.

- j) lower birth rates.
- k) reduced migration from an electrified area.
- l) increased agricultural production due to electrified irrigation pumping, mechanization of processing operations and the ability to process and pack at night.
- m) increased productivity in existing commerce and industry.
- n) attraction of new industrial and commercial enterprises.
- o) increased employment and income due to increased productivity.
- p) the possibility of women taking employment as a result of the reduction in the demands of their household chores through the use of electrical appliances.
- q) conservation of scarce fuel-wood resources.

In addition, it has been claimed that the provision of electricity is part of the process of modernization; by bringing about changes in attitude, electricity can help the spread of innovation (2.15, 2.16). Rural electrification can also serve various political goals; it is seen as a way of unifying a country with different ethnic groupings and thereby consolidating political power; it is also seen as a status symbol associated with development and politicians have found that rural electrification programmes are popular and can help their careers. Thus, in Sri Lanka, until 1979, 62% of rural electrification funds were disbursed by local M.P.s, whilst in Pakistan, until 1977, villages were selected for rural electrification on political criteria. In some areas of Malaysia, the Philippines and Thailand rural electrification was explicitly justified and implemented to serve national security objectives (2.17).

2.3. The Impact of Rural Electrification

Many studies have attempted to assess the impact of existing rural electrification programmes. The large number of variables involved, the difficulty of quantifying some of the claimed benefits and of demonstrating causal relationships limits the validity of their conclusions and the extent to which results from different studies can be compared. However, it is clear that the performance of rural electrification programmes has in many cases been disappointing with many of the anticipated benefits failing to materialize (2.18, 2.19).

2.3.1. The Economic Performance of Rural Electrification Programmes

The provision of electricity supplies, especially to rural areas, involves high levels of capital investment in transmission and distribution systems. Low income levels mean that large sections of the rural population cannot afford the tariffs, connection charges, and appliance purchase necessary to make use of electricity. As a result, administrative costs are also likely to be higher and revenue per consumer lower than for a typical urban system.

For reasons dealt with below, the forecasts of both initial demand and rate of growth in demand used in planning rural electrification programmes have often been over-optimistic in the past. This has meant that in many cases both the load factor (defined as the ratio of average to maximum demand) and the plant factor (defined as the ratio of average load to plant capacity) have been low. A load factor of between 8% and 20% during the early stages of rural electrification is common in comparison with a typical urban load factor of 55% (2.20). This implies that plant is being under-utilized and that revenue from electricity sales is limited. In some cases revenues are insufficient to cover operation and maintenance costs let alone servicing of investment loans (2.21). Under these circumstances long term subsidy of the programme is necessary. This problem has not been confined to the developing world and;

"From a strictly financial and commercial view-point, it was difficult to justify rural electrification even in developed countries. As a result, large programmes for rural electrification have always had direct or indirect governmental support through soft-term credit, direct or indirect subsidies, or outright grants." (2.22)

For many developing countries shortages of development capital impose constraints to the number and type of development projects that can be undertaken. Thus, relatively and absolutely large subsidies to rural electrification programmes limit investment opportunities in other sectors and can place a significant burden on national economies. Such a situation might be acceptable if rural electrification demonstrated the full range of expected benefits, and if rapid load growth meant that subsidies were relatively short term. However, in general this does not appear to be the case. It has further been argued that each of the suggested benefits of rural electrification can more effectively be met by other means (2.23).

2.3.2. Rural Electrification and the Household

Many poor rural households cannot afford to be connected to the power supply. For those that can, power is often used for lighting only. It is only relatively well-off households that can afford to make use of a wide range of appliances so that subsidies of rural electrification benefit the rural elite rather than the rural poor (2.24). Heating/cooking uses relatively large amounts of energy and electricity, being relatively expensive, is rarely used for these purposes in rural areas. As a result rural electrification has little impact on deforestation (2.25, 2.26). Except in well-off households, women's work in the home is not lightened by electrification. In fact, lengthening of the workday may make the plight of women and servants more oppressive (2.27). It would also appear that, rather than reducing migration to urban centres, rural electrification increases it. In particular, out-migration has been found to be higher from unelectrified households in electrified villages (2.28).

There are few rural industries for which the provision of electricity is essential, and in many cases users of power equipment such as pumps and agro-processing mills derive benefits from subsidized electricity prices, not from any inherent quality of electricity. Further the cost of energy is only a small proportion of total costs for many operations and it is argued that a number of other factors such as lack of access to credit and marketing facilities impose greater constraints to small business development than lack of electricity (2.29, 2.30). However, when it is justified, many small industrial and commercial enterprises generate their own supplies in unelectrified areas (and continue to do so in areas that have been electrified). It would appear that the presence of credit, marketing, transport and other infrastructure elements has a greater degree of influence than electricity over the degree to which rural industries develop;

"Investigators are nearly unanimous in finding that industries come up in towns enjoying economic advantages because of location, market density, transport infrastructure, and commercial dynamism. These are precisely the first places to be electrified and this report suggests these places....as most appropriate for rural electrification....Conversely, rural areas not enjoying other advantages....but having electricity will not normally attract industry. There are a few exceptions to this such as small-scale agro-processing based on village produce....." (2.31)

In addition, rural electrification appears to have a neutral or negative effect on employment, at least in the medium term. Mechanization in industry and agriculture does lead to increased productivity for the producer, but reduces labour requirements for the same output. In many cases the lack of a market for expanded production of goods leads to employment reduction rather than creation. In addition, electrified enterprises can often compete more effectively with non-electrified enterprises and so reduce employment indirectly. Since electrification alone does little to stimulate new industries, job creation in this way is minimal. Women

appear to suffer job losses due to rural electrification more frequently than men (2.32).

2.3.4. The Social Impact of Rural Electrification

The social benefits of rural electrification may derive from several different sources. Increased employment and/or income as a result of electrification can create social benefits through increased spending power. Electrification may mean that services offered by local businesses are improved, for example freezers may result in a wider variety of goods being offered by stores. Social benefits may result from household use of electricity, for instance through increased evening activities, or benefits may derive from new or improved community or municipal services as the result of electrification. However, rural electrification projects are not usually directly concerned with the provision of community appliances or facilities. Several studies have found that many schools, community centres and health centres remain unconnected to the power supply, so that the social impact through formal channels is limited (2.33).

2.4. Implications for Future Rural Electrification Programmes

In the light of existing evidence, the 1983 Report of the Regional Rural Electrification Survey to the Asian Development Bank (ADB) (2.34) suggested that there was a need for a reassessment of rural electrification programme planning. In particular, it was found useful to distinguish between three types of rural electrification project according to the aims that they were attempting to fulfil. These three categories were:

- 1) Supplying power to peri-urban and dynamic rural areas characterized by an existing demand for electricity, an established and growing economic base, good infrastructure, high population density and high average incomes. Such schemes can be viewed as being potentially

financially viable. Most households should be able to afford connection although it may be desirable to subsidize initial connection charges to poorer households.

- 2) Schemes in which the provision of electricity is seen as part of an integrated rural development package. Project genesis should come from rural development departments and electrification should be the real least-cost means of energizing the project area. In many cases other infrastructure projects will have a higher priority. For such schemes financial viability is only likely with considerable complementary investment.
- 3) Schemes in which the provision of electricity is seen as serving social needs and improving social infrastructure. Such schemes are justified on their presumed social impact; altering aspirations, creating a market orientated cultural climate etc. Projects are competing directly with other social infrastructure projects and it must be demonstrated that electrification has a higher priority than these. There is little likelihood of these projects being financially viable and subsidies are likely to prove necessary to stimulate load growth.

2.4.1. Planning Implications

It was stressed that different planning approaches were needed for each of the three categories and that the impact of rural electrification was unlikely to be large except in areas with an already dynamic economy, or where major complementary investments were made in rural development. The following planning implications were suggested by the report:

- a) Attention must focus on the full opportunity costs of rural electrification to ensure that investments do not detract from higher priority rural development needs.

- b) Justification of rural electrification on the basis of its presumed role as a catalyst to development, as necessary to agricultural or rural growth or to health, education, or water supply improvement, or as a brake on rural out-migration, is not warranted by experience to date.
- c) The Financial Internal Rate of Return (FIRR) of Category One projects should indicate that they are commercially viable. Tariffs should reflect the cost of service and subsidies to poor households should not be used to justify a poor FIRR.
- d) Investments in Category Two projects should only be made when rural electrification is part of an integrated rural development plan. Careful attention should be paid to the complementary investments to ensure that they result in the anticipated benefits. Explicit links should be planned into the project to demonstrate how production gains can be brought about. Projects should show positive FIRR's unless explicit government subsidy transfer is made.
- e) For Category Three projects emphasis should be on efficiency through cost reductions. Investments in category 3 rural electrification should be undertaken with extreme care and recognized as having sharply limited economic benefits gained at high cost. The social benefits expressed in terms of motivational changes are quantitatively indeterminate but may be significant.
- f) Government targets expressed in terms of the number of electrified villages or extension to outlying districts are incompatible with the objective of maximizing economic benefits.

2.5. The Role of National Power Utilities in Implementing Rural Electrification Programmes

The national power utilities of most developing countries are government-owned monopolies with strong political connections. Many of them are troubled by deteriorating financial positions and management problems exacerbated by the rate at which they have expanded, and the worsening state of their national economies. In some cases, these problems, combined with the need to subsidize rural electrification programmes that have shown disappointing benefits, have meant that rural electrification programmes have come to a virtual standstill. Existing programmes have tended to concentrate on areas where grid extension is relatively easy and economical. These tend to be heavily populated agricultural plains and prosperous rural areas surrounding major urban and industrial centres. Many remote and less densely populated regions are left unaffected and have little prospect of receiving grid extensions in the medium term (2.35).

2.5.1. Organizational Problems with National Power Utilities

Centralized national power utilities are not ideal agencies for implementing rural electrification programmes, especially when programmes are part of an integrated rural development programme, or are designed to serve remote regions with decentralized generation projects. There are a number of reasons for this which include (2.36):

- a) the fact that national utilities rarely exhibit the kind of sensitivity to local conditions that is required for successful implementation of micro hydro and other renewable energy projects. However, they can work creatively with local organizations by providing finance or skills.

- b) the fact that co-ordination at national, regional and local level is required both internally and with agencies supplying complementary inputs for rural development.
- c) the difficulty of integrating non-technical, sociological and developmental issues in traditionally engineering orientated organizations.
- d) the financially unviable and politically sensitive nature of many rural electrification projects.
- e) the technical, administrative and staffing problems posed by the rural nature of projects.

2.6. Appropriate Rural Electrification Organizational Structure

As a result many countries have established separate rural electrification agencies. Evidence suggests that decentralized projects under centralized co-ordination can be more effective than totally centralized programmes. India and the Philippines have both found this pattern of organization effective (2.37).

2.6.1. The Organization of Rural Electrification in the Philippines

Based on the organizational structure adopted for the 1930's programme of rural electrification in the U.S.A., the Philippines government established the National Electrification Administration (NEA) as a publicly owned corporation in 1971. It was given wide powers to establish, finance and generally oversee the performance of electric co-operatives which are responsible for electrification activity at local level. The NEA's responsibilities include:

- a) centralized procurement of supplies and equipment,

- b) determination of priorities and policy, including regulatory control of tariffs and the authority to grant or revoke franchises,
- c) technical assistance,
- d) monitoring of co-operative management and performance,
- e) acquisition of funding from the government and from international agencies,
- f) the power to appoint and dismiss co-operative managers and Boards in cases of extreme mismanagement.

Acting as intermediaries between the NEA and the electric co-operatives and limiting any tendency towards centralization are two further agencies. These are the Provincial Electric Co-operative Teams and the District Electrification Committees with members selected by the NEA and the local people.

Electric co-operatives are local agencies owned by their members and managed by local staff. Although in some cases co-operatives generate their own supplies it is more common for them to purchase these from the national utility. When effectively managed, co-operatives can play an important role in encouraging productive use of electricity for example by organizing low interest loans for machine purchase and by offering extension and training services (2.38, 2.39, 2.40).

2.7. Conclusions

Rural electrification programmes in developing countries have, to date, required substantial subsidization and the social and economic benefits to consumers have often been limited. However, the impact of electricity supplies and levels of consumption were also initially low in newly electrified rural areas of the USA. Extensive rural electrification is only a relatively recent phenomenon in the Third World and electricity use for industrial, commercial,

agricultural and social purposes will continue to increase over time.

As rural electrification programmes involve high levels of capital expenditure and development resources are limited in most developing countries, it is important that resources be used effectively. It is clear that the provision of electricity alone does not act as a catalyst to rural or regional development. To produce significant benefits electrification efforts need to be linked with other rural development initiatives. Organizational structures must reflect this need.

Where rural electrification is undertaken to provide social benefits or to attempt to reduce regional disparities the costs involved must be clearly recognized.

Electricity as an energy source is not suited to the main energy needs of the rural poor and in situations where communities are suffering from shortages of bio-mass fuels the provision of electricity is not likely to improve the situation.

3. Power Sources for Electricity Generation

3.1. The Scale of Generating Facilities

Large and small are relative terms. With regard to electricity generating facilities, plant that may be considered small in the U.S.A. can be large in terms of the electricity requirements of a small developing nation. To be more specific, the Ramu hydro-power development in Papua New Guinea, with a currently installed capacity of 45 MW, is large in terms of the requirements of that country, although small in comparison with the 12.6 GW Itaipu plant currently under construction on the border between Brazil and Paraguay. It is therefore important to consider not only standard definitions of plant size, but also the scale of plant in relation to the actual requirements of a particular nation. Thus, for the purposes of this discussion, large-scale refers to plants that feed into a national or regional transmission network and exceed 10 MW installed capacity.

3.2. The Cheap Oil Era

For much of the post-war period, and during the 1960's in particular, there was a rapid expansion in the generating capacity of electrical power systems in most developing countries. Much of this expansion was based upon plants utilizing petroleum products as their primary energy source (3.1). For large-scale plants this meant oil fired thermal plants, with gas turbines and diesel generator sets being installed at lower capacities. The predominant reasons for this heavy reliance upon petroleum products were as follows (3.2, 3.3):

- a) on the world market, petroleum products were cheap.
- b) petroleum products are easier and cleaner to handle than alternative fuels, such as coal.
- c) the specific cost (defined as capital cost/kW of installed capacity) of alternative generating systems

such as coal fired plants, hydro-power projects, and nuclear reactors was typically significantly higher than for systems using petroleum products.

- d) many developing countries are poorly endowed with fossil fuel reserves, so that expansion in generating capacity meant relying upon fuel imports.
- e) some alternative energy sources, such as geothermal were relatively new and unproved.
- f) the western powers were not keen to see the proliferation of nuclear reactors in developing countries.

Thus, many developing countries became increasingly dependent upon petroleum product imports to meet their energy needs. However, between November 1973 and January 1974 the price of crude oil increased by 287% (3.4). For the non-OPEC developing countries (excluding China), one result of this 'oil crisis' was that the cost of fuel imports as a percentage of total import expenditure rose from 12% in 1973 to 23% in 1977. The worsening world economic situation made it difficult to expand exports to compensate for increasing fuel prices; this in turn led to the foreign exchange reserves of these nations being put under extreme pressure (3.5).

3.3. Hydro-Power

In the electricity production sector, increased oil prices meant that the operating costs of oil fired plants rose considerably and their attractiveness was seriously undermined. This led to increased interest in reducing dependence upon imported petroleum products. Measures proposed to achieve this aim included encouraging energy conservation, paying greater attention to energy pricing, and developing indigenous energy resources (3.6).

Many developing countries have substantial unexploited hydro-power resources. It is estimated that only 14-16% of the world's potential has been developed to date (3.7). Large-scale hydro-power schemes

are major engineering projects involving high levels of capital investment, long lead time and high specific cost. It is important that final designs are optimized to maximize economic performance and ensure safety and reliability of operation. Many potential large-scale hydro-power sites are found in mountainous regions, sparsely populated and remote from major population centres. Long distance high voltage transmission is therefore often required, again adding to overall costs (3.8).

In many developing countries the skills needed for the design of such schemes are lacking and it is necessary to make use of overseas consultants whose services are expensive. Similarly, much of the equipment, especially the turbine and generating equipment, is likely to be sourced from overseas, as are personnel for construction supervision (3.9). As a result, foreign exchange components are likely to make up a significant proportion of the overall costs of large-scale projects. Because of their long lead times and capital intensive nature, the viability of such projects is closely linked to prevailing interest rates and the terms on which finance can be obtained. While oil prices had been low the high specific cost of hydro-power projects had limited their attractiveness; however, water, the 'fuel' used in hydro-power developments, is essentially a free and renewable resource. Thus, once constructed, hydro-power projects are characterized by low operation costs and can play a significant role in reducing a nation's dependence upon fossil fuel imports. Thus, although interest rates were generally high during the 1970's, there has been a significant increase in interest in hydro-power development and several very large-scale schemes have been completed or are under construction (3.10).

3.4. Small-Scale Plant

In many developing countries a fully integrated national transmission grid has not yet been developed and many towns, let alone villages, remain isolated from a grid supply. Nevertheless a public supply of electricity may be available at these centres with

generators being operated on an isolated basis to supply individual centres. In addition, industrial, commercial, or agricultural businesses may generate their own electricity supplies. Generators may range in capacity from a few kW to several MW. At the upper end of this scale gas turbines, diesel generator sets and hydro-power plants may be considered as the main options; however, as the scale of plant decreases gas turbines become inappropriate. Petrol generators may be considered under some circumstances, especially for installed capacities below about 10 kW (3.11).

During the 1960's diesel generator sets were widely used to generate power in stand-alone situations. Suitable generator sets were, and are, readily available off-the-shelf at low specific cost. Their installation requirements are minimal, they can be located close to the point of demand and they are relatively simple to operate. But diesel generator sets have relatively short lives and demanding maintenance requirements. In addition, for most developing countries both the plant and fuel are likely to be imported (3.12,).

As with larger-scale oil fired thermal plant and gas turbines, the operating costs of diesel generator sets rose significantly as a result of the oil crisis, creating an upsurge in interest in alternative energy sources, one of these again being hydro-power (3.13). This thesis restricts its interest to hydro-power projects with total installed capacities of 1,000 kW or less, with primary consideration given to projects whose total installed capacity does not exceed 100 kW. Projects of this scale are generally classified as micro hydro-power projects, whilst projects with total installed capacities of between 100 kW and 1,000 kW are classified as mini hydro-power projects (3.14).

3.5. Micro and Mini Hydro-Power

Hydro-power projects offer significant economies of scale. As projects become smaller, the proportion of overall costs absorbed by professional engineering services to conduct pre-feasibility, feasibility, hydrological, geological and design studies tends to

rise with unfortunate effects upon the specific costs of projects. The design and manufacture of turbine and generating equipment to optimize performance under specific site conditions also becomes increasingly costly as the scale of projects is decreased. For micro hydro-power projects and to a lesser extent mini hydro-power projects it is necessary to greatly simplify and even abandon some of the design and implementation procedures used for large-scale projects if specific costs are to be held within reasonable limits (3.15, 3.16). At the same time the simplicity that may be achieved, particularly at the lower end of the scale range can make projects applicable in rural areas where technical skills are limited (3.17).

3.6. The Physical Components of a Micro Hydro-Power Project

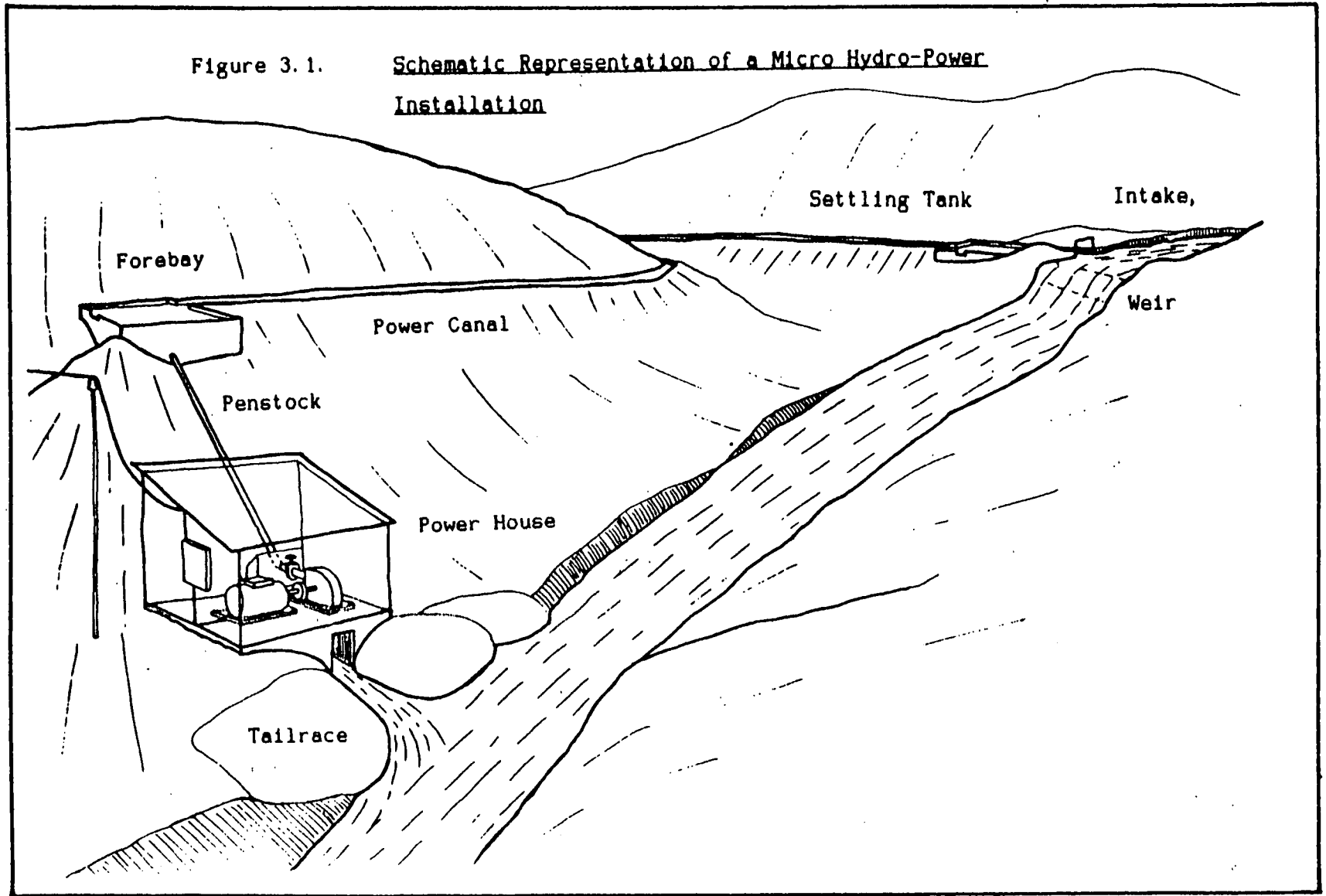
Water flowing in a stream or river has both kinetic and potential energy. In a micro hydro-power installation a proportion of that energy is extracted to provide power for any of a number of purposes. The energy that can theoretically be extracted at a given site depends on the volumetric flow rate of the stream, or that portion of the flow that is diverted for power generation purposes and the head through which the water descends. The actual amount of energy that can be extracted depends upon the efficiency of the extractive device (turbine or water wheel) under the site conditions and on the efficiency of the structures that feed water into the extractive device (3.18).

Figure 3.1. shows a diagrammatic representation of a typical micro hydro-power installation.

3.6.1. The Civil Works

In this scheme a low weir is built across the stream, raising the level of the water behind the structure to create a small area of pondage. Behind or incorporated into the weir is an intake structure which diverts water from the stream into the power canal. Few micro hydro-power projects incorporate significant dams for

Figure 3.1. Schematic Representation of a Micro Hydro-Power Installation



either storage or head gaining purposes since they require a significant engineering input (3.19). Most operate on a run-of-river basis and it is sometimes possible by careful siting of the intake structure to also avoid the need for a weir. The pool formed behind a natural rock bar across the stream bed may be used, or a temporary weir of loose boulders may be constructed (3.20).

The intake structure will usually include a sluice gate (or some other flow control device) to allow regulation of flow into the power canal (also often known as the headrace). A trash rack is also normally installed to prevent floating debris entering the power canal. The power canal is excavated with a minimal gradient to gain height (or head) over the stream bed. If possible, it should be routed to avoid areas of difficult terrain since dealing with slope stability problems, constructing flumes and/or tunnels can add significantly to costs. If difficult terrain cannot be avoided a low pressure pipeline is sometimes used in place of a power canal (3.21).

Water passing through the intake is likely to carry a load of sediment which can damage the turbine runner. By reducing the velocity of water either in a settling tank, sited near the intake, or at the forebay, at the end of the power canal, much of this sediment will settle out and accumulate at the base of the structure. Periodically this can be flushed through an outlet provided. At the forebay a second trash rack is normally installed to intercept floating debris that may have entered the power canal. The forebay also serves as a small reservoir to limit surges in the water level of the power canal when the plant is being closed down, brought into operation, or when there are large changes in consumer load (if a conventional governor is being used). The forebay will be situated at some height above the power house, the greater the height the greater the power that will be available. Having deposited its load of sediment and trash, water from the forebay will enter the penstock; this pipe or conduit may be constructed from a wide range of materials, PVC being a common example for micro hydro-power plants since it is relatively cheap, light and easy to

install. The penstock feeds water into the extractive device (turbine) situated in the power house and usually incorporates a valve at its lower end so that flow to the turbine can be shut off (3.22).

Civil works must be designed to withstand the maximum flood flows that can reasonably be expected. It is unlikely that the headrace channel or forebay of a scheme will be required to cope with full flood flows, but it is important that controls or spillways ensure that the flow entering these structures can be properly regulated (3.23).

3.6.2. The Power House and Power Generating Plant

The power house should be situated close to the level of the stream, maximizing available head, but above flood level. There is a range of different extractive devices suited to differing site conditions. Whichever type is used, water leaves the penstock via nozzles or guide vanes and passes through the turbine or water wheel and is discharged back into the stream via the tailrace.

Water impinging on, or flowing through, the turbine or water wheel imparts a force on its blades or buckets causing it to rotate. The speed of rotation is dependent upon the type of runner, the head and flow conditions under which it is operating and the load to which it is connected. Various devices may be driven by the turbine either directly, via belt, chain drive, or through a gearbox. Common devices are saw-mills and grain-mills, and if these mechanical implements alone are used it is likely that control of turbine speed and output will be achieved by manual adjustment of a valve controlling flow into the turbine (3.24).

Turbine Types

Water wheels have been used for many centuries to extract power from water. However, the output of these traditional devices is limited to a few kW because of the limited head and flow that can be

utilized. They are also relatively inefficient and have low rotational speed which is a disadvantage for some applications particularly electricity generation. A range of turbines has been developed that offer higher efficiencies, higher rotational speeds and the ability to exploit higher heads and greater flow rates (3.25).

Reaction Turbines

A reaction turbine is designed to extract pressure energy from a column of water as it passes through the turbine runner. During operation the runner runs full of water. Water enters the runner under pressure and exerts a force directly on the blades, imparting energy to it. This causes a reduction in the pressure of the water itself as it passes through the runner. The runner is housed in a casing which must withstand the pressure of the water column. In addition, clearances between the runner and its casing need to be minimized to limit leakage losses. The range of reaction turbines includes Francis, Kaplan and propeller units (3.26).

Francis turbines are generally considered for medium head sites. However, the complex cast shapes of turbine runners and the need for fine manufacturing tolerances mean that they are generally too costly for the lower scale end of the micro hydro-power market (3.27).

Propeller and Kaplan turbines are suited to low head sites where they operate at high speed. The efficiency of propeller units is good over only a narrow range of flow conditions, whilst the adjustable blades of the Kaplan turbine maintain its efficiency over a wider range. For micro hydro-power plant automatically adjustable blades add significantly to costs, however turbines are available with blades that can be mounted in a range of alternative fixed angles to suit differing flow conditions (3.28).

Impulse Turbines

An impulse turbine is designed to extract principally kinetic energy from a high speed jet of water. The pressure energy of a water column is dropped across a nozzle and converted to kinetic energy. The jet of water is directed at the turbine runner and imparts much of its momentum to the runner as it strikes. The housing is not required to withstand high pressure. Pelton and Turgo units are both impulse type turbines and suitable for high head sites. For both types their range of application and power output can be increased by the addition of one or more additional jets (3.29).

Turbines: Developments and Trends

Turbines are often the most expensive component of a micro hydro-power project. Many units continue to be scaled down versions of large-scale equipment. However, a range of standard equipment makes it possible for manufacturers to spread design and development costs over many units and some manufacturers are now following this path (3.30). The use of standardized equipment implies a certain loss of efficiency since equipment is no longer optimized for the specific site conditions. But at micro hydro level the benefits of reduced cost generally outweigh the disadvantage of reduced plant efficiency. Indeed it may be argued that there is a case for further reducing costs by using simplified designs (and manufacturing methods) (3.31).

In several developing countries local manufacture of turbines is now being undertaken. Interest has focused particularly on cross flow turbines. These turbines are usually classified as impulse turbines although their operation does contain a reaction component. They have slightly lower efficiency than most other turbine types, but have a very flat efficiency curve and are capable of dealing with a wide range of flows (3.32). They are applicable across a wide range of heads, and by varying the runner width the same basic design can be used to cover a wide range of outputs. They can be manufactured

with relatively basic facilities, and the turbine housing does not need to withstand pressure (3.33).

Relatively inefficient and low cost turbines will not always be the best choice. For a given power output it is necessary for a low efficiency turbine to operate under a greater head and/or utilize a larger flow than a more efficient unit. This has implications for the scheme's civil works costs. The reduced cost of the turbine must therefore be balanced against any increase in civil works costs. In addition, at some sites limited stream flow and/or head may mean that the desired power output can only be obtained by using equipment of high efficiency (3.34).

3.6.3. Electricity Generation and Control

Often the turbine drives an electric generator, in which case some sort of automatic control is generally provided to match turbine output and load. Conventionally this control is achieved by a hydraulic/mechanical governor that responds to changes in turbine speed (as a result of varying consumer load or flow conditions) by altering the flow of water to the turbine (3.35). A recent development is the electronic load controller which monitors the output frequency (or in some cases current) of the generator and maintains this within prescribed limits by switching in and out 'dump' loads in response to changes in consumer demand. The load controller is cheaper than a conventional governor and having no moving parts is inherently more reliable. It also offers scope for reducing the costs of the turbine since the adjustable wicket gates or spear valves controlled by a conventional governor become redundant. In addition, pressure surges in the penstock are limited since flow through the turbine is essentially constant. Therefore the penstock can be designed to withstand operating pressure only (3.36).

Conventionally, synchronous machines are used for stand-alone micro hydro-plants. For capacities above about 15 kW three phase machines are normal as they are more compact and cheaper than equivalent

single phase units. Most generators of less than 100 kW capacity are mass-produced, 2 pole pair machines designed for direct drive at 1,500 rpm by diesel engines. It is important for micro hydro-power applications that the generator is designed to withstand the runaway speed of the turbine. This may be as high as 250% of rated speed and wire wound rotors can rarely withstand such speeds unless specifically designed to do so. Where a suitable generator is not available it may be possible to install an overspeed clutch between the turbine and generator (3.37, 3.38).

Generators with brushless excitation systems are well suited to stand-alone operation since they are capable of starting without relying on remanent magnetism or an external power source, of being able to boost excitation current during sudden drops in output voltage and of avoiding the maintenance requirements of brushes and slip rings. However, the shaft mounted excitation generators make them expensive so that they can usually only be considered for projects towards the top end of the micro hydro-power range. Thus, brushed shunt excited machines are most often used (3.39).

Induction motors are sometimes used as generators when running in parallel with the grid or another generator. Although their efficiency is slightly lower than that of a synchronous machine, they are cheaper, simpler, more robust and more readily available. In addition, they do not require synchronization with the supply. But they are not generally used in stand-alone situations since they require an external source of magnetizing current. Some experimental work has been carried out using capacitors in parallel and series with system load, as a source of reactive power (3.40, 3.41).

If electricity is being generated a range of monitoring and safety equipment is also usually installed to protect both the equipment and life. Often the electric load or loads will be located at some distance from the power house making transmission necessary. As distance increases it rapidly becomes necessary to move to high voltage transmission to avoid excessive losses (3.42, 3.43).

In some cases it may be possible to implement a micro hydro-power project that avoids one or more of the elements shown in the diagram. For example, in low head schemes the dam, embryonic penstock and power house may all be incorporated into one structure completely eliminating the power canal and forebay (3.44).

3.7. The Costs of Micro and Mini Hydro-Power Projects

Internationally there is a wide range in the specific costs of micro and mini hydro-power projects. This reflects:

- a) the tendency for specific costs to increase as installed capacity decreases (3.45).
- b) the site specific nature of hydro-power projects. Thus, high head sites are generally cheaper to develop, but slope stability problems encountered at any project can add significantly to development costs (3.46).
- c) differences in the standard of engineering adopted. A 'large-scale' approach to project design tends to result in costly projects, whereas the use of locally manufactured equipment can significantly reduce costs (3.47).
- d) differences in the approach to project implementation. Thus, for small plants, community involvement in project implementation will often, but not always, result in lower project costs than the use of commercial contractors (3.48).
- e) differences in the costs of labour and materials between countries and different capabilities for local manufacture of project components (3.49).

These factors make it difficult to generalize about project specific costs. However, evidence suggests that by fully involving local communities in project implementation, using labour intensive

construction methods and adopting an 'appropriate' design approach the specific costs of micro hydro-power projects can generally be kept below US\$ 2,000/kW. Indeed, where conditions are favourable, projects with specific costs of less than US\$ 1,000/kW have consistently been developed, for example in Pakistan (3.49). Where a conventional approach is adopted project costs will tend to be significantly higher and specific costs are likely to be in the range US\$ 3,000 - 6,000/kW (3.50, 3.51, 3.52, 3.53, 3.54, 3.55, 3.56).

Some of the cost reduction options applicable to micro hydro-power projects become less appropriate as the scale of projects increases. For mini hydro-power projects, especially larger mini hydro-power projects, a more conventional engineering approach becomes necessary, but some economies of scale also become apparent. These effects tend to counteract each other and evidence suggests that typically the specific costs of mini hydro-power projects are found in the range US\$ 2,000 - 4,000/kW (3.57, 3.58, 3.59, 3.60, 3.61).

3.8. The Role of Micro Hydro-Power in the Rural Areas of Developing Countries

Although electricity supplied by micro hydro-power plant may feed into a large grid system, this is not common in developing countries. Projects are more often developed, by either private or public concerns, to supply power to an isolated system which may consist of a single village, institution, and/or one or more business enterprises (3.62).

The small scale of micro hydro-power projects does not mean that they cannot make a significant contribution to the energy needs of isolated rural areas where incomes are relatively low and the consumption of electricity by individual households reflects this. Thus, in newly electrified areas household consumption of electricity averages less than 40 kWh/month (3.63). A feasibility study for a rural electrification project in Papua New Guinea forecast average household consumption at 8 kWh/month for the first

few years of project operation (3.64). As described in Section 2.3.3., productive use of power also tends to be limited in such areas. Small generating plants can therefore meet the needs of communities of significant size. Thus, a 100 kW generating plant operating at 50% plant factor is capable of generating 36,000 kWh/month. Assuming a household consumption of 36 kWh/month such a plant is capable of supplying power to about 1,000 households. At a consumption rate of only 8 kWh/month over 4,000 households could be supplied.

In practice, domestic load is heavily concentrated in the evening hours so that a plant factor of 20% may be more realistic (3.65). Even so, a 100 kW plant is capable of supplying power to several hundred households, and additionally has the potential for use as a source of power for various social and productive uses during daytime hours. Micro hydro-power projects do therefore have the potential to make a significant contribution to the energy needs of rural communities, businesses and institutions. Individual projects may be implemented to serve a number of different objectives. These include (3.66):

- a) replacing existing diesel generator sets as a means of reducing national dependence upon fossil fuel imports.
- b) replacing existing diesel generator sets as a means of expanding electricity supplies at rural centres and making power available 24 hours/day.
- c) replacing existing diesel generator sets with a cheaper alternative.
- d) using projects as a means of improving the social infrastructure of rural communities by providing power to schools, community centres, health centres etc.
- e) using projects as a means of improving the economic infrastructure of rural communities in the hope that

power will be used to improve productivity and employment.

- f) serving the energy needs of specific industrial or commercial enterprises, or government or private institutions.
- g) using projects as part of a broader investment programme aimed at selected centres in isolated rural areas to encourage their development as service centres or central places.

An individual project, justified on the basis of a particular objective, will in practice often have secondary effects. For example, a project aimed at replacing a diesel generator with a cheaper energy source may also result in social benefits if surplus power is made available to a local school, community centre or health centre.

Because of their limited scale, micro hydro-power projects are rarely of interest to national power utilities. The financial returns on projects are small and the technical and management resources tied up in project implementation tend to be disproportionately large. Instead micro hydro-power projects tend to be developed by agencies specifically involved in rural electrification or rural development, or by individual businesses or entrepreneurs to meet their specific energy needs (3.67).

"It is increasingly recognized that the development of micro hydro-power schemes holds out more promises for contributing to rural development than for significantly increasing a nation's indigenous energy-generating capacity. If the government is to implement such schemes, their effective implementation requires that the government agency involved in rural development, co-operatives, small industries, or possibly agriculture, rather than that involved in the power sector should take on the responsibility." (3.68)

3.9. The Rationale for Establishing a Micro Hydro-Power Support Agency

Much can be done to simplify micro hydro-power projects and reduce their initial cost by careful site selection, attention to design, and implementation procedures. Nevertheless, micro hydro-power projects remain relatively complex engineering projects generally involving significant on-site excavation and construction. Normally a period of at least one year can be expected to elapse between initial feasibility investigations and project commissioning.

In contrast, diesel generators are readily available and have minimal installation requirements. Over its life-time a micro hydro-power project may offer clear economic advantages over a diesel generator set. However, potential developers of micro hydro-power projects often have limited financial resources. Commercial banks are generally not interested in funding projects because of the lengthy pay-back periods involved. It is therefore often the specific cost of a project rather than its long term financial viability that determines whether or not it goes ahead (3.69).

To make matters worse, micro hydro-power is essentially a new technology for the rural populations of large parts of the Third World. Even where water resources have traditionally been harnessed to provide power for small-scale industries, the replacement of traditional water wheels with turbines, the development of significantly higher head sites than is possible using traditional technologies, and the generation of electricity combine to mean that micro hydro-power projects take on many of the aspects of a new technology. The technical and management skills necessary for successful project implementation are therefore unlikely to be available locally. Even at national level these skills are likely to be costly and in short supply (3.70).

"In some countries, local technical experience [of micro hydro-power project implementation] is not readily available and consultants may be employed. However, few

consultants have experience either in implementing cost effective micro hydro-power schemes or in the conditions encountered in rural areas of developing countries. Also, the high costs of consultants can significantly increase the cost of implementing a scheme. For these reasons, resorting to consultants is often not a viable option." (3.71)

Even if finance and professional technical assistance can be obtained the short pay-back period of a commercial loan and the high cost of engineering services are likely to jeopardize project viability.

Finally, even a well designed and constructed micro hydro-power project requires routine maintenance and will suffer from occasional faults and failures. It is therefore important that the on-site operator is familiar with the technical aspects of the scheme and is able to carry out routine maintenance and minor repair work. In addition, for more serious faults professional repair services should be available at reasonable cost.

Projects approached on an isolated basis are therefore faced with a number of costly and difficult obstacles. Often these prevent implementation of potentially viable projects. However, if there is widespread interest in developing micro hydro-power as part of a rural electrification or development programme then there is significant scope for alleviating these problems through the establishment of a suitable support agency (3.72).

3.10. The Functions of a Micro Hydro Support Agency

The agency is likely to be established as an agency or department of a national or regional government and principally concerned with implementing projects seen as serving the policy objectives of the government. However, the services and resources of the agency may be made available to private entrepreneurs or to communities outside the official programme on a commercial basis. A number of areas with which a support agency may be concerned are discussed below (3.73).

3.10.1. Development of Policy and Project Selection Criteria

The agency needs to develop a policy which ensures that its activities are in line with both the government's and its own objectives. Its resources are unlikely to be sufficient to enable the implementation of all potentially viable projects. A clear set of selection criteria is therefore essential. The criteria are likely to cover technical, financial and economic viability, existing and potential energy end uses, and the relationship of the project to other local development initiatives. In formulating selection criteria different factors can be weighted to reflect agency policy. Thus, for example, projects that are technically simple to implement at low specific cost will receive priority (3.74). Similarly, although many projects will not be financially viable, some will offer significantly better economic returns than others, especially where productive end uses of power improve plant factor (3.75).

Potentially a large number of factors are involved, but it is more important that the criteria be clear and practical than totally comprehensive (3.76).

3.10.2. Technical Services

The agency is likely to be established with a core of technical staff involved in examining the feasibility of potential projects, carrying out the detail design of selected projects and correlating available hydrological and geological data, at a national level, to assist in the design of future schemes and reduce the need for in-depth site investigations (3.77).

The agency is likely to be directly involved in procuring materials and equipment for projects, supervising on-site construction and installation using local labour and in commissioning completed projects. An important aspect of this work will be the training of project operators. However, even well trained operators are unlikely to be able to repair major faults and breakdowns. The agency may

therefore additionally offer a repair and spare supply service from centralized facilities (3.78).

The implementation of many projects allows for a degree of equipment and design standardization. This can reduce design time and unit costs and improve the availability of standardized items and spares. There may be an attempt to develop designs of civil works structures and electro-mechanical equipment taking into account local conditions and materials. This may result in the establishment of a local manufacturing capability. Initially production is likely to be limited to relatively simple items such as transmission poles, cross arms, insulator mounting brackets, etc.. Later, the manufacture of more ambitious items such as turbines, gate valves and electronic load controllers may be undertaken (3.79, 3.80).

3.10.3. Financial and Economic Services

A support agency could be effective in alleviating financial constraints to the development of micro hydro-power projects. There is significant international interest in micro hydro-power development and several international funding and donor agencies are currently involved in the field. A micro hydro-power support agency is likely to have government support and be in a strong position to obtain finance at preferential rates (3.81).

Agency staff would be involved in the economic assessment of potential projects. They are also likely to be involved in training project managers and providing on-going back up to ensure that completed projects are competently managed.

Poor households find the 'hook up' fee often charged an obstacle to their being able to make use of electric power. The agency may therefore become involved in offering credit to domestic consumers. Local entrepreneurs considering expanding production by making use of electrical appliances may also be able to obtain advice and/or credit from the agency (3.82).

Rural electrification and micro hydro-power projects are more effective when co-ordinated with other rural development initiatives. Co-ordinating efforts with those of other agencies involved in rural development should therefore be an important aspect of agency activity. In particular, heavy emphasis should be placed on the value of micro hydro-power as a source of power for agricultural processing, small-scale manufacturing and commerce. Close co-operation is therefore required especially with those agencies directly involved in business promotion. This co-operation may include agency involvement in the development of suitable, low-cost, end use equipment if this is not readily available. The technical and financial services of the agency may also be made available to individual entrepreneurs who are interested in developing a micro hydro-power project to serve their specific energy needs (3.83).

Micro and mini hydro-power technology is mature and well developed. But, simply scaling down the design and implementation approach conventionally adopted for larger scale schemes leads to unacceptably high costs.

Shortages of technical skills and credit often inhibit the implementation of potentially viable projects and have detrimental affect upon the on-going performance of existing schemes. But, the limited amounts of power generated by individual micro hydro-power projects can have a major impact on remote rural communities. This is especially true where projects are implemented as part of a broader rural development programme and when income generating end uses develop. In particular, project impact might be maximized when projects are implemented to serve centres which are seen as regional growth poles or service centres.

A small micro hydro-power support agency, by tackling these problems, has the potential to greatly increase the role of micro hydro-power in the rural development process of many developing nations.

4. Papua New Guinea

4.1. Introduction

The remaining sections of this thesis concentrate on Papua New Guinea, using it as a case study to examine the potential role of micro hydro-power in the rural development process. The following section acts as an introduction to the country.

4.2. The Geology and Topography of Papua New Guinea

Papua New Guinea is the largest of the Pacific island nations with a total land area of 461,691 sq km . It is located on the western rim of the Pacific Ocean just south of the equator and comprises the eastern half of the island of Irian, or New Guinea, and over one hundred smaller islands which range from small coral atolls to large island with coastal plains and mountain ranges (4.1), see Figure 4.1. The country occupies a highly mobile zone of the earth's crust between the stable continental mass of Australia and the deep ocean basin of the Pacific (4.2).

The terrain of the mainland and larger islands is rugged and heavily dissected. Over 70% of the country's land area is considered as mountainous. A further 12.5% is swampy and the extent of plains and even gently sloping land is limited (4.3). The country also experiences significant seismic activity which is concentrated in a line along the northern coast and out to the islands of Bougainville and New Ireland. In an average year there are about 500 earthquakes throughout the country in the magnitude range 4.5 to 5.5 on the Richter scale. However, earthquakes with magnitudes over 8.0 do occur and several active and potentially active volcanoes are also to be found (4.4).

The Central Cordillera occupies about 50% of the mainland. It is a complex system of mountain ranges which form the spine of the country and rise to 4,694 m at Mount Wilhelm. It comprises the Central Highlands and the Owen Stanley ranges and re-appears as a

string of islands to the south-east of the mainland. In many areas a deep mantle of volcanic ash has been deposited over the underlying rock forms. The terrain is rugged and heavily dissected, but incorporates a number of broad upland valleys.

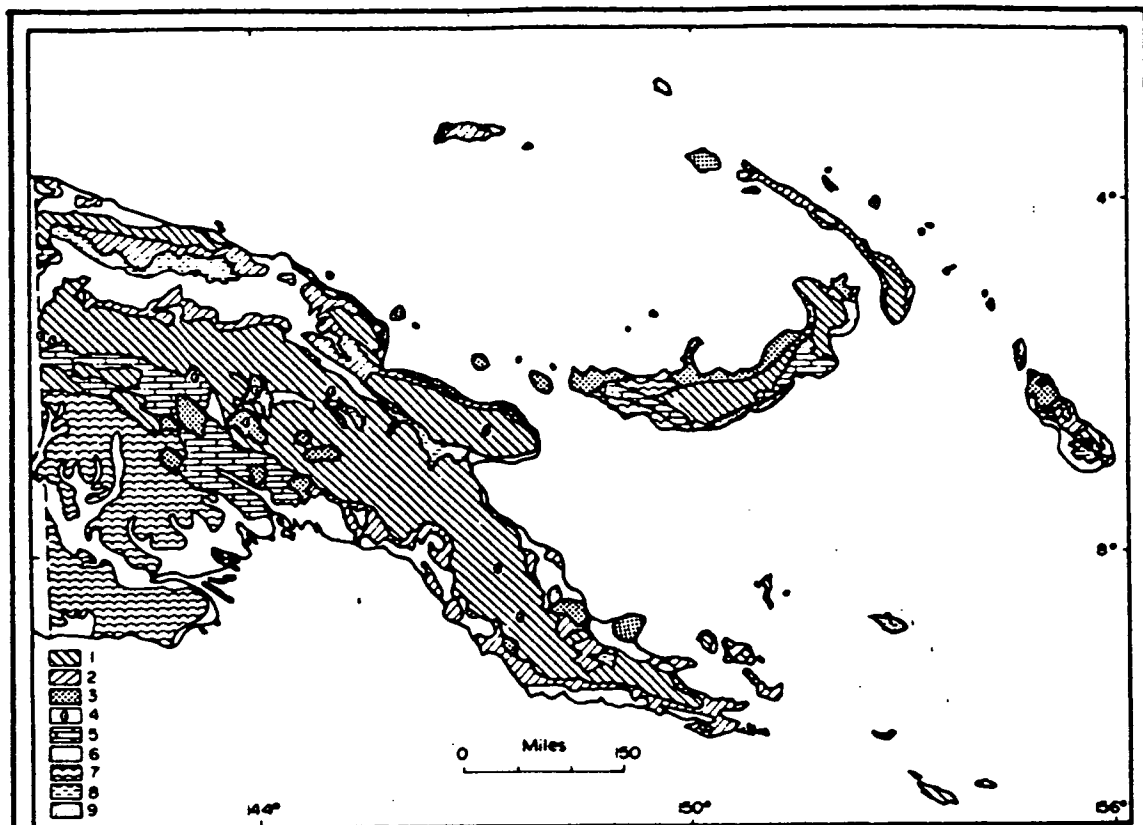
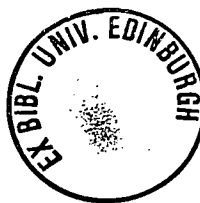


Figure 4.1 The Major Landforms of Papua New Guinea

- | | |
|-----------------------|--|
| 1) Mountains | 6) Alluvial and Littoral Plains and Swamps |
| 2) Foothills | 7) Erosional Landforms |
| 3) Volcanic Landforms | 8) Piedmont Alluvial and Volcano-Alluvial Fans |
| 4) Glaciated Areas | 9) Raised Coral Platforms and Terraces. |
| 5) Karst Areas | |

Source; Encyclopaedia of Papua and New Guinea



Along the north coast is another series of mountain ranges rising to over 3,000 m. Sandwiched between these and the Central Highlands are the valley plains of the Ramu-Sepik-Markham depression. In the south west of the mainland the swampy depression of the Fly-Digil river system includes major deltaic plains and further swampy lowlands are to be found in embayments along the south-eastern coast (4.5, 4.6).

4.3. The Climate of Papua New Guinea

Being located close to the equator, the climate of Papua New Guinea at low altitude is warm and displays only limited seasonal variations in temperature. The normal annual temperature range at Port Moresby, based on monthly averages, is from 24°C to 33.6°C. At Lae the range is from 24.9°C in July to 27.5°C in January. Daily temperature variations are typically 9°C at low altitude. Temperatures in excess of 41°C are extremely rare and cloud cover is generally extensive, especially in mountainous areas. Local temperatures are also highly dependent upon altitude. Some mountain peaks in Papua New Guinea approach the snow-line, so that temperatures especially at night may be low. Daily temperature variation also increases to about 12°C at 1,500 m.

The main winds influencing the country are the south-east trade winds and the north-west monsoon. These winds blow from sub-tropical high pressure zones in each hemisphere towards the inter-tropical front. This front is the low pressure belt of heated, ascending air that moves north and south in response to the seasonal movement of the sun. The north-west monsoon affects the country from December to March, whilst the south-east trade wind blows from May to October. Between these two periods conditions are relatively calm (4.7).

The northern areas of the country generally have a wet season associated with the north-west monsoon whilst in the southern areas the wet season is associated with the south-east trade winds. However, the topography of the country greatly modifies local wind and rainfall patterns. Bougainville Island is both mountainous and

exposed to moisture laden airstreams virtually year round. It therefore experiences an untypical rainfall pattern with precipitation fairly evenly distributed throughout the year (4.8).

Over much of the country mean annual rainfall is high. Extensive areas regularly receive over 5,000 mm per year, see Figure 4.2.. However, the area around Port Moresby is relatively dry because the nearby Owen Stanley mountains lie parallel to the prevailing south-east trade winds which therefore are not forced to rise in the vicinity of Port Moresby and hence to do not release their moisture as precipitation. Port Moresby remains relatively dry from May to October and most rainfall in the area is the result of local thunderstorms that occur outside this period. Such thunderstorms are a significant source of rainfall in many other areas also (4.9). Rainfall in general and from thunderstorms in particular can be very intense (4.10).

4.4. The Vegetation of Papua New Guinea

Forest is the natural vegetation over most of Papua New Guinea. It covers 75% of the land area and there are believed to be in excess of 1,200 tree species in the country. Climatic conditions, soil type and altitude influence forest type.

The tree-line is at about 3,500 m and it is only here and in some swampy areas that grasslands are believed to be the natural vegetation. However, extensive grasslands are also found in many populated areas, where they appear to be the result of gradual degradation of forest cover as the result of human slash and burn activity (4.11).

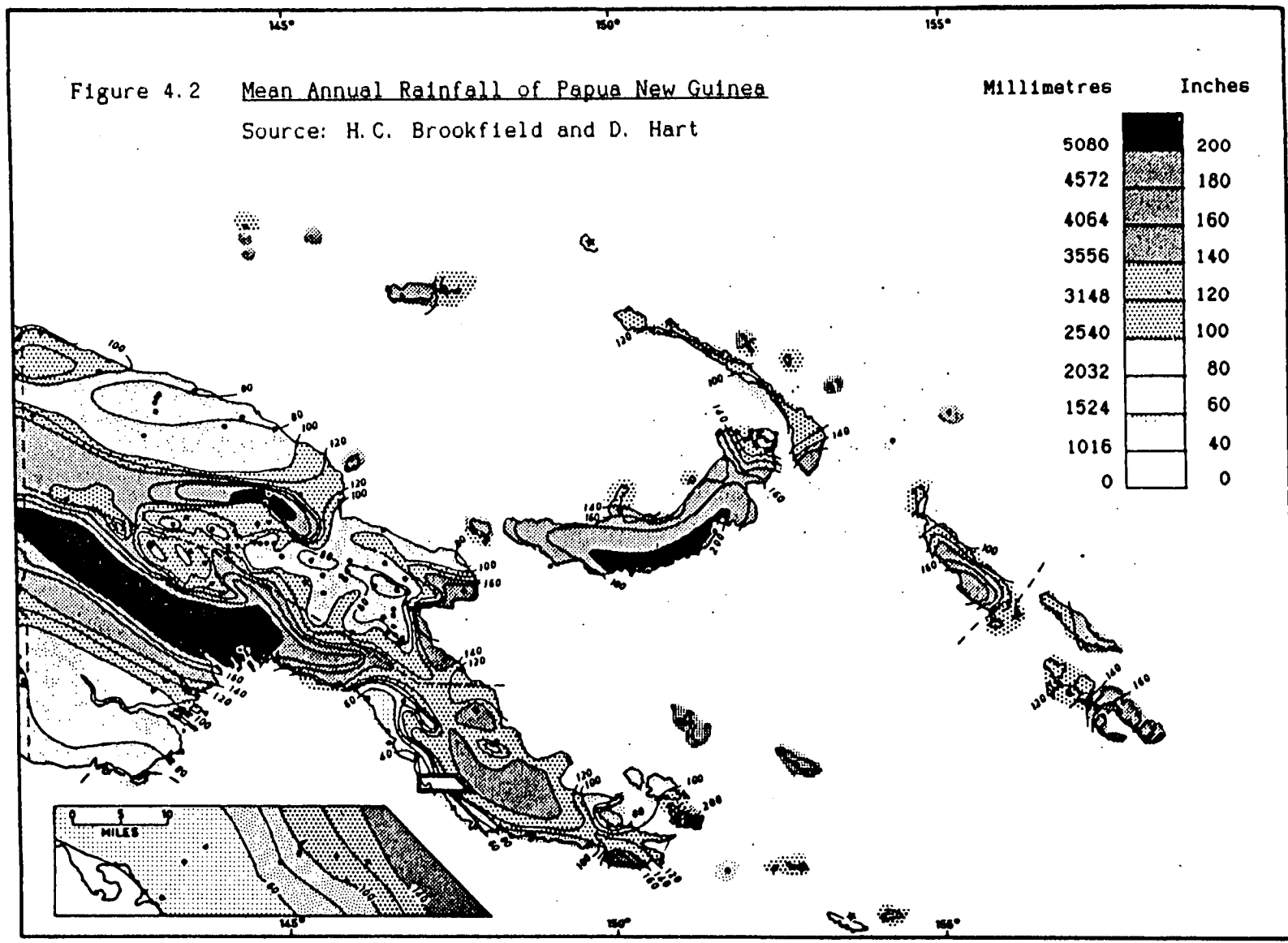
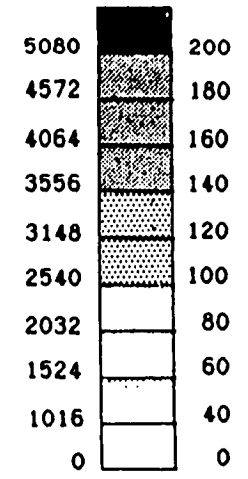
4.5. The Culture and People of Papua New Guinea

The current population of Papua New Guinea is 3.4 million. The 700 distinct languages in use, nearly half the world's total, reflect the number of small cultural units found in the country. There are no distinct and formal tribes as in Africa, but there are

Figure 4.2 Mean Annual Rainfall of Papua New Guinea

Source: H.C. Brookfield and D. Hart

Millimetres Inches



culturally and linguistically similar groups that see themselves as having a group identity. In the lowlands the population of these groups rarely exceeds 5,000, although groups of over 60,000 are found in the highlands (4.12). Although these groups do have an identity, they are not unified but are split up into sub-groups based around individual villages. In pre-colonial times it was these villages that were the largest socially and politically cohesive units in the country. Their size was largely limited by the need to organize collaborative efforts in garden clearing etc. and by the large land requirements of slash and burn cultivation, on which the great majority of villages depended. Root crops such as taro, yam and later sweet potato supplied the dietary staple and were supplemented by cultivated and gathered fruit, nuts and vegetables. Pigs and chickens were also domesticated, although pigs were generally only consumed on ceremonial occasions. Hunting and fishing provided further dietary supplements. In some swampy areas land for cultivation was limited and the starchy flour extracted from sago palms provided the staple diet. Implement manufacture was based on the use of stone and, in some cases, shell.

Each village is associated with a tract of territory that the members consider as vital to their well-being. In most areas of the country this land is associated with the clan or village group rather than the individual. Individuals may stake a temporary claim to a particular plot of land, but it returns to the clan when cultivation is discontinued. The right to reside in and cultivate the land of a particular village group is based upon kinship relations. The majority of societies are patrilineal and the right to cultivate land is passed from father to son. However, some are matrilineal and a few groups base their lineage and kinship claims on both patrilineal and matrilineal descent.

The degree of social and political cohesion of village units varies between different linguistic groups, but in most cases there is some collaboration of members in matters of ritual, defence, garden clearing and house construction. Social relations are largely based around kin ties which are used to provide a degree of social

cohesion and control. In general there is no formalized leadership structure. Men become influential by being successful in a range of prestigious activities such as fighting, gardening, magic and/or trading. They should be generous with their wealth, and gain influence by ensuring that other group members are in their debt (4.13, 4.14, 4.15).

4.6. The Colonial History of Papua New Guinea

The first contact that Papua New Guineans had with Europeans appears to have been with Spanish and Portuguese explorers during the 16th century. In 1828 the Dutch annexed the western half of the island (now known as Irian Jaya and a Province of Indonesia), but European interest in the eastern half of the island remained limited.

During the 1870's the Germans began to trade with the inhabitants of the islands to the north-east of the mainland and Australians with the coastal people of the mainland itself. The traders were interested in such items as pearls, tortoise shell, sandalwood, wild rubber and coconuts. As copra increased in value the Germans, in particular, began to establish plantations on the Papua New Guinean islands. A trade in indentured labourers also developed to supply the sugar plantations in Queensland.

In 1884 the south-western portion of Papua New Guinea (known as Papua) was formally colonized by the British and the north-eastern section (known as New Guinea) by the Germans. In 1906 control of Papua was formally transferred to the Australian government. After the First World War Australia also became responsible for the administration of New Guinea under a League of Nations Mandate. But the administration of New Guinea remained separate from that of Papua (4.16).

In both Papua and New Guinea early colonial development was largely based on copra production, both by European controlled plantations and by local inhabitants. The pace of development was limited and

colonial activity and influence was largely restricted to the islands and coastal areas of the mainland (4.17).

In New Guinea the area under plantation cultivation continued to expand over the inter-war period, although copra prices were depressed for much of this period. But the major stimulus to the colony occurred during the 1920's when there were major gold strikes in the Wau-Bulolo area. In contrast, growth of the Papuan economy was limited. Prior to the First World War several minor gold and copper mining projects had been developed in Papua but production declined after the war. There was little expansion in the plantation sector and largely in response to poor copra prices, there was a gradual move to rubber production. Between the wars the area under Australian influence and control was gradually extended, but at the out-break of World War II, Australian influence in many areas was still limited and contact had hardly been established with the people of the highlands.

During the Second World War the Territories were invaded by Japanese forces and the Australians were pushed back almost to Port Moresby. After the war the administration of the two Territories was combined and there was a marked shift in policy towards the 'Territory of Papua and New Guinea'. This was due to a new awareness of its strategic importance to Australia and to a world-wide change in attitudes towards colonies. Australia rapidly increased its grants-in-aid to the Territory and, in an attempt to foster economic and social development, undertook crash programmes in education, technical training, health services and indigenous agricultural development.

In the post-war period, missions from the United Nations periodically visited the Territory. The early missions broadly accepted the framework of the Administration's activities. But the 1959 mission was concerned that the Territory lacked the basic framework and infrastructure to support a modern economy and that without this, movement towards self-government would be impeded. By 1962 increasing pressure was being put on the Administration to

increase the involvement of Papua New Guineans in the political process and to accelerate progress towards self-government and Independence (4.18, 4.19).

4.6.1. Towards Political Independence

These concerns were taken seriously and resulted in the establishment of the House of Assembly, initially with 64 members, 54 of whom were elected, in 1964. The House was intended to act as the legislative body of the Territory, but initially it remained subordinate to the Administrator and Governor-General. A group which became known as the Administrator's Executive Council (AEC) was also established as an advisory and policy forming body. It comprised the Administrator, three officials of the House of Assembly, a further seven elected members of the House and one additional member nominated by the Administrator (4.20).

The powers and membership of the House and AEC were gradually increased and self-government was granted to the nation of Papua New Guinea in 1973, followed by full independence in 1975. By this time over 150 Local Government Councils had been established throughout the country to increase the involvement of the population in the political process (4.21).

4.6.2. Towards Economic Independence

The moves towards self-government were accompanied by efforts to provide the basis for a viable economy with increased participation of Papua New Guineans. Emphasis was placed on increasing production, particularly from the indigenous agricultural sector, improving infrastructure, and improving social services, particularly education and training.

The Highlands contain almost half the population of the country and much of its more fertile land. The opening up of this area was a major development in the post-war period and led to a major expansion in coffee cropping. In part this was due to new leases

being granted to Europeans, but indigenous production by smallholders, who were strongly encouraged to enter cash cropping, was also important. In lowland area indigenous production of other crops also expanded considerably. Several new crops, for example oil palm, tea, pyrethrum and cardomom, were introduced. There were also developments in the livestock, fishing and timber industries. But the concentration of extension efforts and development initiatives in areas felt to have long term potential meant that regional disparities in levels of development increased (4.22, 4.23, 4.24).

Increased production of primary produce resulted in an expansion in processing operations. A market for small-scale, service (and expatriate) orientated manufacturing also developed and expanded as the number of ex-patriates grew and as the indigenous population became increasingly involved in the cash economy. By 1968/69 234 factories had been established with a total employment of 14,000 (4.25).

Gold production from the Wau-Bulolo area, which had restarted after the war, was in rapid decline by the late 1950's. However, a major gold and copper mining complex at Panguna on Bougainville Island came into production in the early 1970's. This had a major impact on the nation's export earnings and government revenues, its construction industry and the infrastructure of the project area (4.26).

4.7. Development Strategies Since Independence

During 1972 "A Report on Development Strategies for Papua New Guinea" (also known as the Faber Report) was prepared (4.27). The report suggested that there was little prospect of the modern sector of the economy being capable of absorbing the nation's expanding work-force and that the only significant sources of foreign exchange would continue to be from the export of primary produce. It recommended that heavy emphasis should be given to encouraging agricultural production, both of export and domestic crops,

particularly by indigenous smallholders, and to encouraging informal and small-scale operations in both urban and rural areas.

Tied to these recommendations was an emphasis on regional and rural development. It was suggested that further efforts were needed to improve the nation's transport infrastructure and that investment should be channelled to selected growth poles and, at a lower level, to more numerous service centres. Decentralizing the public service was also seen as desirable to bring the government closer to the people and to reduce the primacy of Port Moresby.

Major enclave resource exploitation projects, such as the Bougainville gold and copper mine, were seen principally as sources of foreign exchange in the medium term. It was recommended that government revenues from such projects be maximized and that they be used to fund revenue generating projects rather than social services. The emphasis on revenue generating projects was seen as part of a long term programme to reduce the nation's dependence on foreign sources of capital and manpower. Further elements of this programme were the replacement of ex-patriates by nationals where feasible, a broadening of the nation's tax base, and efforts to reduce the level of food imports by substituting locally produced alternatives.

The report had a major impact upon government thinking. Much of the general development philosophy expressed was incorporated into the 'Eight Aims' which were announced by the government in 1972 and which continue to broadly define the development philosophy. They are (4.28):

- 1) A rapid increase in the proportion of the economy under the control of Papua New Guinean individuals, and in the proportion of personal and property income that goes to Papua New Guineans.
- 2) More equal distribution of economic benefits, including movement towards equalization of incomes among people and

towards equalization of services between different areas of the country.

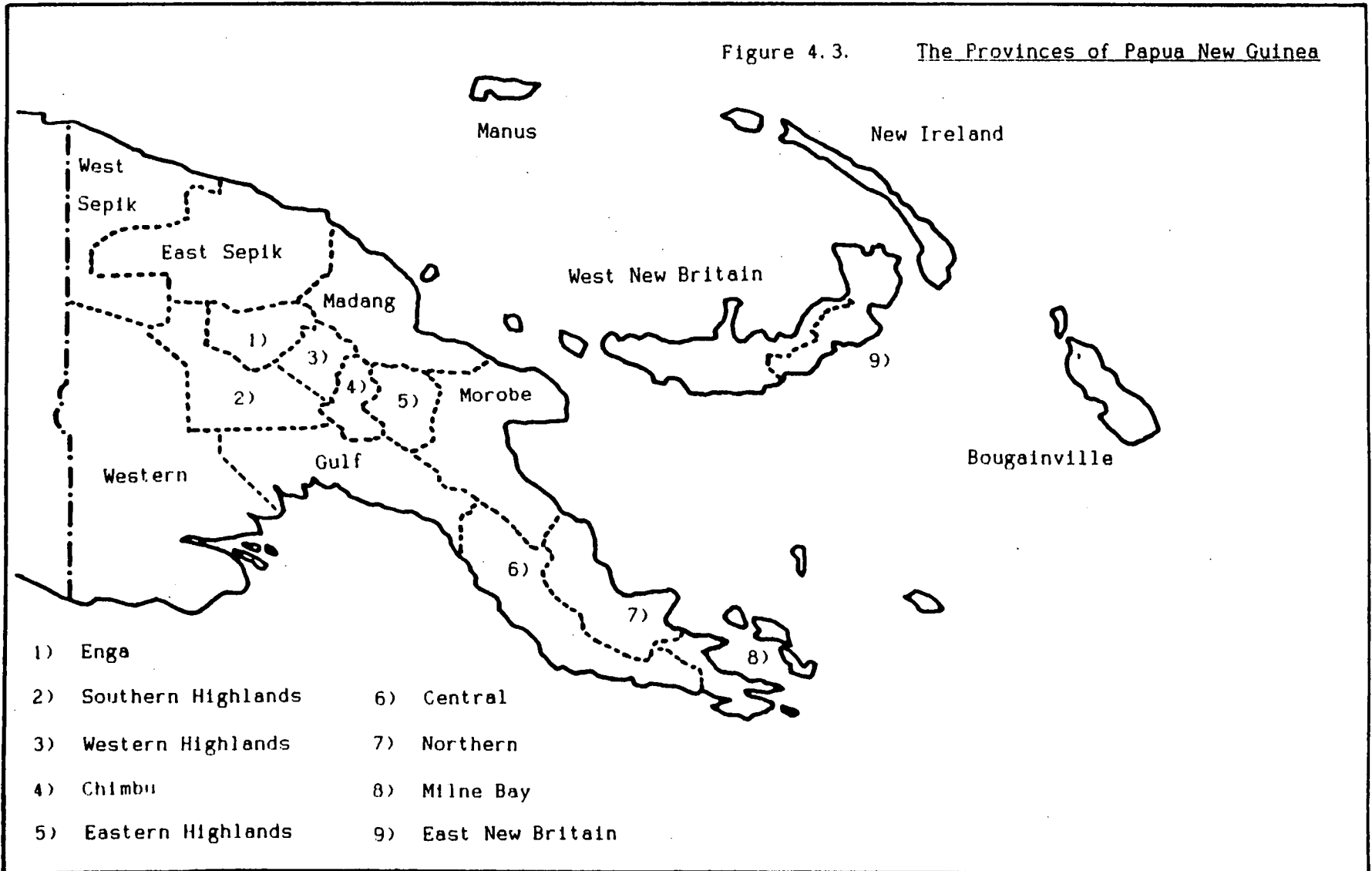
- 3) Decentralization of economic activity, planning and government spending with an emphasis on agricultural development, village industry, better internal trade and more spending channelled to local and area bodies.
- 4) An emphasis on small-scale artisan, service and business activity relying where possible on typically Papua New Guinean forms of business activity.
- 5) A more self-reliant economy, less dependent for its needs on imported goods and services and better able to meet the needs of its people through local production.
- 6) An increasing capacity for meeting government spending needs from locally raised revenue.
- 7) A rapid increase in the equal and active participation of women in all forms of economic and social activity.
- 8) Government control and involvement in those sectors of the economy where control is necessary to achieve the desired kind of development.

4.8. The Current Situation

Papua New Guinea has a total population of about 3.4 million and this is increasing at a rate of 2.1% per annum. The country operates with a Westminster style national parliament and, following the recommendations of the Faber Report, 19 Provincial Governments have also been established, see Figure 4.3..

Papua New Guinea is now classed by the World Bank as a lower middle-income country with a per capita Gross Domestic Product (GDP) of US\$ 660 in 1985. In 1985 the country exported goods with a freight on board (fob) value of US\$ 910,450,000, and imported goods with an fob value of US\$ 875,400,000 (4.29). Significant but declining

Figure 4.3. The Provinces of Papua New Guinea



payments are still received from the Australian government. Largely as a result of the recent world economic recession, the country's rate of economic growth has declined from the healthy levels shown during the 1960's and early 1970's. The country's independence was also accompanied by a decline in the level of foreign investment and by an exodus of ex-patriates, exacerbating an existing shortage of technical and management skills (4.30). The lack of suitably experienced and qualified personnel means that often posts may remain unfilled or occupied by staff with inappropriate skills. This restricts development opportunities and raises the cost of doing business in the country (4.31).

In most years the absolute value of Papua New Guinea's GDP has continued to grow, but on a per capita basis it has remained virtually stagnant. This limited economic growth has restricted the extent to which government revenues were available to fund development programmes. In some cases there has also been a lack of political will to push through radical policy measures (4.32). However, in an attempt to keep government expenditure in line with specified policy objectives the National Public Expenditure Plan was introduced in 1977. The NPEP is organized around specific projects categorized under one of the following strategic objectives that reflect the government's development aims:

Increasing rural welfare.

Helping less developed areas.

Improving general welfare.

Increasing economic production.

Improving food production, subsistence and nutrition.

Improving training and increasing Papua New Guinean participation in the economy.

Urban management.

Effective administration.

Environmental protection.

Each category is allocated a percentage of available funds and project submissions from government agencies are referred to the relevant objective. However, for many of the key objectives there has been a deficit of suitable project submissions which has limited the NPEP's effectiveness (4.33).

In particular there has been a deficit of suitable rural welfare project submissions. Attempts to encourage rural development and the informal sector have been limited and extension efforts aimed at the smallholder have not improved. Over 95% of the nation's land remains under customary tenure. This has some advantages, but the problems involved in obtaining access to land and the difficulty in using customary land as security for commercial loans or as a basis for entering a joint venture agreement, often restrict development opportunities. There has been little real attempt to establish small-scale processing operations in rural areas or concrete action to encourage service centres or co-operative societies. These factors combined with a lack of real improvements in marketing arrangements for small-scale producers have meant that no dramatic revitalization of the countryside has occurred (4.34, 4.35).

4.8.1. Exports

The export of gold and copper concentrates from Bougainville, and more recently Ok Tedi, have had a major impact on export earnings and it seems likely that further mineral extraction projects will be developed in the future. But many of Papua New Guinea's export commodities suffer from widely fluctuating and generally declining prices on the international market. Table 4.1. indicates the quantities and values of the major items exported in 1985 (4.36).

4.8.2. Imports

Because of the limited size of the secondary sector a large proportion of the nation's imports are in the form of manufactured goods, especially machinery and equipment. Fuel is also a major import item and is dealt with in greater detail in Section 6.. Although much of the population is involved in agriculture foodstuffs, in particular rice and canned meat and fish, are significant import items (4.37).

Table 4.1. Major Items Exported from Papua New Guinea in 1985

<u>Item</u>	<u>Quantity in Tonnes</u>	<u>Value in Kina¹</u>
Fish and Prawns	1,450	9,783,000
Coffee Beans	40,630	117,440,000
Cocoa Beans	30,330	60,870,000
Tea	7,020	13,334,000
Copra	104,650	33,922,000
Coconut Oil	38,760	22,700,000
Crude Rubber	5,330	3,736,000
Palm Oil	123,160	60,666,000
Wood and Lumber	1,149 ²	57,250,000
Woodchips	90,700 ²	4,724,000
Copper Ore and Concentrates	591,000	320,000,000

N. B. 1 K 1.00 = US\$ 1.0124 for 1985

2 Quantities given in thousands of cubic metres.

Source; Statistical Yearbook for Asia and the Pacific,
Economic and Social Commission for Asia and the Pacific,
Bangkok, 1985

4.8.3. Agriculture

Less than 10% of the economically active population (those over 10 years of age) are in formal employment. The majority are involved in the informal sector and over 80% are involved in agricultural activity. Of these, only about 30% are predominantly involved in commercial agriculture, the rest being principally involved in subsistence production.

Cash crop production, in particular by small-holders, has continued to increase and the market component of agricultural production first exceeded subsistence production in 1977. A total of about 700,000 ha. are under cash crops with an additional 500,000 ha. under subsistence cultivation. In the medium term the best prospects for increasing production are through encouraging the mixed cash cropping/subsistence sector. The current increases in production are largely the result of cash cropping becoming more widespread. Yields remain low and extension and marketing services over-stretched. Most smallholder plots remain small (in 1979 the average size of smallholder coffee plots was 0.17 ha.). Although at a national level land resources are abundant, in a few areas land available for further expansion is extremely limited.

A potentially important source of increased production may be fully commercial, medium-scale operations, in which traditional landholders amalgamate plots under the control of a single management unit. This form of production appears to be gaining favour and shows signs of being more commercially orientated than the smallholder sector which the government has encouraged to date.

Plantation production has been faced with a number of difficulties over recent years. Uncertainty over the future of the sector has limited re-planting and on many plantations yields are consequently declining. Developments featuring nucleus estates and processing plants with linked smallholdings have recently been established, particularly for oil palm production. These are seen as having good potential for further expanding agricultural production, but, as

with the plantation sector, land acquisition is seen as a major problem (4.38, 4.39, 4.40).

4.8.4. Forestry

Much of the country's forest resource is not suited to large-scale commercial exploitation. The forests of other South-East Asian countries are higher yielding and contain a higher proportion of commercially attractive species. In Papua New Guinea there is a high risk of soil erosion and environmental deterioration resulting from felling operations because the terrain is rugged and steep. Some areas of potential are not yet accessible by road.

In 1980 there were 14 companies exploiting Papua New Guinea's timber resources, all operating under ex-patriate management. Most also had predominantly foreign ownership. In addition, there were about 50 smaller sawmills supplying local demand. Total employment in the sector was about 4,000 and about 75% (by value) of production was exported, mostly in the form of round logs. Other exported items were woodchips, plywood, veneer and sawn timber. Many operators in the forestry industry have experienced heavy losses associated with processing activities established under government pressure. Round log export and sawn timber production for the domestic market have remained profitable and as the timber resources of many South-East Asian countries become exhausted prices are likely to rise with beneficial effects for the industry in Papua New Guinea (4.41, 4.42).

4.8.5. Fisheries

Small-scale fishing operations are locally important in many coastal areas and along the Sepik. There is scope for increased production to meet domestic demand and a need for better storage facilities. The country also has significant deep sea fishing resources, especially tuna. Two foreign owned companies currently work the tuna resource. There is room for expanded production and there are plans

for the establishment of a tuna cannery at Kavieng which would increase both foreign exchange earnings and employment (4.43, 4.44).

4.8.6. Secondary Industry

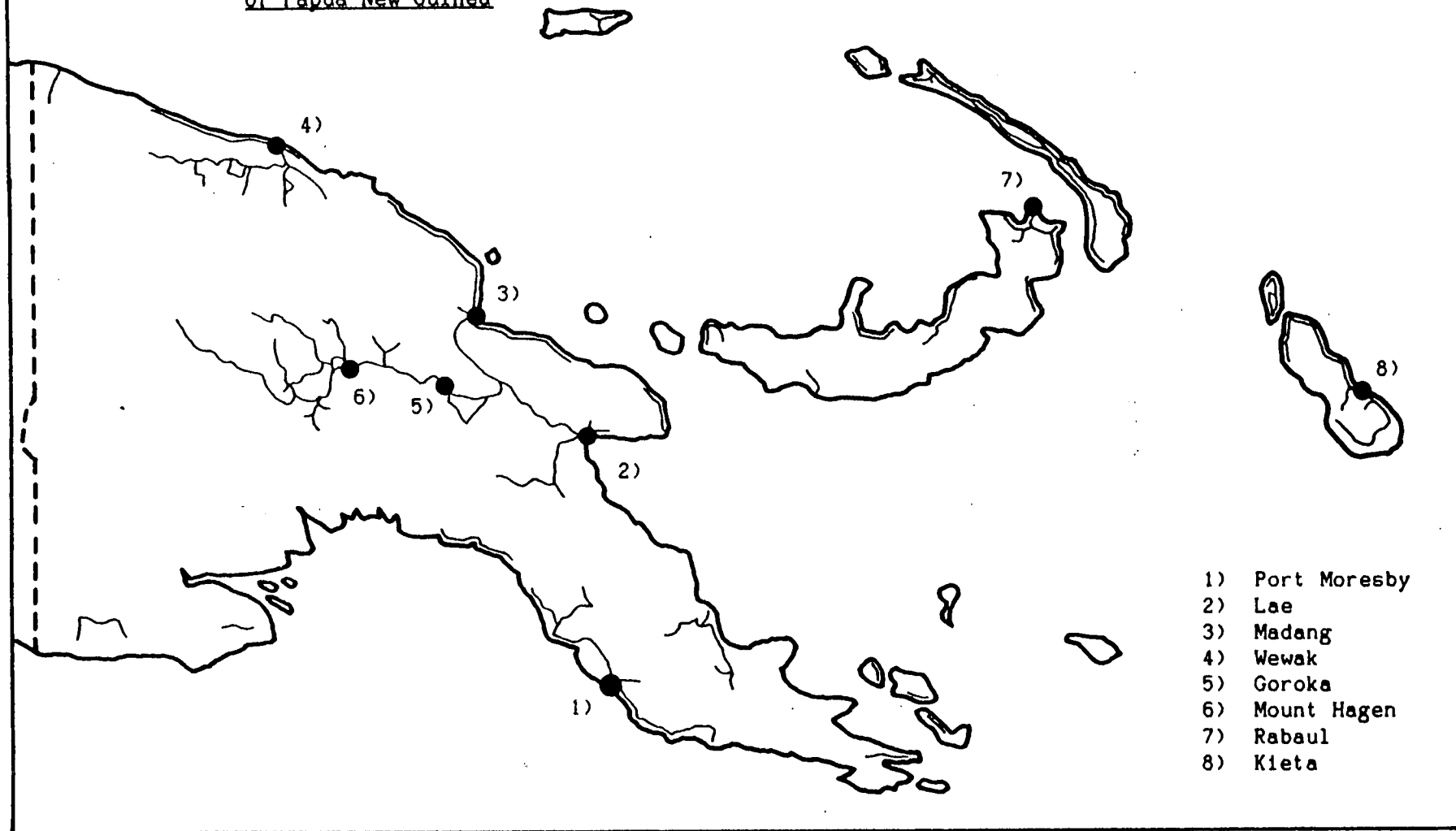
In 1981 manufacturing accounted for about 10% of Papua New Guinea's GDP, while the share of industry as a whole (including the construction, electricity, water and gas industries) was 14%. There were 492 factories employing a work-force of about 19,000, or 11% of formal employment. In comparison the public sector was responsible for about 30% of formal employment and was itself heavily involved in the secondary sector with direct interests in 34 public enterprises.

Typically for a country in the early stages of industrialization, a large share of the manufacturing value added was contributed by food (29%), beverages (13%) and wood products (18%). Remaining manufacturing was fairly evenly divided between consumer and industrial products. The domestic market remains small and is fragmented by poor transport facilities. Although a disadvantage in the short term, it encourages the development of a number of regional urban centres which may prove an advantage in the longer term (4.45, 4.46, 4.47).

4.8.7. Urban Centres

Figure 4.4. shows the road network and locations of Papua New Guinea's major urban centres. A centre may be classed as 'urban' with a population of only 500 so long as it displays 'urban characteristics'. Using this classification, 13.2% of the nation's population was considered urban in 1980 and there were a total of 63 urban centres. But urban population figures are limited to those living on government controlled land so that some people in peri-urban settlements around both major and minor centres may be excluded. In addition, some villages have populations in excess of 500, but are not considered as 'urban'.

Figure 4.3 Map Showing the Road Network and Major Urban Centres
of Papua New Guinea



In 1980 the eight major urban centres whose populations are shown in Table 4.2. accounted for 73% of the total urban population. But it was the various provincial capitals that were showing the strongest growth in response to the programme of decentralization. Although the overall urban population growth rate was higher than the national average at 3.8% per annum, the growth of the small centres was slow and in several cases declining. These small centres are known as 'C' centres. In all they number just over 100, but many are too small to be classified as urban.

Table 4.2. The Population of Papua New Guinea's Eight Major Urban Centres in 1980

<u>Centre</u>	<u>Population</u>
Port Moresby	124,000
Lae	62,000
Madang	21,000
Wewak	20,000
Goroka	19,000
Mount Hagen	19,000
Rabaul	15,000
Arawa/Kieta/Panguna	14,000

Source Population of Each Urban Area, by Citizenship and Sex 1980 Census, National Statistical Office.

The 'C' centres have developed from patrol posts that were established prior to independence as the colonial influence spread from coastal areas. They were used as bases for exploration, imposing law and order on the local population, the recruitment of labour and establishing plantations. In many cases church organizations established missions in association with the patrol posts.

As the posts developed they began to offer a number of services such as trade stores, agricultural extension services, medical treatment

and education, the latter two often being provided by the mission. These services tended to induce some resettlement of local people around the periphery of the post. Some patrol posts grew to become the major national and provincial centres of the country ('A' and 'B' centres). But the 'C' centres have remained small and isolated. However, they are seen as playing an important role in the rural development process. They act as administrative headquarters and service centres of the districts or sub-districts that combine to make up the 19 provinces of the country. The facilities and services available at the smaller centres are likely to include the District Office, a health centre, agricultural, business and forestry extension services, a police station, a mission station and, often in association with this, a community school. There is also likely to be a small commercial sector comprising a local produce market and several trade stores. Additional services may be available at larger centres, but there has been little development of processing or manufacturing activities at any but the largest and most dynamic 'C' centres (4.48).

4.8.8. Villages

There are about 10,500 rural villages in Papua New Guinea which contain over 80% of the nation's population. In 1975 the average population of these villages was 188, although the range was from 18 to 1,535. Often these villages are nucleated settlements, but, especially in the Western Highlands and Enga Province, households are scattered over a wide area around a central meeting point. The average population of these dispersed villages was about 650 in 1975.

Often traditional patterns of life have not been greatly disrupted, although in the majority of villages there has been some development of cash cropping both of export and non-export crops. In many cases the inaccessibility of villages creates marketing difficulties and limits incentives to produce. A survey of over 1,000 villages in 1975 indicated that in 75% of villages lack of transport was a problem in marketing produce. In nearly 30%, transport difficulties

resulted in crops being either not harvested or spoiled after harvesting. Largely as a result, in many villages incomes are both low and seasonal.

Apart from cash cropping (and in coastal areas, fishing), economic enterprises in villages are largely limited to trade stores and, where applicable, Public Motor Vehicle (PMV) or motor boat operation. Nearly 60% of villages have at least one trade store and many have several, but often they are not profitable and may be run for status as much as business purposes. In 1975 trucks were owned by 19% of villages although only 67% were in running order. Of villages located near navigable water, 31% possessed at least one outboard motor (4.49, 4.50).

4.9. The Hydro-Power Resources of Papua New Guinea

In Section 3.6. of this thesis it was pointed out that the power available at a hydro-power site is proportional to both the head and flow that can be utilized. The rugged terrain, abundant rainfall and humid atmosphere of Papua New Guinea mean that run-off is plentiful, exceeding 2,500 mm per annum over large areas of the country, and that the country has vast hydro-power resources (4.51). It has been estimated that the exploitable hydro-power potential if developed could produce 95,000 GWh of electricity per annum (4.52).

For a given power output, a high head hydro-power site will generally be cheaper to develop than a low head site. In most areas of the country there are a multitude of steeply descending small streams and rivers that would appear to be ideal for the development of relatively high head mini and micro hydro-power schemes. However, there are a number of physical factors that pose difficulties to the low cost development of these resources.

4.9.1. The Influence of Physical Characteristics on Project Costs

As mentioned in Section 4.3. rainfall in Papua New Guinea can be very intense. The catchment areas of streams utilized for micro hydro-power projects are often only a few square kilometres in area so that a period of heavy rainfall is likely to be experienced over the whole catchment area with little of the averaging out that occurs with large catchment areas. In addition, these small catchments often cover steep terrain so that, during periods of heavy rainfall, run-off is maximized and heavy flooding likely.

The civil works of micro and mini hydro-power schemes therefore often have to be designed to withstand heavy flood flows. In many instances it is not feasible to install stream gauging equipment to gather flow measurements over an extended period. Project design and implementation must often proceed with less than ideal knowledge of flow conditions. This makes the selection of scheme capacity difficult and implies that civil works be designed conservatively.

The heavy rainfall and rugged terrain also mean that, as a result of rapid erosion, many streams and rivers flow in deeply incised valleys. The valley sides are often unstable and the problem is exacerbated by the fact that many of these slopes are used for gardening purposes. This has implications for the design of civil works structures, in particular the power canal. In some parts of the country schemes must also be designed to withstand significant seismic loadings (4.53, 4.54).

Rivers and streams tend to be heavily sediment laden, especially during periods of heavy flow. This implies a need for incorporating suitable settling areas into scheme designs. Provision needs to be made for the removal of load deposited and, during periods of flooding and heavy flow, the material transported may include gravel and boulders, even large boulders. This makes removal difficult and heavy boulders can pose a serious threat to the integrity of weirs and intake structures.

The rugged terrain of the country also contributes to micro hydro-power development costs by increasing transport costs. Road haulage and coastal shipping rates are high by international standards, but some 'C' centres are only accessible by light aircraft or foot, and many villages by foot only. Not only are the costs of transporting materials and equipment to inaccessible sites high, but design limits may be imposed by the need to size components for air freight or hand portorage and by the need to use labour intensive construction methods (4.55).

4.10. Conclusions

The economy of Papua New Guinea is heavily dependent upon the production of a range of primary products, particularly gold, copper, coffee, cocoa, timber and copra. The rugged terrain of the country has restricted the development of a national road network and limits opportunities for economic development in the more remote areas of the country. Over 80% of the nation's citizens remain in the rural environment and a significant proportion of them are only marginally involved in the cash economy.

The national government, in theory at least, places heavy emphasis upon rural development through the improvement of rural services and infrastructure and by encouraging increased agricultural production and the establishment of rural industries. By acting as service centres the nations 'C' centres are seen as having a valuable role to play in this process.

The country has significant hydro-power resources, but a number of physical factors mean that, if they are to be developed, careful attention needs to be paid to controlling costs.

5. Energy Consumption and Electricity Generation in Papua New Guinea

5.1. Introduction

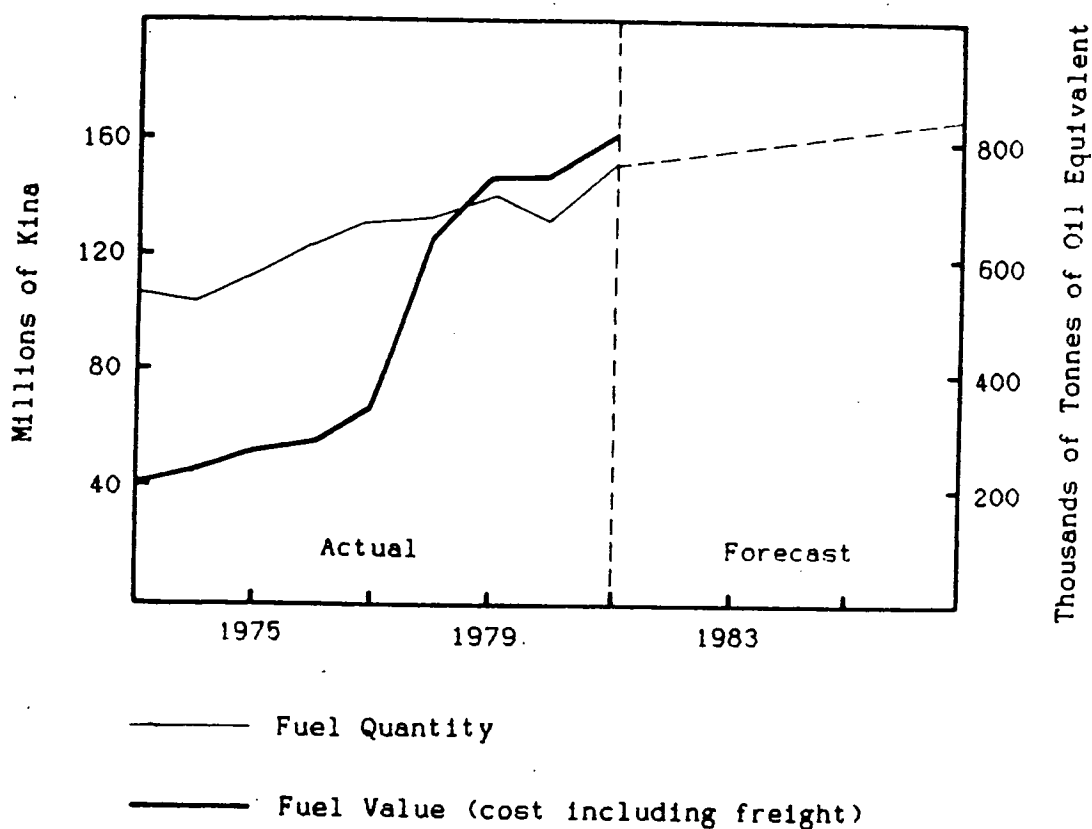
With 85% of its total population still living in rural areas, and with a large proportion of that population only marginally involved in the cash economy, fuel wood remains an important source of energy in Papua New Guinea. In most rural villages fuel wood is the only everyday source of energy for cooking and heating and it remains a major source of energy for lighting. Even in urban centres fuel wood remains an important source of domestic energy for cooking and heating and accounted for 48% of urban domestic energy use in 1979 (5.1).

Papua New Guinea has abundant forest resources, but there are rural areas in which increased pressure on the environment, as a result of population growth and increased cash cropping, has led to localized deforestation, soil erosion and fuel wood shortages. The problem is more serious around many of the country's urban centres (5.2).

Although fuel wood is still important as an energy source it is estimated that it now accounts for less than 40% of the nation's total energy consumption. Use of commercial fuels, mainly petroleum products, has expanded rapidly as the economy has developed, become more diverse and 'modern', and as the urban population has grown. Between 1956 and 1976 there was a seven-fold increase in the use of fossil fuels. Papua New Guinea's average per capita energy consumption grew at about 3% per annum throughout the 1970's and was about 380 kg of oil equivalent in 1981, broadly in line with that of neighbouring South East Asian countries. However, the commercial sector representing about 15% of the nation's population was responsible for about 60% of total energy consumption, with 90% of that consumption being in the form of fuel imports. This suggests an energy consumption of 1,600 kg of oil equivalent per capita in the commercial sector (5.3).

Some oil and gas reserves have been discovered in Papua New Guinea. These have not been exploited and all mineral fuel requirements (exclusively in the form of petroleum products) have been imported. Fuel imports as a proportion of the nation's total imports by value had been less than 4% during the early 1970's. However, rapidly rising fuel costs and continued growth in consumption meant that, the cost of these imports, both absolutely and as a proportion of total imports, rose dramatically after the oil crisis of 1973/74, see Figure 5.1. In 1982 the nominal value of fuel imports was equal to 25% of Papua New Guinea's export earnings, but fell back to 22% in 1983 (5.4). The current slump in world oil prices is likely to have temporarily reduced this proportion further. However, the long-term price movement of these imports is likely to remain upwards.

Figure 5.1. Fuel Imports: Quantities and Values



Source: Medium Term Energy Strategy: Energy Strategy: Discussion Papers, National Planning Office, 1984.

The country's total energy consumption in 1981 was 1269,200 tonnes of oil equivalent (TOE) of which 55% was accounted for by fuel imports, see Table 5.1.. It is estimated that by 1990 consumption will have risen to 1728,800 TOE. The proportion of total energy requirements met by fuel imports should have been reduced to 50% by that time as the result of a number of initiatives aimed at developing indigenous energy resources, but the absolute volume of fuel imports will continue to rise (5.5).

Table 5.1. Sources of Primary Energy for 1981

<u>Source</u>	<u>Quantity in TOE</u>	<u>Percent</u>
Distillate	285,900	22.5
Fuel oil	235,000	18.5
Other petroleum	183,600	14.5
	-----	----
Total Imported	704,500	55.5
Wood	467,300	36.8
Hydro	90,000	7.1
Solar	7,400	0.6
	-----	----
Total Indigenous	467,300	44.5
	-----	----
Overall Total	1,269,200	100.0

Source; Medium Term Development Strategy: Energy Strategy Discussion Papers, National Planning Office, 1984.

The high level and cost of these imports is a source of concern to the national government since such dependence upon imports is contrary to its development philosophy and because foreign exchange expenditure on fuel imports is effectively expenditure lost to other development initiatives. The national government is keen to reduce

its dependence upon fuel imports by developing indigenous energy sources and improving the efficiency of energy utilization (5.6). It has actively sought and encouraged the exploration of Papua New Guinean territory for oil and gas reserves by overseas oil companies, with a view to their longer term development (5.7). In addition, an Energy Development Company Ltd was established as a public enterprise in 1980 with the aim of promoting the use of alternative sources. However, the company ran into difficulties and although a number of initiatives were undertaken, its activity was limited (5.8). Several other energy sector initiatives have also been proposed or implemented, mainly through the Department of Minerals and Energy, and these will be dealt with below.

5.2. Domestic Energy Consumption

In 1981 households were the largest consumers of energy, see Table 5.2., and the majority of their energy needs were met by fuel wood. In both rural and urban areas much cooking is still undertaken on open fires and improved stoves have the potential to greatly increase utilization efficiency. Local fuel wood shortages had been considered a problem and reforestation and the development of wood lots to provide fuel wood supplies has been undertaken in selected areas. In addition, charcoal production by local entrepreneurs and business groups has been encouraged to supply both Port Moresby and Lae. In Port Moresby this activity was undertaken by the Energy Development Company who leased out charcoal kilns to local businesses. In Lae charcoal production has been encouraged by the Appropriate Technology Development Institute. Improved wood, charcoal and saw-dust burning stoves have also been developed and solar water heaters have been encouraged, particularly by the Papua New Guinea Housing Commission (5.9, 5.10, 5.11).

5.3. Electricity Production

The second largest energy consuming sector was electricity production and 74% of the sector's total energy input was in the form of imported fuel. Official electricity supplies do not serve

most rural areas of the country and the capacity of official supplies at many smaller urban centres is limited. Therefore private generation by agricultural, mining, forestry, industrial and commercial enterprises is significant (5.12).

Table 5.2. Major Primary Energy Consuming Sectors

<u>Sector</u>	<u>Percentage of Total Consumption</u>
Electricity production	21.9
Households	35.9
Transport	17.7
Mining industry	8.0
Other industry	13.3
Government services	0.7

Source; Medium Term Development Strategy: Energy Strategy Discussion Papers, National Planning Office, 1984.

The largest single producer of electricity is Bougainville Copper Limited (BCL) with 135 MW of oil fired thermal plant. In 1982 BCL was responsible for 62% of total electricity production in Papua New Guinea. The majority of remaining private generation is from diesel generator sets, and the range in installed capacity is from several MW to a few kW. There is one 5 MW private hydro-power scheme (called Baiune) serving a timber milling and processing operation at Bulolo. In addition, there is an oil palm kernel fired steam turbine plant operating in West New Britain Province (5.13, 5.14, 5.15).

The official supply to general consumers is principally met by the Papua New Guinea Electricity Commission (Elcom). It supplies power to approximately 43,000 consumers and in 1982 was responsible for 35% of total electricity production. In addition, the Department of

Finance is responsible for electricity supplies to over 100 'C' centres whose supplies are met from diesel generator sets.

It is forecast that by 1990 the proportion of total electricity production generated by Elcom will have risen to 36% only, with BCL's share of production declining to 44%. Ok Tedi will be responsible for 13% of production with the remaining 7% being generated by minor enclave industries and at 'C' centres.

As a means of reducing the proportion of fuel imports used for electricity generation, the government has encouraged the development of hydro-power schemes to meet official supplies. The development of hydro-power schemes has also been proposed to meet the needs of the major mineral extraction projects at Bougainville and Ok Tedi. A demonstration wood fired steam plant has also been proposed (5.16) as have a number of fuel substitutes for diesel generation. Since these are also applicable to the transport and industry sectors they are dealt with below.

5.4. Transport Sector Energy Consumption

In 1981 the transport sector was responsible for 17.7% of primary energy consumption. Virtually all of this was in the form of fuel imports. Thus, the sector consumed 32% of total fuel imports. Several initiatives have been proposed to reduce the sector's reliance on fuel imports. Of these the production of ethanol from sugar by Ramu Sugar Holdings Ltd is the only one to have proceeded beyond pilot project stage. Annual production is between 6 and 9 million litres and this is mixed in a 1:9 ratio with petrol for sale at service stations (5.17).

Alcohol production was also proposed using cassava as the raw material, and the Baiyer River Alcohol Company Ltd was formed in 1980 to establish production in Western Highlands Province. The major shareholder in the company was the national government through the Energy Development Company Ltd with Shell Oil having a 25% stake and Davy McKee 15.4%. Project establishment costs were initially

estimated at K 2.6 million. During implementation it became clear that cost over-run would be significant and that the project feasibility studies had been based on over-optimistic forecasts of fuel price escalation. As a result, poor economic returns were anticipated and the project was abandoned (5.18).

A further ethanol production project using sago as its raw material has been proposed for the Sepik region, but at present remains a proposal only. Other fuel substitution proposals include the use of coconut oil and palm oil in diesel engines. A demonstration project for the former is believed to be currently underway in Sepik Province (5.19).

5.5 The Energy Consumption of Mining and Other Industry

Mining and industry were responsible for 21.3% of primary energy consumption in 1981. However, this figure appears to exclude private electricity production and total industrial energy use would have been significantly higher. Thus, in 1979 industry had been responsible for the consumption of 43% of fuel imports. Of this nearly 80% was consumed by Bougainville Copper Limited, principally in its 135 MW thermal generating plant. Remaining industries therefore consumed only 10% of fuel imports.

Within industry 43% of energy was used for furnace heating and steam raising and there is considerable scope for both fuel conservation and substitution. Some of the projects and proposals described above are applicable to the industrial sector and further proposals include: (a) direct furnace burning of agricultural and industrial wastes, in particular, coffee husks and wood waste, (b) pyrolytic conversion of wood wastes to char, oil and gas for subsequent use in furnaces or converted engines, (c) the large-scale production of bio-gas from industrial and agricultural wastes for subsequent combustion and (d) increased use of solar water heaters to provide low grade hot water (5.20).

5.6. The Papua New Guinea Electricity Commission

5.6.1. Introduction and Historical Review

The Papua New Guinea Electricity Commission was established in 1963 as a Commercial Statutory Authority and given responsibility for the planning, co-ordination and supply of public electricity throughout the country. It is responsible for generation, transmission, distribution to, and revenue collection from, its consumers. By virtue of its enabling act, Elcom is profit orientated and has an obligation to adhere to the national government's criteria on project investment. As such it should only undertake new investments on which it can be expected to earn at least the required rate of return (currently 10%). If it wishes to undertake a non-commercial investment for socio-political reasons it must make a submission to the National Executive Council seeking approval for a budget subsidy sufficient to make the project commercial to Elcom (5.21).

Until 1963 electricity supplies had been the responsibility of the Electrical Undertakings Branch of the Commonwealth Department of Works. Electricity had been supplied to whatever sites the Administration felt warranted them. Little regard was given to the economics of supply since electricity was considered a facility expected by Administration officers at all stations (5.22).

Elcom's situation was very different. Initially it took over responsibility for supplies to the nation's four major urban centres of Port Moresby, Lae, Rabaul and Madang, which were seen as being immediately profitable. By July 1976 Elcom had also taken over Keravat, Kieta/Arawa, Mount Hagen, Kundiawa and Kainantu. In the case of the three highlands centres, their takeover was made practicable by the completion of a major hydro-power project on the Ramu River, and by the construction of associated transmission lines. In January 1979 a further twelve centres were taken over and several smaller centres have since been added as Elcom's transmission network has been extended. By December 1985 Elcom was responsible for electricity supplies to the nation's 8 largest urban

centres, to all 17 'B' centres, to 8 smaller urban centres and to various agro-industrial loads. It operates 18 independent power systems, see Figure 5.2. (5.23, 5.24, 5.25).

The Port Moresby system supplying the National Capital District is the largest in terms of installed capacity and demand. However, the Ramu system is the most extensive supplying the coastal towns of Lae and Madang, the inland centre of Mumeng and the highlands towns of Kainantu, Yonki, Goroka, Kundiawa, Mount Hagen, and Mendi. The Gazelle system, serving Keravat, Kokopo, Rabaul, Warangoi and Nonga is the only other system with significant area coverage. The remaining systems serve single urban centres or conurbations and at most of them generation is diesel-based (5.26).

In December 1985 Elcom's total installed generating capacity (site rated) was 204.58 MW, of which 117 MW was hydro-power capacity. Gas turbine capacity was 32 MW and the remaining 55.58 MW was diesel. Elcom's installed hydro plants have limited storage capacity and each power system requires stand-by capacity. Thus, total firm capacity was only 121.59 MW (5.27). In addition to its own generation plants, Elcom buys power from Bougainville Copper Limited to supply the urban conurbation of Arawa/Kieta/Panguna and from the Baiune hydro development to feed into the Ramu system. Further information on Elcom's systems can be found in Appendix A.

5.6.2. Elcom Load Growth, Past and Forecast

From 1964 to 1972 the rate of growth in demand on the Elcom systems averaged 15.2% per annum. Demand continued to grow through the 1970's but at a lower rate and in the early 1980's there was a slight decline. Since 1983 the improved national economic situation has resulted in renewed growth. This growth is expected to continue, see Figure 5.3., but the different development potential of specific regions and the government policy of encouraging industrial developments to locate outside the major urban centres means that forecasts of growth for individual systems show wide variation (5.28).

Figure 5.2. Elcom's Existing Transmission Systems and Supply Centres

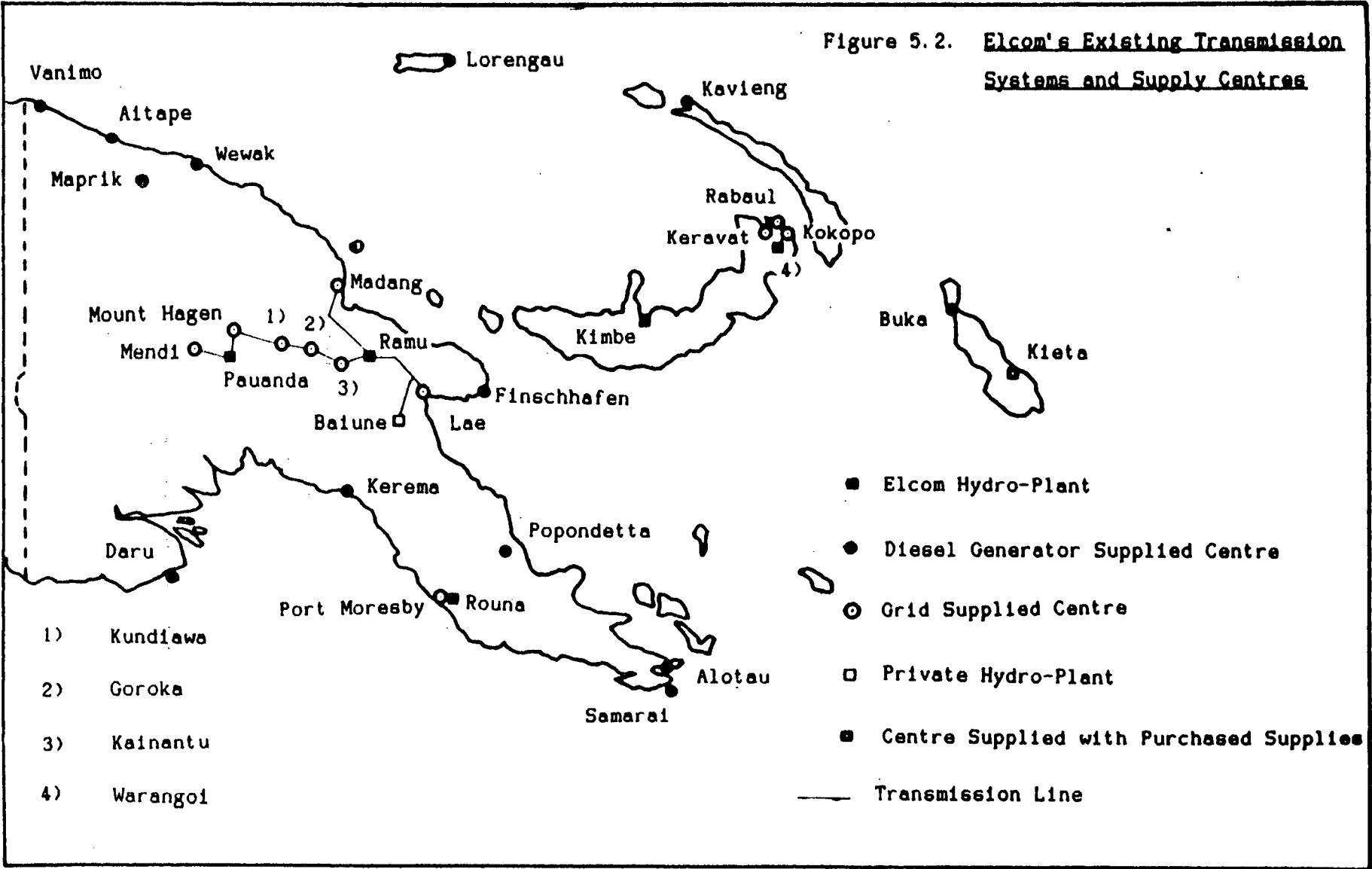
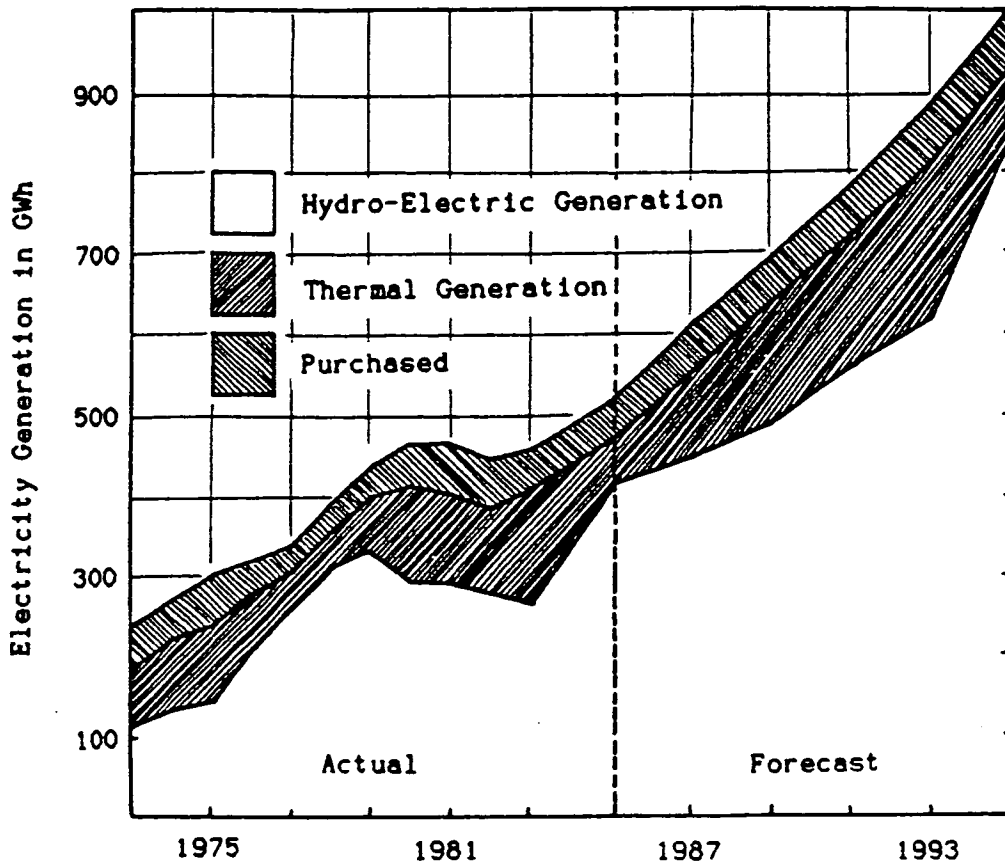


Figure 5.3. Elcom Generation 1973-1995



Source: 21st Annual Report, Elcom 1983 and
 Ten Year Plan 1986-1995, Elcom, 1985

5.6.3. Generation Planning and System Development Plans

In 1983 there were a total of 42,500 consumer connections. These were classified as either 'general' or 'domestic'. The 8,000 general consumers comprised industrial and commercial enterprises, schools, offices, hospitals etc.. They were responsible for 60.2% of consumption and 69.2% of Elcom's electricity sales revenue. Hydro-power met 79.2% of total demand with an additional 9.3% being

purchased from private sources. The sum of individual system maximum demands was 99.94 MW (5.29).

In addition to meeting future electricity demands, replacement of thermal based generation with hydro-electric (or other renewable energy) generation, whenever financially justified, is an important Elcom policy. Several hydro-power projects are planned and hydrological data is currently being gathered at a number of sites to enable future assessment of their potential. At most of the smaller systems, generation will remain entirely diesel based to 1995. In 1985 hydro-power plant was responsible for 80% of Elcom's total generation and fuel use at thermal plant totalled 19 million litres (5.30).

5.6.4. The Economics of Elcom Operations

The overall cost of electricity produced by Elcom is high by international standards. Factors that contribute to this include:

- a) the high costs of diesel based electricity generation at Elcom's smaller centres.
- b) Elcom's system load factor is lower than would be the case if the industrial base load (at present largely met by private generation) were supplied by Elcom (5.31).
- c) the relatively small size of Elcom operations limits possible economies of scale.
- d) the relatively high level of capital charges incurred by Elcom as a result of rapid expansion, particularly of hydro-power facilities, in response to system load growth (5.32).

As a result of factors a) and c) in particular, the cost of producing electricity at one of Elcom's small diesel based centres is significantly higher than for a large hydro-power based system like Ramu. These cost differences are not reflected in the tariff

structure which, at the request of the national government, is uniform and based on monthly consumption. The uniform national tariff is seen as a means of serving equity aims and reducing regional inequalities. The level of the tariff is set so as to recover Elcom's costs on a nation-wide basis, to earn the return on investment specified by the Minister for Finance, to service debt arising from construction of major projects, and to finance smaller projects from internally generated funds (5.33). The 1983 tariff for domestic consumers is shown in Table 5.3. The charge for large industrial and commercial consumers was set at a somewhat lower level.

Table 5.3. Elcom's Uniform National Tariff as of 1st June 1983

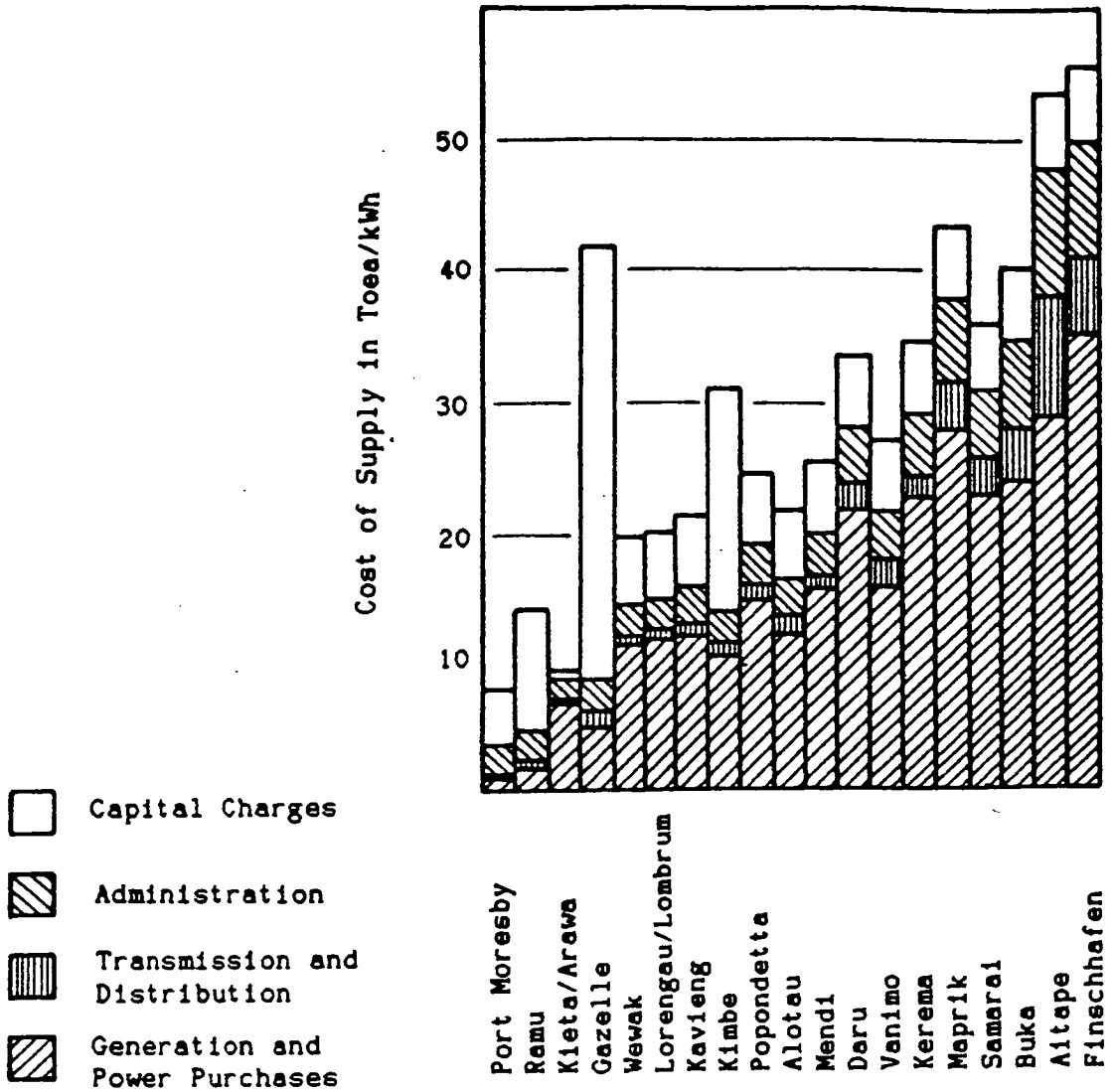
<u>Monthly Consumption</u>	<u>Toea/kWh</u>
First 100 kWh	12.0
Additional Consumption	16.0

Source; 21st Annual Report, Papua New Guinea Electricity Commission, December 1983.

In 1983 the average cost of electricity produced by Elcom was 10.77 toea/kWh, and the average return on each kWh sold was 14.07 toea. Electricity sales were 397.7 GWh and Elcom made a before tax profit of K 6,368,000 (5.34). However, in 1984 the only Elcom systems for which the cost of supply was below 16 toea/kWh were the largest three in terms of annual energy sales, see Figure 5.4. The cost of supply for the remaining systems was above the tariff charged so that the uniform national tariff has the effect of subsidizing consumers of these systems at the expense of consumers from the Port Moresby, Ramu and Kieta/Arawa systems (5.35).

There is continuing debate about the desirability of the uniform tariff and, within Elcom and the Department of Minerals and Energy, growing opposition to it. It is argued that artificially low prices

Figure 5.4. Elcom Electricity Production Costs by System



Elcom Systems Ranked in Order of Descending Annual Energy Sales

Source: Unpublished Material

in many centres encourage wasteful consumption with minimal benefits to the less well off, whilst high tariffs at low cost centres raise the cost of doing business and can result in other energy sources being used when from a national standpoint electricity may be the least cost option.

5.7. Official Electricity Supplies at Non-Elcom Centres

5.7.1. Introduction

Elcom has gradually increased the number of centres that it supplies in response to government pressure and as its hydro based systems, in particular the Ramu system, have been extended, making the connection of these centres financially viable. However, as of December 1984 there were 108 'C' centres at which electricity supplies remained the responsibility of the national government. Approximately 40 institutional centres ie. research centres, hospitals, educational establishments etc. are also supplied with electricity by the national government (5.37)).

5.7.2. The Logistics of Operations

Electricity supplies to the nation's 'C' centres are currently the responsibility of the Department of Finance. However it is not physically involved in supplying these centres and Elcom is used as a contractor to operate and maintain service and equipment. Revenue collection remains the responsibility of the Department of Finance, but, at local level it is the responsibility of the District or Sub-District cashier. Responsibility for supplies to the institutional centres lies in the hands of the Department of Works (5.38).

Electricity generation at virtually all 'C' centres is by diesel generator. There are generally at least two diesel generator sets at each centre, one acting as standby, and in many centres it is not possible to operate the sets in parallel. Although power is available 24 hours/day at a few centres, normally the generators are operated for several hours each morning and again each evening. A

survey of 27 'C' centres in 1982 indicated that daily operation averaged 9.5 hours/day. Two centres, Tapini (which has a micro hydro-power project) and Wabag, had power virtually 24 hours/day, while at Kairuku power was available for only 3 hours/day. A breakdown of operating hours at three selected centres is given in Table 5.4. Installed capacity at 'C' centres averages about 100 kW, with very few centres having a capacity of greater than 300 kW (5.39, 5.40).

Table 5.4. Hours of Operation at Selected 'C' Centres

<u>Centre</u>	<u>Weekdays</u>	<u>Weekends</u>
Okapa	6.00 pm to 10.30 pm	6.00 pm to 11.00 pm
Tari	6.30 am to 9.30 am 3.00 pm to 11.00 pm	6.30 am to 9.30 am 2.00 pm to 12.00 pm
Menyamya	8.00 am to 12.00 am 4.00 pm to 10.00 pm	8.00 am to 12.00 am 4.00 pm to 10.00 pm

Source; Interviews with Power House Operators.

At most 'C' centres an Elcom trained operator is employed who is responsible for plant operation and routine maintenance. The operator is usually paid by the local District Office from Department of Finance funds assigned to electricity generation. Major maintenance and repair work is carried out by Elcom staff usually based at Elcom's provincial headquarters. Elcom is also responsible for the distribution system at 'C' centres. In 1982 the average cost of maintenance at 'C' centres was K 11,465 (5.41).

Staff shortages limit the frequency and effectiveness of Elcom's maintenance operations with the result that extended periods of outage are not uncommon. The situation is exacerbated by the limited training of operators, and the age of plants. The remoteness of many centres adds significantly to these problems and to the on-site cost

of diesel fuel. Of the 27 'C' centres at which electricity use was examined in 1982, three had neither road nor marine access. Thus, fuel, spares and maintenance personnel all needed to be flown in by light aircraft. As a result, the cost of a 200 litre drum of diesel at the inaccessible centre of Telefomin was K 201.35 in comparison with a cost of K 74.00/drum at the coastal centre of Bogia (5.42).

5.7.3. Electricity Use

In the past electricity supplies at 'C' centres were largely restricted to administrative offices and workshops and to the homes of public servants. Nowadays in many of the larger 'C' centres electricity supplies are also available to non-public sector households and to local businesses. Electricity usage by consumers is not metered, although in some cases load limiters are installed. Domestic users are required to pay a monthly charge. For high covenant housing the current charge is K 6.30/month and for low covenant houses it is K 2.10/month. In many centres there are a considerable number of households that would be keen to be connected to the power system, but are unable to do so because of the restricted capacity of the installed generator. This limited capacity also means that certain appliances, in particular electric cookers and electric kettles, may be banned to try and prevent overloading of the system. In spite of restrictions electric jugs, cookers, and washing machines all remain popular (5.43, 5.44, 5.45).

Businesses that receive power from the official town supply are also charged on a flat rate monthly basis, the exact charge being dependent upon the number and type of appliances installed. However, because of the limited capacity of existing generators, businesses are often forced to generate their own supplies or do without. As a result, at many centres the installed capacity of private generation is on a par with that of the official supply (5.46, 5.47).

5.7.4 The Economics of Supply

Collection of the flat rate monthly charge from consumers is the responsibility of the government cashier at the centre. Being diesel based, generation at these centres is inherently expensive and these charges are set at too low a level to cover generation costs even if tariff collection were efficient. At many centres revenue collection from domestic consumers is virtually non-existent. This is a throwback to the days of the Australian Administration when an electricity supply was a facility expected by administration officers. This attitude still exists.

As a result of both the unrealistically low level at which tariffs are set, and the poor record of tariff collection, electricity supplies to 'C' centres are highly subsidized by the national government. Data on generation levels and costs is limited, but in 1981 it was estimated that total generation at 'C' centres was about 5 GWh at a cost of 56 toea/kWh. In 1983, actual expenditure on electricity supplies at 'C' centres amounted to K 2.8 million. Less than 1% of this was returned in the form of revenues and the extent of subsidy was effectively K 1,400 per consumer per year (5.48).

As the price of fuel imports rose through the 1970's the level of these subsidies was increasingly seen as a burden by the national government. This led to a reluctance to increase generator capacity at these centres. Limited official supplies therefore mean that private generation is often necessary. Although keen to control the cost of electricity supplies to 'C' centres the national government sees these centres as important real, or potential, service centres and growth poles for stimulating rural development. However, the present unreliability and lack of capacity of electricity supplies is seen as a constraint to the development of commercial and industrial enterprises needed for the service centres to fulfil their role. As a result, whilst attempting to limit costs, the government has been keen to find a means of improving electricity supplies to these centres. A number of initiatives, dealt with in later sections, have been undertaken with this aim. The long term

objective is to make the electricity supply systems at these centres commercially viable so that they can be taken over by Elcom (5.49).

5.8. Conclusions

Total energy consumption in Papua New Guinea is still increasing and, if economic development is to continue, this is desirable. The current slump in world oil prices has gone some way towards alleviating the country's problem of heavy dependence on fuel imports, however in the longer term this problem is likely to again worsen unless development of (and further exploration for) Papua New Guinean oil and gas reserves proceeds.

At a domestic level fuel wood is likely to continue to be the principal energy source for cooking and heating for many years. Although some reforestation has been attempted to improve fuel wood supplies results have been mixed and in general the situation continues to deteriorate. The collapse of the Energy Development Company Ltd has meant that charcoal production has declined. The scope for increased use of improved stoves remains large.

A number of steps have been taken to reduce the nation's dependence upon fuel imports. It would appear that the production of ethanol from the Ramu Valley has played a part in limiting petrol imports. The combustion of agricultural and industrial wastes is also becoming more common and has few technical problems. It has been estimated that (excluding wood waste) as much as 20% of all industry's fossil fuel use could eventually be displaced by waste combustion. Continuing development of hydro-power resources is likely to reduce the electricity sector's dependence on imported fuels. In particular development of hydro-power projects to supply power to Ok Tedi and BCL would have a major impact. In the longer term, as the official supply is extended and its capacity increased, the proportion of private, mostly diesel generation is likely to decline.

In the medium term, it is unlikely that the remaining fuel substitutes are likely to have significant impact. Although several of the proposals have been proved either in Papua New Guinea or elsewhere at pilot project stage, they have not been proved commercially and as such are high risk ventures, especially in a country with only limited technical skills.

The overall cost of electricity produced by Elcom is high by international standards, largely because of Elcom's reliance upon diesel generator sets to supply its smaller isolated centres.

The cost of supplying electricity to the nation's 'C' centres is also very high and the lack of adequate power supplies at these centres is seen as a constraint to their development as rural service centres.

6. Official Rural Electrification Activity in Papua New Guinea

6.1. Introduction

Rural electrification is generally considered as the organized extension, usually by means of extended transmission and distribution, of electricity supplies to rural areas and communities that had previously not had access to an electricity supply. Although there has been, and continues to be, much debate in Papua New Guinea about the pros and cons of establishing such a rural electrification programme, to date there has been little in the way of concrete action.

In a more limited role, rural electrification in Papua New Guinea is seen as the improvement of electricity supplies to the nation's existing 'C' centres. A number of initiatives have been designed to improve supplies and reduce costs at these centres. These will be dealt with in Sections 6.4. to 6.11.. The broader rural electrification debate and initiatives are dealt with below (6.1).

6.2. The Rural Electrification Debate

By the early 1970's, several of Papua New Guinea's neighbouring South East Asian countries had begun to implement ambitious rural electrification programmes with overseas technical and financial assistance. Many of the problems of poor performance now often associated with rural electrification programmes had not become evident and rural electrification was enthusiastically seen as being a catalyst to rural development and a means of minimizing the disproportion in living standards between urban and rural areas.

There had been a growing awareness at Elcom of a desire, on the part the rural population of Papua New Guinea, for electricity supplies to be extended to villages. But Elcom had not yet taken over responsibility for electricity supplies to the nation's 'B' centres and discussion about rural electrification tended to concentrate on

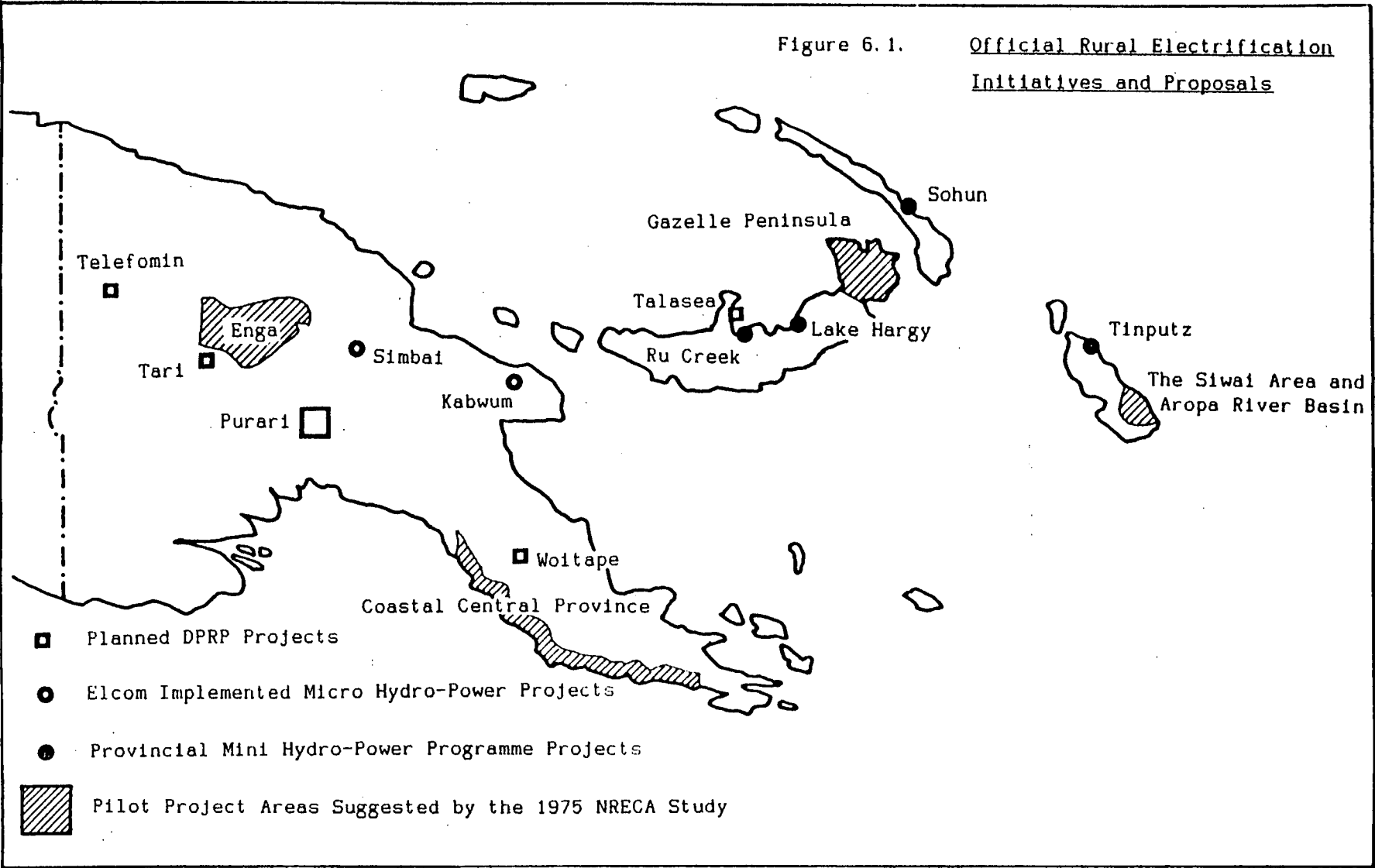
the high cost of extending supplies to rural areas and the conflict with Elcom's profit orientated nature. The oil crisis of 1973/74 worsened Elcom's financial situation and made its position with respect to rural electrification even more difficult.

However, the development of the Ramu No. 1 hydro-power station and associated transmission lines, see Figure 5.2., meant that villagers in the area began to press for the extension of power to their villages. Villagers in the area of the proposed large-scale Purari hydro-power development, see Figure 6.1., also expressed interest in obtaining electricity supplies. The move to self-government, and publication of the government's Eight Aims also affected peoples' perceptions and spurred demands for rural electrification. In response to the growing debate about, and pressure for, rural electrification, it was agreed that Elcom would prepare a report on the subject for the Minister for Minerals and Energy (6.2).

During November 1974 staff from the World Bank visited Papua New Guinea. One of the topics discussed was the possibility of obtaining financial assistance for a rural electrification programme. At the time, the World Bank was becoming involved in several rural electrification programmes in the region and it was suggested that Elcom undertake a study of the programmes in Taiwan and the Philippines. It was thought that an examination of the different methods, organizational structure and performance of the two programmes would be useful in formulating an appropriate rural electrification programme and organizational structure for Papua New Guinea and in assessing its viability. This suggestion was taken up and a study visit was made to both Taiwan and the Philippines by E. S. Dryer, Assistant Manager of Elcom, during December 1974 and January 1975. The findings of this study visit were used extensively in the preparation of his report "Rural Electrification in Papua New Guinea" (6.3).

Figure 6.1.

Official Rural Electrification
Initiatives and Proposals



6.2.1. Rural Electrification in Papua New Guinea: An Elcom Report

The Philippines

In 1973 the Philippines had a population of 42 million, of whom 30% had access to electricity, the majority of them inhabiting metropolitan Manila and other urban centres. The total electrification of the country on an area coverage basis by 1990 had been declared a national policy objective in 1969. The organizational structure of the programme was based on that used during the rural electrification of the USA during the 1930's. The American based National Rural Electric Co-operative Association (NRECA) was heavily involved in the early stages of the programme which began in 1969 with the establishment of the MORESCO and VRESCO pilot electric co-operatives. These appeared to be viable and the programme was expanded so that by June 1974 feasibility studies for co-operatives in 67 provinces had been completed with a further six in progress. Seven co-operatives had completely energized their backbone systems and a further 19 were supplying power to some consumers. MORESCO, one of the pilot co-operatives, was visited by Dryer. He was impressed by the apparent dynamism of the area, the number of home improvements and new houses under construction, the number of new businesses being established and the general enthusiasm for electricity (6.4).

Taiwan

Taiwan is a densely populated island for which rural development and improved agricultural productivity were seen as essential to the nation's development. A 20 year rural electrification programme was proposed by Tai Power in 1954 and supported by the Joint Committee on Rural Reconstruction (JCRR). Tai Power was a private company with the major shareholder being the national government, hence, like Elcom, it was a profit orientated organization. By 1966 26% of rural electricity consumption was for productive end uses. By 1973 over

2,500 villages had been electrified under the programme and 98% of the nation's households had access to power (6.5).

Conclusions of the Report

Dryer had been impressed by the implementation and impact of the rural electrification programmes in both the Philippines and Taiwan and believed that the availability of electricity had decentralized economic activity, created great agricultural development, enabled the development of village industries and improved the way of life in the villages to the extent of reducing urban drift.

Nevertheless, the high population density, better education and relatively high initial standard of living in Taiwan meant that its rural electrification had been both easier and brought quicker financial returns than was likely to be the case in Papua New Guinea. A closer similarity was seen with the situation in the Philippines and it was felt that much could be learned from that programme if a rural electrification programme was to proceed in Papua New Guinea. One of the recommendations of the report was that NRECA be approached to undertake a study in Papua New Guinea to select suitable areas for pilot rural electrification projects after independence. (6.6).

6.2.2. The NRECA Reconnaissance Survey

This survey took place during May and June of 1975 using the following concept as the basis of the report;

"Rural electrification is the supplying of adequate and reliable 24 hours a day electric service at reasonable cost, usually on a non-profit basis, to a large area and including all homes, farms, schools, businesses and industries in the area to provide broad social and economic benefits to all the people as a part of a total area development programme to improve the quality of life of rural and village people. It deserves to be treated essentially as a part of the basic infrastructure of the country along with such items as roads and schools." (6.7)

Recommended Organizational Structure

A central co-ordinating agency dedicated to fulfilling programme objectives was seen as necessary if a rural electrification programme was to be implemented. Seen as separate from the national government, this agency would fulfil a supportive and controlling role with respect to electric co-operatives responsible for rural electrification within specific areas. Its main functions and areas of responsibility would normally be (6.8);

- a) policy and programme formulation and administration.
- b) acting as a loan agency to electric co-operatives.
- c) development of engineering policies and specifications,
- d) design, construction, operation and maintenance of electric co-operative power systems and equipment.
- e) negotiation of wholesale power purchases.
- f) provision of management assistance to electric co-operatives.

It was stressed that a successful rural electrification programme would need strong government commitment and co-operation to ensure continuing availability of long term, low interest finance. A large number of consumers and/or a significant volume of service, would also be needed to provide a sound economic base to the programme. Thus, the study recommended that District Rural Electrification Co-operatives or Institutions be set up of sufficient size to make them commercially viable. These co-operatives would be responsible for power transmission and distribution, revenue collection and consumer service programmes to help consumers make the most of the service and develop productive end uses for power. Where possible the co-operatives would buy their power from Elcom, only resorting to generating power themselves where this was not possible. In the event of isolated generation proving necessary, it was recommended

that connection to the national power system be planned as soon as possible (6.9).

Selected Pilot Project Areas

The report suggested the following areas as being suitable for pilot rural electrification projects (6.10):

- 1) The Gazelle Peninsula of East New Britain, see Figure 6.1., which had a high population density and a well developed economy based mainly around cocoa and copra production. Several cocoa processing plants operated in the area and were already connected to the Elcom supply. It was noted that the Gazelle people were progressive and possibly had the highest income of any part of Papua New Guinea. In addition, most of the villages in the area were served by a well developed road network.
- 2) The coastal area of Central Province where there was a need for reliable power to serve the fishing industry. The proposed area stretched from Kwikila to Cape Rodney, also possibly encompassing Yule Island where there was an existing demand for at least a 100kW supply. If the Purari hydro-power scheme went ahead, there was the prospect of the whole coastal area of both the Gulf and Central provinces being electrified, though probably not on an area coverage basis.
- 3) The Aropa River Basin and the Siwai area of Bougainville, see Figure 6.1., had a higher than average population density and a well developed economy based on cocoa and copra production. The Aropa area had a population of about 2,500 and was served by several crop processing plants, stores, health centres, schools, a sawmill, and a sand and gravel operation. The Aropa River had potential for hydro-power development with the prospect of subsequent connection to Kieta. However, the area itself was fairly small so that its electrification would best be undertaken as part of a broader programme.

- 4) Enga Province was behind many areas in terms of development, but had the advantage of a large population with a common language bond. Any rural electrification programme would need to include a simultaneous rural development programme to build up involvement in cash cropping, and small business.

6.2.3. The NRECA Study of the Gazelle Peninsula

As a follow-up to their initial study, in 1976 NRECA were commissioned to draw up a proposal for a pilot rural electrification project in the Gazelle Peninsula, see Figure 6.1.. The project was to provide power to all 156 villages in the area which had a total population of 76,220. In the longer term, it was envisaged that lines could be extended to serve additional areas (6.11). The report suggested that;

"Simultaneously and co-ordinated with the implementation of the project, development teams from the provincial and national government should work with the villagers: in the development and improvement of the cash crop agriculture sector of the rural economy, in the establishment of many types of commercial services, in the development and operation of village orientated industries, and in the improvement of social conditions and relationships within villages." (6.12)

It was recommended that a publicly owned Gazelle Peninsula Electric Energy (GPEE) Corporation be set up, probably along the lines of a co-operative, to be responsible for the distribution of power within the project area and for the collection of revenues from consumers. Power generation and transmission from diesel generators at Kerevat and Rabaul would remain the responsibility of Elcom. Once established the Corporation was to acquire 120 km of 11 and 22 kV line with 2,033 residential and 856 commercial and industrial connections together with related equipment from Elcom. These lines would then be converted to a 22 kV four wire set up. A further 347km of 22 kV line would be constructed to serve an additional 7,500 residential and 1,035 commercial and industrial connections.

The cost of carrying out the proposed work and operating the project for the first five years was estimated at K 3 million. Based on forecasts of connections and consumer demand, it was estimated that Elcom would need to increase their generating capacity from 6.98 MW to 11.5 MW during the first six years of project operation (6.13).

It was recommended that soft loan finance be obtained by the national government to be re-lent to the GPEE Corporation, preferably through an independent authority established by the government, or through a Department of Rural Electrification established within Elcom. Based on forecast costs and revenue, the feasibility of the proposal became doubtful if loan terms could not be obtained at, or better than, a 25 year repayment period with a 5 year deferment on principal repayments and an interest rate of 4%.

6.2.4. Official Response to the NRECA Studies

The NRECA investigation of the Gazelle Peninsula had been funded by the national government. It had been hoped that funding for further studies of the Papuan Coast and of Enga Province and for implementation of the Gazelle project would be made available by USAID (6.14, 6.15). In the event this funding did not materialize and the investigations were cancelled. No progress could be made on the Gazelle project without a commitment from the national government to enact the legislation necessary to establish a rural electrification agency, and to provide the concessionary finance necessary to make the project feasible.

By the end of 1976, the government had taken no positive action in this direction since there were a number of concerns about the viability of the project. At the time Elcom was planning to implement a 10 MW hydro-power scheme on the Warangoi river which would serve the project area. Implementation of the rural electrification project would have required Elcom to install additional generating capacity, and it was thought that the project should be postponed at least until the Warangoi hydro scheme had been completed (6.16).

A number of concerns related more directly to the NRECA report and its assumptions. It was felt that in most other countries with which NRECA had been involved the population density tended to be higher, communities significantly larger, infrastructure better developed, and the rural people traditionally more involved in small-scale processing, industrial and commercial enterprises. The report itself had stated that in the project area very little village-based commercial activity existed, other than a surplus of small tradestores. A lack of adequate electricity supplies was suggested as one reason for this and a number of possible small-scale industries suitable for development were proposed. However, it was argued that a lack of electricity was unlikely to be a severe constraint to their development. There was also concern that the forecast level of new connections would not be achieved. This would have a detrimental affect upon project feasibility. Thus, it was pointed out that the level of attendance at village meetings, held during investigations to sound out opinion to the proposal, had been disappointing. Few people had been prepared to confirm that they would definitely connect to a power supply if it were available and it was observed that;

"There are some 60 miles (96 km) of rural power lines in the Gazelle, the majority of these lines having been in existence for the last 8 years. The pattern of village connections to these lines over this period is the Church, the Trade Store and the Social Club. The number of village houses connected are negligible. There are village houses that have had low voltage power lines passing their front door for the past 20 years, and yet these houses have still not connected to power." (6.17)

6.2.5. Elcom Proposals

Although no concrete action had been taken, the studies by Dryer and NRECA had had a major impact upon Elcom thinking, as expressed in the Elcom Ten Year Plan 1977 to 1986 (6.18). Thus, it was envisaged that Elcom would assume the role of a Generating Authority divesting itself of distribution and customer accounting responsibilities by 1986. It was suggested that the national government should issue no new permits for private generation and should acquire all major

private generation facilities for transfer to Elcom. Elcom would concentrate on the development of generating facilities, principally hydro, and of a national grid system. Specific hydro developments for mining ventures, such as Bougainville or Ok Tedi, would feed excess power into the national grid and would be planned accordingly.

Responsibility for distribution and consumer services would be taken over by the provincial governments who would buy electricity from Elcom at a uniform national tariff for resale to consumers. Until the provincial governments were in a position to assume this role, it was envisaged that Elcom would take over responsibility for supplies to the nation's 'B' centres and undertake the training of provincial staff to make the future transfer of responsibilities possible.

It was considered that a favourable commitment from the national government could lead to the establishment of a National Rural Electrification Programme concerned solely with power distribution and sale. To this end, it was recommended that a Rural Electrical Authority be established within two years to assist the provinces in establishing Rural Co-operatives/Authorities. Although Elcom was not considering becoming heavily involved in any rural electrification programme, except as a supplier of power, it was proposed that a separate division be set up within the organization to investigate the possible takeover of the nation's 'B' and 'C' centres, and to carry out micro hydro-power project investigations. Elcom was already in the process of carrying out a province-by-province survey of potential low-cost, small-scale hydro developments, which might provide the basis for provincial electrification in areas which could not be reached by Elcom's distribution system. Until a National Rural Electrification Programme was established, it was suggested that provincial governments be encouraged to fund small systems utilizing existing minor station potential, and/or micro hydro-power schemes identified by the Provincial Electrification Studies.

The Government Response

The need to subsidize rural electrification meant that Elcom could not proceed without government support. By late 1977 it had become evident that the national government was not likely to support an extensive rural electrification programme. The reasoning behind this decision subsequently became clear with the publication in 1979 of a White Paper "Energy Policy and Planning for Papua New Guinea" (6.19). The paper stated that most of the claimed benefits of rural electrification could be better achieved by other means and that investment in rural electrification was investment lost to such areas as improved roads, health and education facilities. It was also noted that rural electrification often resulted in the creation of rural elites rather than broadly based rural development. As a result, the view was endorsed that;

"The government should only subsidize rural electrification, especially at village level, if and when it has been determined that the basic needs of the community, particularly in the supply of food and fuel-wood, are being met, and that the expenditure proposed could not provide more equitable benefits to the community if invested in other village level developments. Funding of rural electrification should only be considered if this assessment has been made and the project is still, on balance, supported." (6.20)

Subsequent Rural Electrification from Elcom's Grid System

For Elcom, the situation was exacerbated by the uniform national tariff. The inability of Elcom to charge an economic tariff inhibited the extension of electricity supplies to areas that might otherwise be financially viable (6.21). As a result, Elcom was forced to abandon some of its more ambitious development proposals. In particular, its emphasis upon the development of a national transmission grid was replaced by a low key policy of gradual grid extension which continues to the present. The existing and potential loads in rural areas include agro-industrial enterprises, small mining ventures, government 'C' centres, government and private institutions, and rural village communities. Where a rural

extension is requested and investigation indicates that it is likely to be economic to Elcom, then Elcom finances the extension through normal budget procedures. In practice no significant extensions have been made from Elcom's diesel-based centres, and extensions from the hydro-based systems have been largely limited to agro-industrial loads, 'C' centres and government institutions (6.22).

6.3.1. Extensions from the Ramu System

Most connections have been to the Ramu system and several further connections are planned. Thus, in Enga Province distribution is being extended to the 'C' centres of Wabag (complete) and Wapenamanda. Several schools, missions and agro-industrial loads along the transmission route are also to be connected. Henganofi in the Eastern Highlands was due to be connected to the grid by late 1986 and several agro-industrial connections were also expected in Eastern Highlands, Morobe and Western Highlands provinces. In addition, supplies are to be extended to several villages in the area of Yonki (6.23).

6.3.2. Extensions from Other Elcom Systems

Expansion of the Port Moresby system is proposed. This would involve construction of a transmission line to serve the Kwikila-Kupiano-Cape Rodney areas. The extension would serve several villages, a mission, a school, a boating resort, a fish processing plant and several cool stores.

Expansion of the Gazelle system is also being considered with connection to the system of several schools, a mission, several plantations, a township, two sawmills and a coconut oil factory (6.24).

The construction of a 2 MW hydro-power project is proposed to serve the Popondetta area. Commissioning of the plant is planned for 1989 and its completion will make possible the connection of a number of industrial consumers outside the centre (6.25).

6.3.3. Village Connections

The number of villages supplied by Elcom has remained extremely limited. As a pilot project, Porebada, a large peri-urban village near Port Moresby was electrified in 1978. The number of household and commercial connections has been very low (less than 50 of over 500 households) and this is often cited as a being a reason for not proceeding with a more ambitious rural electrification programme (6.26, 6.27).

When villages have expressed an interest in being connected to the Elcom system, subsequent investigations have indicated that in virtually all cases the required line extension is unlikely to prove economic to Elcom. Under these circumstances a refundable capital advance is required before a village extension project can be undertaken. The advance consists of an interest free loan for which application must be made to the Provincial Government Office concerned. The decision as to whether to award the advance lies in the hands of the Provincial Government Office and the village may be required to contribute towards this advance. If the advance is obtained, then the villagers must agree to allow Elcom access to land along the proposed distribution route and to clear the route of trees before Elcom will implement the project. No compensation is given for either land or felled trees.

In the event of the above conditions being met, Elcom will in theory install a distribution system. However, Elcom will not install household reticulation and the villagers must employ an Elcom approved contractor to undertake this work, which is inspected by Elcom before connection is possible. A connection charge of K 10.00 is also payable by each household before connection is made. Consumption is billed on a monthly basis and a minimum charge is imposed to cover billing and administrative costs. Four years after the connection has been made the advance is refunded, provided the value of electricity consumed equals or exceeds the amount of the advance. Where the value of consumption is less than the advance, the refund is the value of the electricity used, the remainder being

forfeited. Any street lighting provided is financed from Elcom funds with operation and maintenance costs being met by the local council or similar governing body, on a fixed annual charge basis (6.28, 6.29).

6.4. Official Rural Electrification Activity Based upon Micro and Mini Hydro-Power Projects

The national government was not prepared to subsidize any broadly based rural electrification programme. But during the mid-1970's, it became increasingly concerned at the cost of supplying electricity to the nation's minor centres. Elcom was encouraged to take over responsibility for supplies to these centres but did not consider that they could be made viable while generation remained diesel-based. Attention was therefore diverted to Elcom's plans for the progressive development of "Provincial Electrification" based on supply from small isolated hydro sets, or from connection to existing hydro systems (6.30).

During 1976, Elcom's province-by-province studies of small-scale hydro-power potential had been continuing, and studies of West New Britain, New Ireland and North Solomons had been completed. However, the rate at which 'in house' studies could proceed was limited, and during 1977 further areas had been investigated using consulting engineers Norconsult A. S. working under a Norwegian/Papua New Guinea Government Aid Agreement. They had undertaken field pre-feasibility studies for sites in Enga, Southern Highlands, Milne Bay, Manus, Northern, Morobe and West Sepik Provinces (6.31).

6.5. Kabwum and Simbai Micro Hydro-Power Projects

As part of this interest in small-scale hydro-power, plans were developed for the implementation of two micro hydro-power projects to serve the 'C' centres of Kabwum and Simbai, see Figure 6.1.. Elcom were to be responsible for the design and implementation of the projects and for training of a plant operator. Funding was to be provided by the national government under the Government Works

Programme. Upon completion, the projects were to become assets of the Department of Finance and they were to be managed as government centres (6.32, 6.33,).

6.5.1. The Simbai Project

Simbai is a 'C' centre located in Madang Province close to the border with Chimbu. During February 1976 Elcom engineers established that a 25 kW micro hydro-power project to supply the centre was feasible utilizing flow diverted from the Yinink River (which runs through the centre). The proposed scheme was to lie entirely within the centre's boundaries obviating the need for high voltage power transmission.

Economic analysis indicated that construction of the project, details of which are provided in Appendix B, would be preferable to the installation of an equivalent diesel generator set with back up. Under the 1975/76 Government Works Programme funds were allocated to the project to cover plant purchase and civil works costs. The costs of distribution and reticulation to about 30 households were to be met by the Department of Works.

Work on the project began in August 1976 with Elcom providing supervision of locally recruited labour. Commissioning was scheduled for February 1977, but a number of problems, in particular seepage along the power canal, delayed progress. Thus, installation of the electro-mechanical equipment did not get underway until June 1977. The scheme was commissioned towards the end of that year and continues in operation to date.

History of Major Project Faults

Shortly after commissioning, continuing seepage caused the collapse of a 12 m section of the power canal. This was rebuilt, but another collapse occurred in August 1978. This was again repaired and the power canal was concrete-lined along its entire length. At this time

it was noticed that a labyrinth seal on the turbine had also failed causing bearing failure and damage to the runner shaft.

In August 1984 the governor drive failed; as a result the plant was out of operation for 5 months. Problems of sediment deposition were also being encountered both behind the diversion weir and along the power canal. No settling tank had been provided and the power canal needed frequent draining and clearing. Failure to regularly do so had resulted in the depth of the deposit building up to the extent that the water level in the canal had risen above the top of the concrete lining. Subsequent erosion behind the lining was again placing the canal at risk. By March 1985 the pond behind the weir had become completely filled. There had also been significant damage to the weir structure itself and significant re-habilitation of the project was being proposed to ensure its continued operation.

Generation

The Simbai micro hydro-power project was justified largely on the basis that the cost of energy produced would be significantly lower than that produced by equivalent diesel generators, see Table 6.1.. It was also suggested that the project would result in long term foreign exchange savings to the nation. However, there is some doubt about the validity of several of the assumptions used in this analysis. Information available to the author on the level and costs of generation from the Simbai scheme is limited, but the operational problems of the project imply that its true maintenance costs are likely to have been significantly higher than anticipated. These same operational problems mean that, to achieve a fairer comparison of costs, a standby diesel generation should have been provided with both the diesel and micro hydro-power project. The actual level of generation appears to have been significantly below that anticipated at just over 3,000 kWh/month for 1981, implying a load factor of less than 20% (6.34). Using these modified assumptions it appears that the project is marginally unattractive, see Table 6.2..

Table 6.1. A Comparison Between Forecast Costs of Hydro-Power and Diesel Generation at Simbai

	<u>Hydro 25 kW</u>	<u>Diesel (2 x 25 kW)</u>
<u>Capital Outlay in Kina</u>		
Foreign Exchange Component	25,000	12,500
Local Component	35,000	3,500
	-----	-----
Total	60,000	16,000
	-----	-----
Annual Generation in kWh	109,500	109,500
<u>Generating Costs</u>		
Interest and Redemption on Capital at 12 % pa.	7,200	1,920
Fuel Cost at 2.75 kWh/litre and K 0.365/litre	nil	14,542
<u>Operating and Maintenance Costs</u>		
Operators Wages	2,000	2,000
Maintenance Labour	200	3,500
Spares	100	1,500
	-----	-----
Total Generating Costs	9,500	23,462
	-----	-----
<u>Cost of Electricity at</u>		
<u>Bus-Bars in toea/kWh</u>	<u>8.7</u>	<u>21.4</u>

Source: Unpublished Material

Table 6.2. A Modified Comparison Between Costs of Hydro-Power and Diesel Generation at Simbai

25 kW Hydro with 25 kW Diesel Standby Diesel (2 x 25 kW)

Capital Outlay in Kina

Foreign Exchange Component	31,250	12,500
Local Component	35,000	3,500
	-----	-----
Total	66,250	16,000
	-----	-----
Annual Generation in kWh	37,000	37,000

Generating Costs

Interest and Redemption on Capital at 12 % pa.	7,950	1,920
Fuel Cost at 2.75 kWh/litre and K 0.365/litre. Assumes 15 % diesel generation for hydro- power option	737	4,911

Operating and Maintenance Costs

Operators Wages	2,000	2,000
Maintenance Labour	3,500	3,500
Spares	1,000	1,500
	-----	-----
Total Generating Costs	15,187	13,831
	-----	-----

Cost of Electricity at

<u>Bus-Bars in toea/kWh</u>	<u>41.0</u>	<u>37.4</u>
-----------------------------	-------------	-------------

6.5.2. The Kabwum Project

Kabwum is a 'C' centre located on the Huon Peninsula of Morobe Province. In the mid-1970's the centre had a population of about 300 and facilities that included 2 schools, a small hospital, the district office, the local government council chambers, a Department of Agriculture Stock and Fisheries office, 3 stores and a Lutheran mission. The centre has an airstrip but is inaccessible by road.

In August 1975 the Department of Finance assigned K 43,400 for the construction of a micro hydro-power scheme at Kabwum. The scheme was designed to utilize flow from the Pimuni River and was initially to have a capacity of 25 kW, although provision was to be made for a subsequent increase to 50 kW. The project was to be undertaken jointly by the Department of Works, who would be responsible for the civil works, and Elcom, who were to be responsible for overall design, installation of electro-mechanical equipment, testing and commissioning of the project and for the provision of a suitably trained project operator. Construction of the project, further details of which can be found in Appendix C, was undertaken using largely local labour and the scheme was successfully commissioned in November 1977 at a final cost of about K 50,000.

History of System Faults

During construction, slope stability problems along the power canal route resulted in the collapse and rebuilding of one section. After commissioning the scheme operated with only minor problems until June 1981 when flooding of the Pimuni River caused substantial damage to the weir and intake structure. In part this damage resulted from the impact of large boulders carried downstream in the flood. The weir toe was also undermined and the slope both above and below the power canal showed signs of instability.

The damage to the weir and intake structure was sufficiently severe to put the scheme out of operation. However, as a temporary measure a smaller side creek was tapped, and fed into the power canal to

keep the scheme operating at reduced output. Action to stabilize the power canal and to repair the weir and intake structure was proposed. But, in April 1982 further flooding completely washed away the weir and intake structure, destroyed approximately 30 m of the power canal and flooded the power house damaging the generator. In addition, a further 50 m length of the power canal had been filled with deposits, apparently as the result of a landslide and the bed of the river had been eroded to a depth of approximately 2 m below its earlier level. No action has been taken to re-habilitate the project (6.35, 6.36).

6.6. The Provincial Mini Hydro-Power Programme

During the period that they had become involved in the implementation of the micro hydro-power projects at Simbai and Kabwum, Elcom had also submitted to the national government a proposal for the development of four mini hydro-power schemes to serve the minor centres of Kimbe, Namatanai, Bialla and Tinputz, see Figure 6.1. In February 1977 the Asian Development Bank (ADB) sent a Project Identification Mission to Papua New Guinea and the proposal was put forward as being suitable for funding. It was intended that the four schemes would be the first in a larger Provincial Mini Hydro-Power Programme (6.37).

Appraisal teams from the ADB were subsequently sent to assess the proposal in April and August of 1977. Elcom was to be responsible for both design and implementation of the four schemes. The ADB considered the designs to be basically satisfactory although a few minor modifications were recommended. In particular, better information on the flow characteristics of the rivers involved was available by this time and meant that the proposed capacities of the Lake Hargy and Ru Creek schemes needed revising. The recommended capacities of the four projects are shown in Table 6.3. (6.38, 6.39).

Table 6.3. Proposed Mini Hydro-Power Project Capacities

<u>Scheme</u>	<u>Centre</u>	<u>Capacity</u>
Lake Hargy	Bialla	2 × 750 kW
Ru Creek	Kimbe	2 × 400 kW
Tinputz	Tinputz	2 × 100 kW
Sohun	Namatanai	2 × 100 kW

Source; Appraisal of Four Mini Hydro-Electric Schemes in Papua New Guinea, Shawinigan Eng. Ltd., ADB, May 1977.

6.6.1. Project Economics

The total estimated cost of the four projects (based on preliminary designs) was K 3,231,900, see Table 6.4.. It was estimated that there would be a cost rise of 60% for the civil works alone if private contractors were used. In the case of the Lake Hargy scheme, costs were based on initial installation of a single turbine-generator unit only, although the civil works were to be designed to allow for the subsequent installation of a second unit.

Economic analysis of the projects revealed that an overall Financial Internal Rate of Return (FIRR) of 32% could be expected, assuming that an ADB loan was available to Elcom to cover foreign exchange component costs. The loan would have a 25 year repayment period including a grace period of 5 years. Local currency expenditure was to be met by Elcom, from internal income generation. Fuller analysis confirmed a clear advantage over diesel generation for all the schemes except Sohun, where initially low demand and high transmission costs combined to reduce the schemes attractiveness (6.40). Even so, the report recommended that Sohun and Ru Creek be the first projects to go ahead and that they be undertaken concurrently. It suggested that the Tinputz scheme follow, with the Lake Hargy scheme being built last. The reasoning behind this was that:

"Of all the locations which were visited, there is no doubt that the activities in and around Kimbe warrant the construction of the Ru Creek development on an urgent basis. In contrast to this situation, the plans for the continuing development of the Biialla area are now gaining momentum and some time will be needed to establish demand of the size which will justify the construction of the Lake Hargy scheme. On this basis, this is the last of the four developments which should be implemented. Of the two remaining sites, the somewhat unreliable supply to Namatanai and the fact that some preparatory clearing had been done suggest that the Sohun No. 1 scheme should be implemented before Tinputz." (6.41)

Table 6.4 Estimated Costs of the Four Mini Hydro-Power Schemes

	<u>Total Cost in Kina</u>	<u>Foreign Exchange Component in Kina</u>
Lake Hargy	1,219,000	753,000
Ru Creek	724,000	431,000
Tinputz	354,000	228,600
Sohun	398,000	251,700
	-----	-----
Total	2,696,600	1,665,200
Consistency	535,300	329,000
	-----	-----
Overall Total	3,231,900	1,994,200

Source; Appraisal of Four Mini Hydro-Electric Schemes in Papua New Guinea, Shawinigan Eng. Ltd., ADB, May 1977.

The report concluded that although the four schemes should go ahead, in future a more rational approach to selection was desirable. It was suggested that this could be achieved through the services of an experienced hydro-electric engineer/planner and that the ADB should provide this assistance if requested to do so. It was also suggested that, although the schemes were simple enough to be built by Elcom, there was a need to strengthen the level of staffing and experience in the Construction Branch of its Generation Division (6.42).

Following the approval of the ADB appraisal team, a US\$ 2.7 million (about K 1.8 million) loan was arranged to fund the foreign exchange

components of the four mini hydro-power projects. The loan became effective in November 1977 and construction of both the Sohun and Ru Creek schemes was started during 1978 (6.43).

6.6.2. The Sohun Scheme

The Sohun scheme, technical details of which are given in Appendix D, was designed to supply power to Namatanai. At the time, the population of the 'C' centre and surrounding villages was estimated at 3,000 and the economy of the area was principally based around copra and cocoa production. Namatanai itself was an administrative centre with a small hospital, vocational school, and growing commercial centre. The existing diesel generators could not meet demand and it was estimated that, with implementation of the mini hydro-power project, the peak power demand for the area would be 100 kW in 1980 and that an 8% p.a. growth in energy sales could be expected over the project's life (6.44).

The Sohun scheme was completed, behind schedule and over budget, in January 1981. The cost at completion was 183% of the original estimate. The main factors contributing to this large cost over-run were that:

- a) work on the project had been adversely affected by staff constraints within Elcom.
- b) the cost estimates had been based on preliminary designs only.
- c) the volume of concrete required in construction had been severely under-estimated. The final quantity used was 250% of the original estimate and concrete was a major cost item.
- d) the cost of control gates had been estimated at K 3,000, whilst the actual cost was K 48,000.

- e) Elcom did not possess sufficient heavy plant in the area to carry out construction work on the scheme. It had been arranged that the National Works Authority's heavy plant would be made available to obviate the need for Elcom to either purchase plant itself, or use commercial contractors. In the event, the National Works Authority's heavy plant had not been made available.
- f) there had been unforeseen delays in procuring equipment.
- g) land compensation claims had proved more difficult to settle than expected.

Following commissioning, the Sohun scheme was initially operated as an Elcom centre. However, because an economic tariff could not be charged, it became clear that Elcom would incur heavy losses in operating the scheme. It was estimated that annual losses would be in excess of K 70,000 and that the revenue from electricity sales would barely cover operating costs. As a result, negotiations led to the schemes assets being taken over by the government toward the end of 1981, returning the hydro-power scheme to 'C' centre status. The hydro-power project continues in operation and current peak demand on the Namatanai system is about 130 kW with annual generation from the hydro-power plant of about 550 MWh (6.45, 6.46, 6.47).

6.6.3. The Ru Creek Project

The Ru Creek scheme, technical details of which are provided in Appendix E, was designed to supply the 'B' centre of Kimbe. Kimbe is the administrative headquarters of the West New Britain Provincial Government. Kimbe and the surrounding area, being the location of a major oil palm project, was under-going strong economic development at the time. At Stettin Bay, along the coast, a major saw-milling operation had been established. Forestry and oil palm research centres had also been set up and there was significant cocoa and coconut/copra production in the area, both from smallholdings and plantations. There was significant official and private diesel generation and it was estimated that in 1980 the peak

power demand for the area would be 1,250 kW, and that an 8% p. a. growth in energy sales could be expected over the life of the project. The overall load factor on the existing plant around Kimbe was estimated at 0.72.

In response to concern over the cost over-runs that were being experienced with construction of the Sohun project, an economic and financial re-appraisal of the Ru Creek scheme was undertaken in June 1980. This suggested that the scheme remained viable to Elcom in spite of a 100% estimated cost increase. Work on the scheme therefore continued and the project was commissioned in October 1982. Since then it has been operated as an Elcom centre.

Maximum demand on the system at Kimbe is about 1 MW so that for periods of the day diesel generator sets are brought on line to supplement hydro-generation. At night the hydro operates without diesel back-up. In 1983 energy production at Kimbe centre totalled 3,882 MWh of which 66.7% was generated by the mini hydro-power plant. In 1984 at just over 10 toea/kWh Kimbe had the lowest generation costs of any of Elcom's 15 isolated generation centres. However, the overall cost of supply at Kimbe was relatively high at 31 toea/kWh. This was the result of the large proportion (55%) of overall costs attributable to capital charges, principally incurred as a result of constructing the hydro-power scheme (6.48, 6.49, 6.50, 6.51, 6.52).

6.6.4. The Tinputz and Lake Hargy Projects

By mid-1980 work had commenced on the Lake Hargy and Tinputz schemes, technical details of which are provided in Appendix F. However, cost over-runs were also expected with these projects and so a re-appraisal of them was undertaken in May 1981. Work on the schemes was halted pending the results of the enquiry. In particular the re-appraisal aimed to clarify:

- a) whether the projects were still desirable from a national point of view in spite of increased costs.
- b) whether the projects were still financially viable to Elcom.
- c) hence, whether or not the schemes should proceed.

For both the Tinputz and Lake Hargy projects the costs of completion were estimated to have risen by at least 50% and in both cases the original load forecasts were felt to have been over-optimistic. As a result, neither of the projects could be considered as viable to Elcom since, over the analysis period, the Net Present Values (NPVs) of both projects were negative. However, it was suggested that further investigation was justified since:

"In general, the performance of the projects is dependent critically on the level of demand.... There remains uncertainty as to just what developments in loads can be expected. One problem in assessing load growth is that the only cost experience many domestic consumers have is the K 2.00 flat rate charged by the Bureau of Management Services. On this basis it follows, almost automatically, that they will express eagerness to take supply from the hydro-power, especially when it has been proclaimed as 'cheap power'. Furthermore, the systems concerned are so small that wide fluctuation in load estimates result from the addition or subtraction of one or two large consumers." (6.53)

A comparison of hydro and diesel based generation was also undertaken. The reduced operating costs of the hydro-power option meant that the return earned by completing the hydro project was expected to be well in excess of 10% (the National Planning Office's test rate). Thus it was suggested that if the government, as opposed to Elcom, were committed to upgrading the supply of electricity in the project areas then hydro-power was to be preferred to diesel generation (6.54).

Elcom Response

As a result of the re-appraisal, it was agreed that Elcom would not re-commence work on the Tinputz and Lake Hargy schemes. More generally, it had become clear that very small hydro-power schemes needed to be subsidized by the government and/or realistic tariffs charged if they were going to be viable propositions to Elcom. This approach was confirmed in May 1981 when the Elcom Board agreed that Elcom would not in future proceed with any mini hydro-power schemes (ie. less than 5 MW) not connected to an existing major grid system, unless (6.55).

- a) land acquisition was complete.
- b) the scheme would return better than 10% Internal Rate of Return (IRR) against actual cash flows.
- c) load, existing and forecast, was sufficient to achieve the required rate of return, and that this be confirmed by the National Energy Planning Council (NEPC).
- d) schemes were to be costed conservatively with greater than 10% contingencies after final design.
- e) the price of electricity charged to consumers at 'C' centres be increased to at least the national uniform tariff.
- f) the full cost be charged to industrial and commercial consumers at these centres, or that they be directly subsidized by the government.

Although neither the Tinputz or Lake Hargy project was viable to Elcom, an attempt was made to persuade the national government to assume responsibility for the projects and carry them through to completion on the basis that they were still in the national interest.

In mid-1983 it was still hoped that the national government would step in and fund the projects, although no commitment to this effect had been given. Possibly in an attempt to bring about such a commitment, a further economic and financial evaluation of the Lake Hargy and Tinputz schemes was undertaken. The projects were evaluated using updated costs and a recent market survey which had been carried out in each area. At this time Bialla was undergoing fairly rapid growth and it was concluded that the Lake Hargy scheme was again viable to Elcom but that the Tinputz project was not. Thus, in October 1983, approval was given by the Elcom Board to seek Asian Development Bank assistance in completing the Lake Hargy project. Negotiations with the Bank continued through early 1984 and an extension of the original loan's closing date was agreed. The Bank also agreed to help meet project cost over-run if it could be proved that no other source of suitable finance was available to Elcom.

Staffing shortages and existing construction projects meant that it was not possible for Elcom to undertake either project detail design or implementation at this time. In addition, the Tinputz project was again being considered for completion. Thus, suitable design consultants were invited to express their interest in both projects in April 1985. The contract for the design of both the Tinputz and Lake Hargy projects was awarded to MWP-MAIN of Brisbane. The detail designs were to be based on Elcom's earlier preliminary designs, however, a number of modifications were suggested by Elcom, largely aimed at minimizing costs. In particular, the Lake Hargy project was now to accommodate only a single 750 kW turbine-generator unit. Elcom estimated the cost of completing both projects as K 3.1 million, see Table 6.5. (6.56, 6.57, 6.58).

Design of the two projects proceeded through 1985 and the civil works contracts for both projects were put out to tender in early 1986. In June 1986 a contract for K 2,466,000 plus 10% contingencies was awarded to Hornibrooks for construction of Lake Hargy civil works and work on the scheme had recommenced by September 1986. Hornibrooks also submitted the lowest tender for the Tinputz

project. However, in light of the high level of the bid further economic evaluation again indicated that the project was unviable. In October 1986 it was therefore decided not to proceed (6.59, 6.60, 6.61).

Table 6.5. Estimated Completion Costs for the Lake Hargy and Tinputz Mini Hydro-Power Projects, March 1985

	<u>Cost in Kina</u>
<u>Lake Hargy</u>	
Civil Works	1,381,000
Electro/Mechanical	308,000
Transmission	200,000
Switchyard	43,000
Contingency	290,000
Design/Admin	220,000

Total	2,444,000
<u>Tinputz</u>	
Civil Works	400,000
Electro/Mech (installation only)	30,000
Transmission	120,000
Contingency	60,000
Design/Admin	50,000

Total	660,000

Total For Both Projects	3,104,000

Source: Unpublished Internal Elcom Report

In conjunction with the original loan provided by the Asian Development Bank to finance the Provincial Mini Hydro-Power Programme, the Bank also agreed to provide funding to allow two hydro-power planners/engineers to undertake a "Hydro-Power Development Study of Papua New Guinea". This report, published in 1980, attempted to evaluate alternative strategies for developing the country's hydro-power resources over the following 15 years. The report recognized that Elcom operations were only financially viable because of the relatively low cost of electricity produced by its major hydro-power plants. Its thermal plants were run at a loss and the report recommended that the greatest cost savings could be gained by replacing thermal plants at Elcom's relatively large centres. The report concentrated on potential projects that could be developed to serve this purpose, most of which were in excess of 1 MW capacity. However, the report suggested that there was also significant scope for replacing existing diesel generators with mini hydro-power projects at many of the nation's minor centres (6.62).

The report recommended that the design and construction of at least one mini hydro-power project should be started in each province as soon as possible. However, it was recognized that Elcom was not ideal as an implementation agency for this type of project and that a new sort of institutional arrangement was required. This would need to take responsibility for:

- a) the integration of mini hydro-power development into the overall economic development of the country.
- b) the development of an engineering capability for hydro-power studies and construction.
- c) management of the mini hydro-power development programme including project financing and, possibly, operation.

- d) training for all levels of personnel involved in the programme.

6.9. Subsequent Government Response

The government remained concerned at the inadequacy and high cost of 'C' centre electricity supplies and the hydro-power development report appears to have had a significant influence on thinking within the government and the Department of Minerals and Energy in particular. Elcom's decision in 1981 to curtail its micro and mini hydro-power development activities meant that the onus for any further development of such schemes was passed back to the national government. In the same year the inter-departmental Power Development Group (PDG) was established to oversee and advise on the economic replacement of diesel power in government centres by hydro-power or other desirable renewable sources of supply. It is also concerned with other rural electrification projects which are not viable to Elcom. The PDG is chaired by the Secretary for Minerals and Energy and is composed of representatives from the Energy Planning Unit at the DME, Elcom, Department of Finance and the National Planning Office (6.63).

In 1982 the consultants Cameron McNamara Kramer were commissioned to examine the problems and management of electricity supplies at 27 'C' centres. Their report "'C' Centre Power Supply Survey" (also known as the Sykes Report) supported the view that there was significant scope for the replacement of 'C' centre diesel generators with mini or micro hydro-power plants (6.64).

6.10. The Mini Hydro Resource Inventory and Diesel Power Replacement Programme

With the aim of establishing a national programme to improve services to 'C' centres, the Department of Minerals and Energy obtained approval through the National Public Expenditure Plan to establish the Mini Hydro Resource Inventory (MHRI) in 1982. The MHRI was to use consultants to identify and evaluate the technical

feasibility and economic viability of replacing diesel generators with mini hydro-power developments at selected 'C' centres. The consultants Beca Worley International were awarded the initial contract to conduct pre-feasibility studies at 31 centres, many of them identified in the Sykes Report. The method of study to be used was laid out in the terms of reference and used the following steps (6.65, 6.66, 6.67, 6.68):

- 1) Review reports of previous investigations and other records which may be relevant.
- 2) Review maps of the region to determine whether suitable rivers and/or potential sites were evident. This part of the work has been performed in close co-operation with the Bureau of Water Resources.
- 3) Identify areas where aerial photography might be useful.
- 4) Review, where relevant, existing hydrological records (stream gauging, rainfall records etc.).
- 5) Identify and carry out on-site inspection of a suitable number of promising sites (up to three per load centre if possible).
- 6) Visit the load centres to view and discuss the existing local situation and future development.
- 7) Select from confirmed potential sites the most promising and carry out preliminary survey (ground and/or air mapping) and geo-technical/geological appraisals.
- 8) Identify possible transmission line routes and establish point of inter-connection to existing distribution system.
- 9) Prepare schematic designs for those sites which appear feasible.

- 10) Prepare cost estimates for civil, electro-mechanical and transmission components of feasible schemes.
- 11) Assess hydro generation operating costs, in conjunction with existing diesel generation operating costs and costs of inter-connection to an existing system where practicable.
- 12) Identify the least cost hydro option for comparison with other options as under (11) above.

6.10.1 Project Assessment Details

In selecting and sizing schemes the aim was to meet the expected power demand at each centre after 20 years of operation. Load forecasts were based on existing projections, if any, and on expected development initiatives in and around the centre. If only a smaller capacity scheme were possible, its use for providing base load was investigated. In many cases hydro potential far exceeded the projected demand for power. In some such cases it was recommended that civil works for a larger scheme be constructed.

In order to compare the potential hydro-power project with alternative power sources (mainly diesel) and in order to examine the economic viability of the project a Net Present Value (NPV) analysis was carried out. This used a discount rate of 10%, an assumed hydro plant life of 40 years and an assumed diesel plant life of 10 years. The analysis covered a 20 year period at the end of which it was assumed that the hydro plant would have a 50% residual value. The diesel plant would have zero value since it was generally assumed that a new diesel was purchased for year one and replaced in year 10. Operation and maintenance costs for the diesel plant were based on an Elcom survey "Government Minor 'C' Centres, Power Station Maintenance and Distribution/Electrical Maintenance, 1981-82 Actual Expenditure"

By November 1984 pre-feasibility reports had been received by the Department of Minerals and Energy for all 31 centres. Nine of these

were selected for further investigation and possible implementation. In November 1985, a contract for pre-feasibility studies at a further 14 centres was offered and subsequently awarded to MacDonald Wagner Pty Ltd. These studies were completed by October 1986 (6.69).

6.10.2 Project Selection and Programme Implementation

In 1985 the Diesel Power Replacement Programme (DPRP) was established to implement micro and mini hydro-power schemes selected from studies undertaken under the MHRI. The programme is nationally funded and administered by the Power Development Group through the Department of Minerals and Energy. Broadly speaking, the objectives of the programme are to reduce the cost and increase the quality of electric power supplies to isolated rural communities. In practice this means 'C' centres, and the replacement of existing diesel generators with micro or mini hydro-power plants.

At some 'C' centres a mini hydro-power project to serve the centre is not technically feasible. Where a scheme is technically feasible it may not be economically viable. Projects implemented under the DPRP should provide an economic rate of return of 10% or greater to the nation. This return will generally be in the form of a reduction in losses over diesel plant. The number of potentially attractive sites exceeds the capability to see them implemented in the short term so that a process of project selection is necessary to ensure that the best projects proceed. A typical project is likely to pass through six stages. In the first of these, pre-feasibility studies are carried out at a number of potential sites. When these are submitted by the consultant an economic review is carried out and projects are ranked according to economic criteria. Selected projects then move into a detailed engineering phase with geological and topographical surveys being undertaken and preliminary hydrological studies being carried out. A full feasibility report is then prepared by the consultants. A further technical and economic review is undertaken and an aid commitment is sought from overseas sources. All being well the project is given approval and the following stage involves carrying out detail design, selecting

contractors for a) construction supervision, b) civil works, and c) electro-mechanical equipment supply, negotiating any necessary land compensation deal, and upgrading site access. With these stages complete the project can then proceed through the implementation, commissioning and acceptance stages. The time-scale for the complete process is likely to be about three years (6.70).

The aim of the programme is that the management of completed projects be taken over by Elcom and that the uniform national tariff be charged to consumers. Although the implementation of these projects remains unattractive to Elcom, by presenting completed schemes, without any capital charges, to them, it is hoped that Elcom will subsequently be able to operate the schemes at a profit (6.71, 6.72).

6.10.3. The Tari Scheme

The 'C' centre of Tari, with a population of about 600, is the administrative headquarters and main commercial centre of Tari District in the Southern Highlands Province, see Figure 6.1.. It is located in the densely populated Tari Basin at an altitude of 1,680 m and lies near the limit of the highland road network. Its services and facilities include general administrative functions, agricultural and business extension services, a small hospital, two nearby primary schools, banking facilities, eight large trade stores and several smaller ones, two service stations, one including a road maintenance operation, a social club/bar and a guest house. Also in the locality are a high school, a teachers' training college and a large tourist hotel (6.73).

The present official electricity supply is met by a Caterpillar diesel generator set, plate rated at 135 kVA. Two Deutz units, plate rated at 80 kVA, act as standby. The official supply is insufficient to meet potential demand and several businesses operate their own diesel or petrol generator sets. The total installed capacity of private generators exceeds 150 kVA (6.74).

Site Investigations

Under the Mini Hydro Resource Inventory a pre-feasibility study for a mini hydro-power plant to supply power to Tari was carried out by Beca Worley International during 1983. A load forecast for the centre was prepared which suggested that a plant capacity of 300 kW was required to meet forecast load after 20 years of operation (6.75).

The study identified two possible mini hydro-power sites. One scheme would utilize flow from the Piwa River at a site about 8 km east of Tari. The other was about 7 km south of Tari and would utilize a 20 m head difference between the Huria and Arua Rivers with a further 10 m being gained by the headrace in contouring the intervening ridge. Both schemes were capable of supplying the forecast load of 300 kW and the estimated cost of both was about K 950,000. Analysis indicated that both schemes would be economically viable.

The projects were selected for further investigation and subsequent geological investigations suggested that the scheme utilizing flow from the Huria River was preferable. It was therefore decided to proceed with that scheme. The selection process described above was compressed and the feasibility and detail design studies were combined. These were again undertaken by Beca Worley International and their report was completed in April 1985. Technical details of the proposed project are given in Appendix G.

The cost estimate included in the design report was K 1,492,939 exclusive of land acquisition, engineering supervision and escalation from May 1985. This was appreciably higher than that given in the pre-feasibility study. Reasons for this included a 36% increase in the length of the headrace channel, a 28% increase in the penstock length, an increase in the volume of earthworks, and the need to use a larger section canal and impermeable membrane because of soil conditions.

In spite of the increased cost, in February 1985 representatives from Beca Worley International, the DME and the European Economic Community agreed a programme for implementation of the project. A subsequent economic review carried out in October 1985 confirmed that the project remained viable. Tender documents were prepared and bids invited from suitable civil contractors, electro-mechanical equipment suppliers and construction supervision consultants. The cost of bids received was significantly above that anticipated and the total value of contracts due to be awarded was K 2,421,070. As a result a further review of the economic viability of the scheme was carried out which indicated that the project was no longer viable. Despite this, it was decided to proceed on the basis of the inadequacy of the existing power supply at Tari and on the project's role as a demonstration and initiating project in the broader Diesel Power Replacement Programme (6.76, 6.77).

Project implementation was due to start in July 1986, but work was delayed by the fact that the land compensation negotiations had not been completed, and by the funding agency objecting to the contractors awarded the civil works contract. These problems were subsequently resolved allowing work on the scheme to start. By early October 1987 the power house and intake structure had been completed, the low pressure conduit running across the flood terrace was in place and construction of the transmission line was well underway. The penstock had been delivered but not installed and the electro-mechanical equipment was en route. Commissioning of the project is due in February 1988 (6.78, 6.79).

6.10.4. Other Projects

The detail designs for three further schemes at Talasea (550 kW), Woitape (60 kW) and Telefomin (100 kW) have been completed, see figure 6.1. for locations. MacDonald Wagner (who had been responsible for design of the Telefomin and Woitape schemes) have been appointed as contractors for these two projects. They are to act as the DME's agents for equipment tenders, and are responsible for materials purchase, and project supervision. The contracts were

awarded on a 'lump sum' basis and the schemes are to be hand built using local labour. It is anticipated that work on the projects will commence in early 1988, but the land negotiations have yet to be finalized and may cause some delay.

In October 1987 no aid funding had yet been secured for the Talasea project and the project was at a stand-still. Nine further projects were expected to have proceeded through the feasibility design stage by the end of 1987. It is anticipated that an average of two schemes per year will be commenced during the next five years of the DPRP. The specific costs of schemes for which reliable estimates are available are in the range K 5,000 - 7,000/kW (6.80, 6.81, 6.82).

6.10.5. Future Development of the Programme

In the medium term the Diesel Power Replacement Programme will continue to restrict its attention to 'C' centres. However, if the programme proves successful, it is anticipated that in the longer term attention will also be turned to rural villages. Thus, it is intended that a Mini Hydro Development Unit will eventually be established within the Department of Minerals and Energy which will become directly involved in project surveying and feasibility studies, design engineering, construction supervision and operator training for low cost hydro-power projects to serve rural villages requesting such services. Initially the Unit is likely to consist of a senior co-ordinator, a civil engineer, an electrical engineer, a hydrologist and an economist.

As a first step towards establishing this Unit, the DME has recently instituted a training programme to provide national engineers with a broad range of experience relevant to micro and mini hydro-power development. Trainees are initially to be involved in the DME's current activities including economic analysis, tender document preparation, land acquisition, liaison with outside agencies, and evaluation of proposals. In addition, trainees are to be seconded to consulting engineers on contract to the DME to provide them with design and field work experience. Finally, trainees will be expected

to attend relevant aid-funded training courses such as those sponsored by the Hangzhou Regional Centre for Small Hydro-Power (6.83, 6.84).

6.11. Conclusions

The national government remains reluctant to subsidize any broad based rural electrification programme, in part because of its belief that the claimed benefits of rural electrification can be better met by other means. Its interest is restricted to reducing the cost and improving the standard of electricity supplies to the nation's 'C' centres.

Because of its commercially orientated nature, Elcom's future rural electrification activity is likely to be restricted to the gradual extension of its transmission systems from its hydro-power based systems. Only under exceptional circumstances is it likely that rural villages will be connected to Elcom supplies.

The earlier attempts by Elcom to develop micro and mini hydro-power projects were not without problems. Although completed at relatively low cost, the operational problems associated with the Simbai and especially the Kabwum projects mean that they cannot be considered successful. The large cost over-runs experienced with the Sohun and Ru Creek schemes also give cause for concern. The unsuitability of Elcom as an agent for implementing such projects has been recognized for some time.

It is too early to judge the DPRP, however, the specific costs of the projects, for which reliable estimates are available, are high by international standards. Whilst such high costs may be acceptable where a hydro-power project replaces expensive diesel generation, this situation is not likely to apply if and when the scope of the DPRP is expanded to include the implementation of projects to serve villages where there is no existing supply of electricity.

The large difference between the original estimates of project costs and the contract award price for the Tari scheme is also a cause for concern. If such cost discrepancies continue then the validity of ranking projects on the basis of feasibility study estimates becomes dubious.

7. Other Micro and Mini Hydro-Power Developments

7.1. Introduction

Since the mid-1970's there has been significant official interest and activity in the development of small-scale hydro-power resources. But, to date, most projects have been implemented by non-government organizations and individuals, in particular various mission organizations and the Papua New Guinea University of Technology (Unitech), see Table 7.1.. Case studies of a number of these schemes, both existing and proposed, are presented in Appendices H. to N. and their locations shown in Figure 7.1.. Basic data on the remaining schemes is supplied in Appendix O. There follows a more general discussion about these projects and the organizations and individuals involved in developing them.

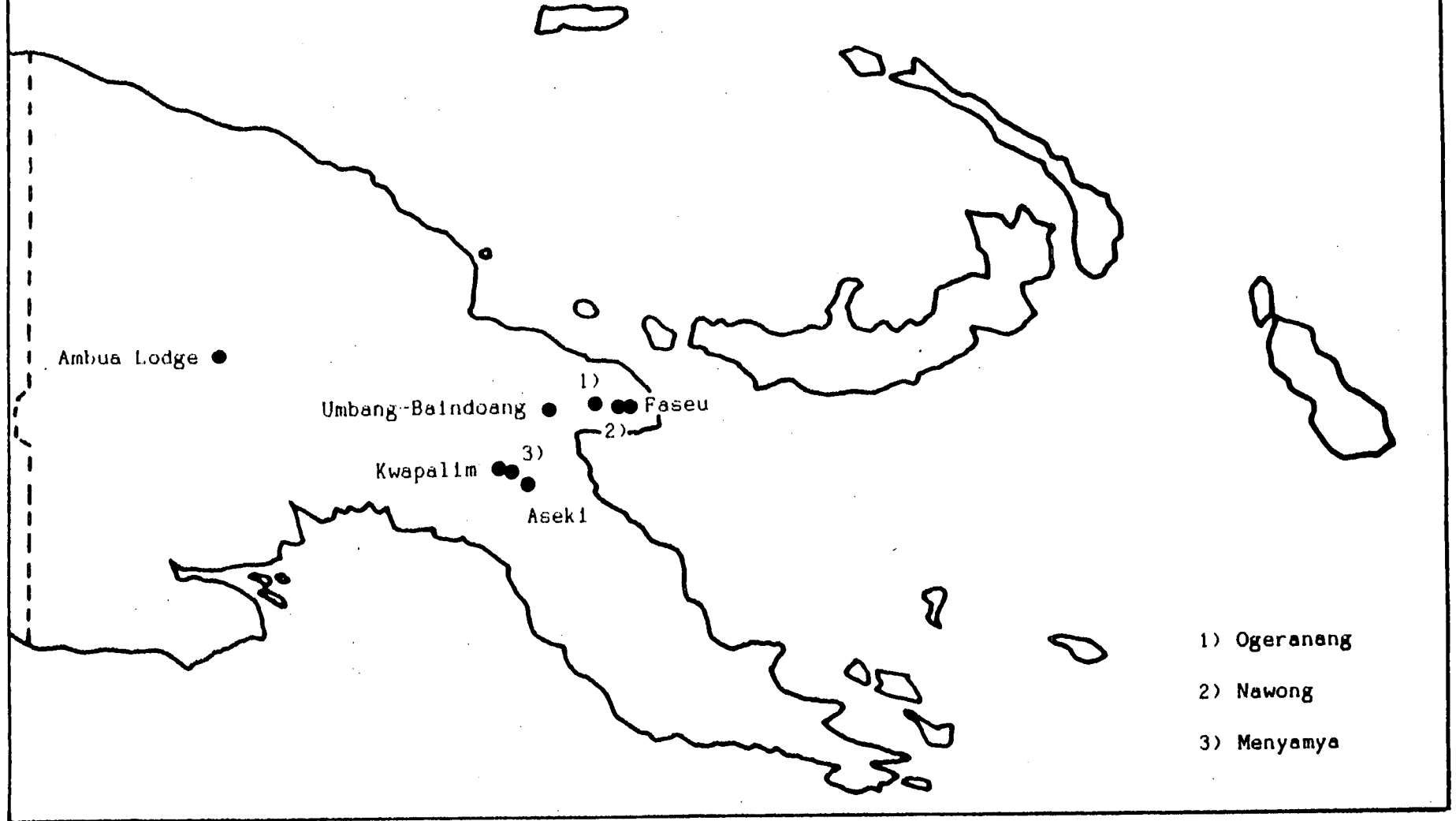
Table 7.1. Types and Numbers of Micro and Mini Hydro-Power Projects

<u>Type</u>	<u>Number Implemented</u>	<u>Number Out of Service</u>	<u>Planned</u>
Mission	35	5	---
Village	9	5	3
Private and Commercial	3	1	---

7.2. The Activity of Mission Organizations

Religious organizations have played an important role in Papua New Guinea. During the colonial period, mission stations were often established in newly opened up areas soon after, or in some cases prior to, the establishment of Administration patrol posts. Apart from their religious activities, the missions were actively involved in education, both formal and vocational, in providing health care

Figure 7.1. Locations of the Case Study Hydro-Power Projects



and in improving indigenous agriculture. As Papua New Guinea moved towards independence, the expansion of Administration activities meant that the overall importance of the missions' role declined. However, their input continues to be significant (7.1, 7.2, 7.3).

The Mission stations were usually established by European or Australian Christians, accustomed to a supply of domestic electricity. In addition, as the stations were developed and schools and health centres or hospitals built, a source of power became desirable for wood-working and mechanical workshops and for lighting, refrigeration etc. in the schools and health centres. Over 30 mission stations have installed micro or mini hydro-power plants to supply these needs. In most cases the supply is restricted to the mission station and associated schools, vocational centres and/or health centres. The effect of the hydro-power projects upon the local population is therefore limited to the indirect benefits associated with their use of the improved mission facilities (7.4, 7.5, 7.6, 7.7).

The smallest of the hydro-power plants currently in service uses a water wheel and has an output of a few hundred Watts (7.8.). The largest is located at Yagusa in the Eastern Highlands and is designed for a maximum output of 250 kW. It is dealt with as a case study in Appendix H. (7.9). The average installed capacity of those schemes on which information is available is 45 kVA (7.10). The earliest operational scheme of which the author is aware was implemented in the late 1950's, but it is understood that a scheme was constructed utilizing a Francis turbine in the Popondetta area prior to World War II (7.11). The most recent project was implemented at Mougulu, a mission station in the Southern Highlands, in 1986 (7.12).

In many cases mission personnel had access to charitable sources of finance through contacts in their home country. It is from these sources that most of the hydro-power projects were funded and usually these funds took the form of grants or donations rather than loans. The construction of a hydro-power project avoided the

recurrent fuel cost involved in diesel or petrol generator operation, and on this basis was an economically sound proposition. In many cases the projects were designed and implemented by members of the church with a technical background, either from the mission station itself, or from some other station within the country. In this way the cost of professional engineering services was avoided. Costs were also minimized by the fact that voluntary or low paid labour was available from local believers and/or students of the mission's school or vocational centre. In addition, land compensation payments were rarely required (7.13).

Most of the mission hydro-power developments have provided reliable service over a number of years. However, problems have been encountered, and their continued operation depends heavily upon the presence of technically able and interested personnel. Mission staff may be based at a station for a relatively short period and several schemes are now out of operation as a result of a lack of staff either interested in or capable of maintaining the project and repairing faults. In particular several schemes fell into dis-use in the period immediately after Independence when there was an exodus of ex-patriate personnel from the country (7.14, 7.15).

7.3. Village Schemes

A number of micro hydro-power schemes have been implemented since the mid-1970's to serve rural villages. At all of the schemes implemented to date, there has been a significant input to the project by individuals or organizations not native to the village. It is doubtful that any village schemes would have been developed in the absence of such inputs. The schemes have all suffered from problems of unreliability, largely resulting from a shortage of technical skills at village level. On-going external support has often been required and this has been provided by a handful of ex-patriates with a belief in the projects. As individuals have come and gone the level of project support has fluctuated and, in recent years, generally declined. As a result, several village hydro-power projects have fallen into disrepair.

7.3.1. Activity of the Papua New Guinea University of Technology and Appropriate Technology Development Institute

The Papua New Guinea University of Technology (Unitech) is located in Lae, Morobe Province, and offers degree courses in technical and professional subjects. Also located on the campus is the Appropriate Technology Development Institute (ATDI) which is involved in the development and dissemination of simple, low-cost tools, equipment and technology for application principally in the rural areas of the country (7.16).

Since the mid-1970's, staff from ATDI and various Unitech departments, especially the Department of Electrical and Communication Engineering (DECE) have been interested and involved in the low-cost and appropriate development of the country's micro hydro-power resources. Unitech and ATDI have been the organizations most actively involved in supporting village micro hydro-power schemes within the country and in particular they have:

- a) been directly involved in the implementation of several village micro hydro-power projects on a community self-help basis (7.17, 7.18).
- b) offered maintenance and repair support to several other village micro hydro-power projects (7.19).
- c) carried out research and development work aimed at developing appropriate project hardware (7.20, 7.21, 7.22).
- d) undertaken project feasibility studies for interested rural groups (7.23).
- e) offered technical support to one commercial and several mission micro hydro-power projects (7.24).

- f) organized several seminars and workshops on the subject (7.25).
- g) liaised with Elcom and the Department of Minerals and Energy over their micro and mini hydro-power activities (7.26).
- h) established, in conjunction with the Morobe Provincial Government, a provincial mini hydro-power development programme (7.27, 7.28).

By late 1975 staff at Unitech and ATDI had become interested in establishing a pilot village micro hydro-power project. Contact was established with an interested rural group and, after lengthy discussions, investigations, and fund-raising efforts, implementation of a 6.7 kW scheme was commenced towards the end of 1976 (7.29). This project, known as the Umbang-Baindoang project, is dealt with as a case study in Appendix I..

7.3.2. A Proposal for the Establishment of a Morobe Provincial Mini Hydro Programme

At this time, Unitech, ATDI and Morobe Provincial Government all received a number of enquiries from villages about the possibility of receiving assistance with the implementation of micro hydro-power projects. Unitech undertook several feasibility studies and by the end of 1977 Unitech and ATDI were considering the implementation of further projects. However, it was agreed that Unitech was not an ideal project implementation agency, largely because of the teaching commitment of most staff and a lack of suitable funding (7.30).

As a result, a proposal to develop micro hydro-power projects under a five year programme was submitted, by the DECE of Unitech to the Morobe Provincial Government. It was envisaged that micro hydro-power projects would be implemented to serve isolated rural communities on a community self-help basis. Thus, communities would be expected to provide labour, materials where appropriate and a proportion (about 10%) of project costs. The operation and basic

maintenance of completed schemes would also be undertaken by the villagers.

The proposal suggested that up to five hydro-power schemes with an average rating of 10 kW could be installed during each year of the programme. This would allow the establishment of both an equipment manufacturing project aimed at reducing costs, and a central repair facility to undertake repairs beyond the scope of village operators. It was suggested that the DECE could provide the survey, design and management services necessary for project implementation, but that the Provincial Government should recruit a group of technical staff to undertake project implementation. Support could be provided by the Local Government Section of the Department of Works and Supply (LGSDWS) and it was hoped that various other organizations would supply supplementary inputs (eg. business extension services) (7.31).

7.3.3. The Morobe Provincial Mini Hydro Programme

The proposal was accepted and in 1978 the provincial government funded a number of project feasibility studies. A VSO volunteer, David Talbot, was recruited to undertake this work in collaboration with Unitech staff, and to prepare for implementation of the programme from 1980. It was hoped that an engineer from Elcom would be seconded to the programme, to work and train alongside David Talbot. This did not happen and no other national engineer was recruited.

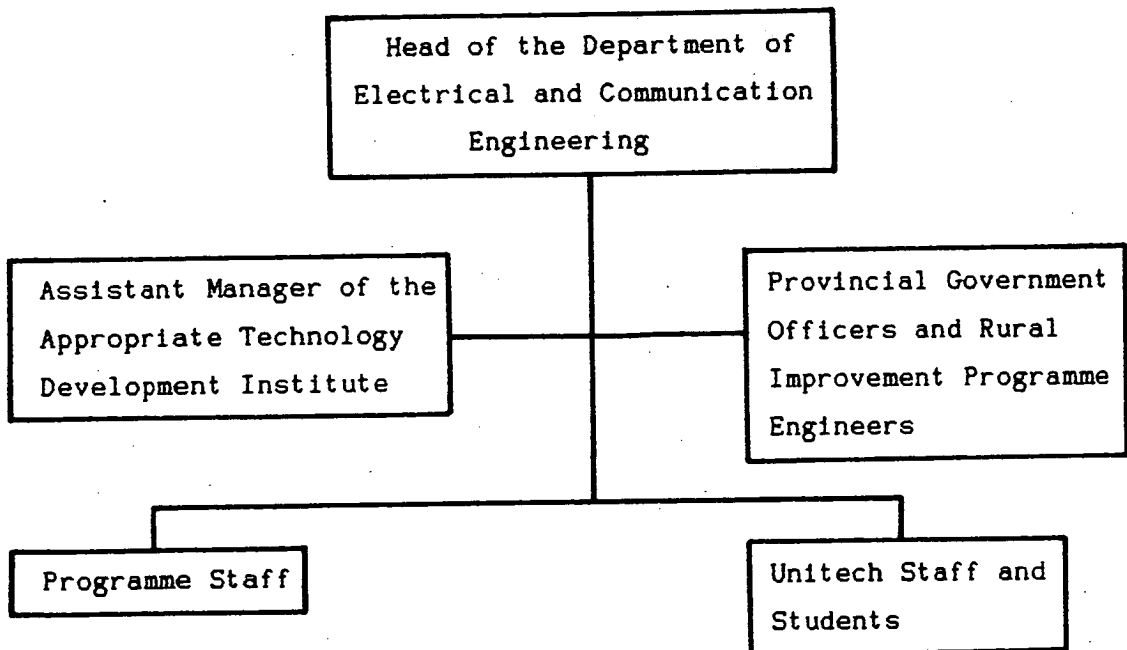
By mid-1979 eight potential sites had been surveyed. A submission was made to the National Public Expenditure Plan seeking funding for a four year programme which was to involve the development of six projects in the first two year period, followed by a further ten in the second. The cost of the programme was estimated at K 451,000 and a further submission to the Village Economic Development Fund sought assistance in establishing a small foundry to manufacture, amongst other things, small hydro-power turbines (7.32).

The submission to the NPEP was rejected; however the provincial government decided to proceed with the programme on a less ambitious scale. As a result of detailed investigations at Watut, Wantoat and Ogeranang, it was decided to proceed with implementation of a 20 kW project at Ogeranang on the Huon Peninsula. Thus, in early 1980 the Provincial Government allocated the following funds to the programme:

Continuing programme of site investigation and survey	K 16,000
Implementation of Ogeranang project	K 20,000
Establishment of foundry	K 4,000

Peter Greenwood, then head of the DECE at Unitech, was to act as programme co-ordinator on a temporary basis until the role could be taken on by a suitable person within the provincial government. The organizational structure adopted was as shown in Figure 7.2..

Figure 7.2. Organizational Structure of the Morobe Provincial Mini Hydro Programme



Source: Unpublished Material

Work, in earnest, on the Ogeranang project commenced after Easter 1980 and the project is dealt with as a case study in Appendix J.. David Talbot initially acted as the site supervisor, with design work being undertaken at Unitech and support coming from the Local Government Section of the Department of Works and Supply. But, staff changes at the LGSDWS and the departure of David Talbot at the end of 1980, meant that the input to the project by LGSDWS declined dramatically. Because the provincial government did not recruit or allocate further staff to the programme, as specified in the original proposal, the programme became increasingly reliant upon the enthusiasm of Unitech staff (and students). By mid-1981 they had become disillusioned with this lack of support and in September 1981 Unitech withdrew from its position of responsibility for the Ogeranang project. However, it remained prepared to assist with specific aspects of the project and the broader programme, under a more formal and explicit arrangement (7.33).

On 18th November 1981 a meeting was held at the Provincial Government offices with the aim of creating a more formal framework for the continuing programme. A committee was set up to formulate a policy, establish a suitable organizational structure, review existing progress and suggest future areas of activity. The committee was composed of representatives from the Provincial Government Policy and Planning Research Section, Rural Improvement Programme, LGSDWS, Unitech, ATDI, and the Community and Village Industries Programme (CAVI). Frequent personnel changes hindered the effectiveness of the committee and no clear set of project selection criteria was developed although greater emphasis began to be placed upon economic, rather than social, considerations. It was increasingly accepted that future projects would be selected either to act as diesel replacement projects at government centres (possibly undertaken in conjunction with Elcom), or where there was a strong likelihood of income generating end uses developing (7.34).

The division of responsibilities between the various departments and organizations involved in the programme remained poorly defined. The problem was particularly acute at the project implementation stage.

When Unitech ceased to be responsible for work on the Ogeranang project, the role was taken on by the manager of LGSDWS who allocated staff to work on it. However, several alternative organizational structures were discussed. Subsequently the Provincial Industrial Development Officer (PIDO) became responsible for project implementation, through Development Engineering Services (DES). In 1980 DES had been established with K 4,000 allocated to the mini hydro programme. It operated as an engineering workshop and non-ferrous foundry and was an integral part of the provincial government's CAVI programme. Thus, DES became the agent for micro hydro-power project implementation (7.35).

During 1981 work at Ogeranang and on feasibility studies had been continuing with the funds made available in 1980. No further funds had been made available in 1981, but in 1982 the provincial government allocated K 50,000 to the programme to enable work to continue. Further feasibility studies identified several potentially attractive sites (7.36, 7.37):

Wantoat Considered an attractive diesel replacement site, with a good hydro site, but no real potential for developing other economic end uses and with poor site access.

Siassi A suitable site had been located at Bunsil on Siassi Island which could be developed to supply power to the proposed Umboi Timber Project. It was suggested that development and funding of the site should be in conjunction with the timber project.

Sialum Had good hydro potential and the proposed development of an abattoir would provide an economic end use for the power. It was suggested that development and funding of the two projects be combined.

Aseki Considered a site with good potential. It is dealt with in more detail in Appendix K..

By mid-1982 it had been proposed that Aseki be the next site to be developed, followed by Wantoat when road access to the centre had been established. A submission seeking approval to proceed with the Aseki project was made to the Sam Sewe (the executive body of the Provincial Government) in the third quarter of 1982. However, an administrative error meant that no funds were allocated to the programme for 1983. Some funds were subsequently redirected to allow work to continue on the Ogeranang project, but overall programme activity declined. Work could not therefore proceed on the Aseki project (it is also not clear whether or not the Sam Sewe had given its approval to the project).

By the end of 1983, the Ogeranang project was nearing completion, although it was not actually commissioned until January 1985. The community input into the project had been limited and, at completion, it was significantly behind schedule and over-budget. The larger programme had come to a virtual stand-still. Staff departures and disillusionment had curtailed Unitech's and ATDI's interest in the programme. In the light of these problems the Provincial Government's interest had also waned and the PIDO and DES had shifted their area of interest away from hydro-power and towards the development of a low-cost, portable saw-mill. The Morobe Provincial Mini Hydro Programme was therefore abandoned (7.38).

7.3.4. The Pindiu Village Schemes

Three simple, low-cost micro hydro-power projects were implemented over the period 1975 to 1979 to serve the villages of Gemaheng (1.5 kW), Korbau (2.5 kW) and Nawong (1.0 kW) in the vicinity of Pindiu, on the Huon Peninsula of Morobe Province. All three schemes incorporated a simple weir diverting flow into a hand dug, unlined power canal and hence into a settling pond. From there flow passed through a trash rack into a PVC penstock leading to the turbine. At all three sites the original turbines were built at the Finschhafen Vocational Centre and the generators belt-driven. The schemes operated on a constant load, constant flow basis supplying a domestic lighting load only. Protection was limited to the

installation of a single fuse in the power house and further fuses within the villages. The power houses were of bush materials construction; distribution and reticulation were by buried cable. (7.39, 7.40, 7.41)

The impetus for the development of these schemes came from Ian Bean, a Department of Primary Industry officer stationed in the area. He had been involved with the vocational centre in Finschhafen in the development of a low-cost water wheel for driving coffee pulpers. From this work Ian Bean and Bob Taylor (an electrician at the vocational centre) became interested in the idea of developing a low-cost micro hydro-power project to supply electricity to a rural community. They felt that the provision of electric lighting would have a significant impact upon rural village life and so aimed to establish a demonstration project to test out their ideas. The area around Pindiu was felt to be most suitable as it experiences little seasonal variation in rainfall, being located towards the centre of the Huon Peninsula and influenced by both the north-west and south-east rain bearing winds (7.42).

A number of villages were approached about the possibility of implementing such a project. The inhabitants of Korbau village responded enthusiastically and in further discussions they agreed to contribute their labour and some cash towards the project. The Korbau scheme was subsequently implemented and the interest it generated in the area led to a number of other villages requesting assistance to implement schemes (7.43). This led to the implementation of the Nawong project, which is dealt with as a case study in Appendix L..

The input of Ian Bean and the other DPI staff involved in project design, implementation and supervision was on an essentially voluntary basis and none of them had a formal engineering background. The projects, especially the first at Korbau, were undertaken in an experimental manner. At all three schemes the unskilled labour and local materials used were provided without cost by the village inhabitants. In addition, about 50% of the cost of

each of the schemes was raised by the villagers. Ian Bean had been involved in the establishment of a Pindiu Rural Development Association which was intended to undertake village based activities. The Association was set up with K 1,000 contributed by inhabitants of the area and appears to have been further supported by a grant from the Pindiu Council. The Association covered about 25% of project costs and the remainder was obtained from various overseas sources (7.44).

7.3.5. Continuing Unitech and ATDI Activity

Throughout, and following, the period of collaboration with Morobe Provincial Government, staff at both Unitech and ATDI continued to be involved in micro hydro activity external to the Morobe Provincial Mini Hydro Programme. Thus staff continued their involvement with the Uambang-Baindoang project and became involved in the implementation of another project to supply power to the village of Romsis in North Solomons Province (7.45).

Neither the training programme nor the proposed central maintenance facility which had been envisaged as part of the Morobe Provincial Mini Hydro Programme had been set up. However, Unitech continued to offer maintenance and repair support to the Uambang-Baindoang project and, after the departure of Ian Bean in late 1979, also became involved in supporting the three Pindiu schemes. They ran several training courses intended to provide village operators with the basic skills necessary to keep their plant operational (7.46, 7.47).

In addition, several electronic load controllers and turbines (both cross-flow and pelton) were developed (7.48, 7.49, 7.50). Some experimental work was carried out using an induction motor as a generator in a stand-alone situation (7.51) and efforts were made to develop suitable protection and wiring standards for rural micro hydro-power projects. Unitech has also been involved in a number of further project feasibility studies (7.52, 7.53, 7.54, 7.55) and recently organized a UNESCO sponsored "Workshop on Micro Hydro Installations" (7.54).

7.3.6. Discussion of the Performance of the Village Schemes

The following discussion draws heavily from Appendices I to N.

At all the village projects, except Ogeranang, that have been undertaken to date, land, large sums of money (by the standards of the people involved) and significant voluntary labour have been invested in the projects. These investments were made on the assumption that the completed projects would produce subsequent benefits to the community.

Although there is general acceptance that rural people are keen to gain access to electricity it is worth noting that at most of the village micro hydro-power projects implemented to date the original interest in and impetus for development of the projects has not come from permanent residents of the village. In addition, the villagers' limited experience and technical knowledge of the projects means that their interest is based upon unrealistic expectations. The installation of a micro hydro-power project does not of itself produce benefits. The benefits derive from the uses to which the power is put and the development of end uses at the existing projects has been severely constrained by a number of interrelating factors:

- a) the lack of maintenance and repair skills at village level results in poor project reliability.
- b) poor reliability acts as a disincentive to investment in end uses (7.55).
- c) lack of end uses results in a low level of tariffs from consumers.
- d) lack of revenue means that repairs cannot be paid for and this contributes to project unreliability.
- e) lack of technical knowledge about potential end uses hinders their development (7.56).

- f) the inaccessibility of projects limits the viability of potential income generating end uses (7.57, 7.58, 7.59).
- g) the lack of income generating end uses means that funds are not generated for investment in social end uses.

Unless this vicious circle can be broken, village micro hydro-power projects are unlikely to generate significant benefits. It is unlikely that this circle will be broken in the absence of the support of an agency established along the lines discussed in Sections 3.9 to 3.11.. Effective training of village operators and managers and the provision of reasonably priced repair services are vital to project reliability. Much greater attention also needs to be paid to developing end uses, particularly income generating end uses, as an integral part of future village micro hydro-power projects.

Economic Costs and Benefits

Unless the tariffs collected from power consumers are sufficient to cover project operation and maintenance costs then the project is likely to become a financial burden upon the community served. This situation seems to apply to several of the village micro hydro-power projects implemented to date (7.60, 7.61, 7.62, 7.63). However, it is possible that the use of electric lighting and/or the availability of cheaper food-stuffs resulting from the installation of a freezer in a village tradestore may reduce domestic expenditure for some or all households within a community. The project may still therefore have an overall economic benefit. But, reduced household expenditure is not evident at the schemes implemented to date and any benefits are more likely to be social rather than economic in nature.

Significant economic benefits are likely to occur only where the community or individuals within it undertake activities, such as the operation of a hydro-powered saw-mill or electric crop drier, which produce a good or service that is saleable outside the community.

The inaccessibility and remoteness of many rural communities acts to limit the opportunities for such activities. Thus, the operation of a small saw-mill increases the income of the community as a whole only if sawn timber can be sold outside the community. Poor accessibility and the bulk of the product can make the external market extremely limited. Similarly activities such as the operation of a freezer or the showing of videos is likely to principally result in circulation of money within a community, rather than significantly increasing overall income. The range of goods suitable for production is therefore limited and there is very little tradition of small-scale industrial production in, even the urban areas, of Papua New Guinea to build upon.

Social Costs and Benefits

At several of the micro hydro-power projects it was never envisaged that the schemes would generate significant economic benefits. They were justified on the basis of the social benefits that the implementors envisaged would develop. These potential benefits included;

- a) the improvement of facilities and services at health centres,
- b) the availability of power making it is easier to attract a higher standard of teachers, health workers, DPI Officers to the relevant communities,
- c) the availability of hot water for showers resulting in a reduction in the level of skin disease,
- d) improvement in the diet of the people through the operation of freezers and refrigerators,
- e) better and safer lighting, leading to increased evening activity such as the showing of videos and films for both entertainment and educational purposes.

- f) fostering of a strong co-operative community spirit in the villages as result of co-operative efforts involved in building the micro hydro-power project,
- g) increased status of the community in the eyes of surrounding villages as a result of the project,
- h) a reduction in the level of migration of youths away from the relevant villages.

The benefits of the existing projects have not lived up to the expectations of either the members of the communities involved or the personnel providing outside assistance. It seems likely that the greatest benefit to these communities was the increase in status that the projects brought them before the problems of system unreliability became manifest. However, it is worth noting that the leaders of Baindoang village were concerned that they would be ridiculed by neighbouring villages if they could not be seen to be utilizing their status project.

In the cases of both the Ogeranang and Umbang-Baindoang projects it would appear that the micro hydro-power projects have decreased, rather than increased, the unity of the communities. The poor reliability of the projects, and lack of end-uses, appear to have prevented any other significant social benefits from materializing. In fact it it seems likely that the poor performance of these projects is likely to adversely affect the peoples' perceptions of any future proposals for assistance with development initiatives.

The three Pindiu schemes were completed at low cost, but, at the expense of project performance given the low level of understanding that the villagers had of the technicalities of the projects. The Ogeranang and complete Umbang-Baindoang projects both suffered from higher costs, and these costs would have been significantly higher, especially in the case of the Umbang-Baindoang project, if the cost of staff and student travel between Lae and the project site was included.

7.4. Private and Commercial Developments

Since the Second World War only three micro hydro-power projects are known to have been developed. Of these one is now dis-used and another acts only as a supplement to diesel based generators. The third and most recent scheme is dealt with as a case study in Appendix N. The scarcity of commercially developed micro hydro-power projects is surprising but seems to be largely attributable to the following factors;

- a) the urban location of much industry and commerce.
- b) the ready availability of diesel generators.
- c) a scarcity of commercially available skills and equipment for implementing micro hydro-power projects.
- d) the riskiness and high capital cost of micro hydro-power projects.

7.5. Conclusions

The mission schemes can be considered as rural electrification projects in a limited sense only since in few cases is access to power for domestic or other purposes extended beyond the mission boundaries. Nevertheless, the mission schemes are of importance in demonstrating that the construction and operation of micro hydro-power projects in the rural areas of the country is entirely feasible under the right circumstances. Many mission projects have provided a reliable source of power over an extended period of time and any serious micro hydro-power programme could learn much from them.

Information on project costs is available from only a few mission schemes, but at these the specific costs of projects have been held to less than K 2,500/ kW through the use of voluntary labour and an appropriate approach to design. The only project to have been recently developed by commercial interests also indicates that

project costs can be kept within reasonable limits under the right circumstances.

The three Pindiu projects were completed at low specific costs. But the low standard of engineering adopted meant that project reliability was adversely affected. Given the lack of technical skills in the villages served and the lack of regular project support, it would appear that higher priority should have been given to project reliability. Such an approach was adopted for both the Baindoang-Umbang and Ogeranang projects. The specific costs of these projects were relatively high, and particularly in the case of the Baindoang-Umbang project, would have been significantly higher if the costs of transporting Unitech staff (and students) to and from the site was included. However, project reliability in both cases has also been poor.

The benefits that have derived from the village projects undertaken to date have been limited. If projects are to create significant benefits (both of an economic and social nature) it is important that some of the power generated is used for income generating purposes. At most villages such end uses are unlikely to develop unless the implementation of micro hydro-power projects is undertaken in conjunction with specific efforts to establish such end-uses.

Few, if any village, micro hydro-power projects are likely to be developed without substantial external technical and financial assistance. If developed the benefits deriving from projects are likely to be limited unless such support includes;

- a) specific efforts to develop power consuming end-uses, particularly of an income generating nature.
- b) a significant training input to enable the community to operate, maintain and manage the project.
- c) access to reasonably priced repair services.

Even if such support is available, investment in other projects is, in many cases, likely to be more effective at generating social and economic benefits for the target population as demonstrated in Appendix M.

8. A Discussion and Summary of Factors Affecting the Development of Micro and Mini Hydro-Power Resources in Papua New Guinea

8.1. Introduction

Papua New Guinea has abundant small-scale hydro-power resources. In the long term it is likely that their development will play a significant role in bringing electricity supplies to the rural communities of the country. However, these resources will only be widely developed if such development is positively supported. At present little effective support exists and the national government remains reluctant to subsidize any broad based rural electrification, perceiving that the claimed benefits of such a programme can, in general, be better met by other means.

8.2. The Diesel Power Replacement Programme

Nevertheless, the national government, through the Department of Minerals and Energy, is currently undertaking a programme intended to reduce the cost and improve the standard of electricity at the nation's 'C' centres. Under this programme, the Diesel Power Replacement Programme, power supplies will be up-graded, principally through the implementation of micro and mini hydro-power projects to serve individual centres. The principal justification for this programme is the desire to reduce the level of government subsidies of these power supplies, and at the same time to reduce national dependence upon fuel imports. The long-term aim is to make operation of these projects commercially viable to Elcom. However, it remains unclear whether or not an interim management arrangement will be necessary while tariffs are raised to the level charged by Elcom and while the viability of the projects is assessed.

The 'C' centres are seen as important rural central places. By offering a range of goods and services to their surrounding hinterlands they are seen as providing the means and incentives for increased rural productivity. However, it has been argued that the

role of the 'C' centres in stimulating widespread rural development has been constrained by the inadequacy of existing power supplies. The desire to remove this constraint is a further justification of the DPRP.

8.3. Village Micro Hydro-Power Projects

If the 'C' centre projects implemented under the DPRP prove successful, it is anticipated that, in the medium term, the scope of the programme will be expanded to include the implementation of micro hydro-power projects to supply rural villages. However, it is clear that there are major differences between 'C' centre and village projects. Village micro hydro-power projects will not play a significant role in reducing the nation's dependence upon fuel imports since very few villages operate diesel generators. Similarly few village projects can be justified on the basis of their providing a low-cost replacement for existing generators.

The low income of the majority of the rural population and the limited development of small-scale agro-industrial and manufacturing enterprises in Papua New Guinea mean that the demand for electricity in most villages is limited. As a result most village projects will not be financially viable. Because of this Elcom is not likely to assume responsibility for the operation and management of village projects. A separate national management organization may be established, but it is more likely that projects will be managed on an individual basis.

These factors mean that, whilst the current DPRP is concerned only with the physical implementation of economically viable hydro-power projects, a more comprehensive approach to project justification and implementation will be needed if village projects are to be undertaken.

8.3.1. A Broader Definition of Village Micro Hydro-Power Projects

Village micro hydro-power projects should be seen as rural development initiatives and should compete with other rural development projects for available funds. If effective use is to be made of these funds, village micro hydro-power projects should be justified on the basis that they are the least cost method of supplying specific benefits to the community or area. But the benefits of a micro hydro-power project derive mainly from the uses to which the power generated is put. Social and economic end uses are more likely to develop, increasing the impact of projects, if power is supplied as an element of a more broadly based rural development programme. This was recognized in the 1984 Medium Term Development Strategy; Energy Strategy; Discussion Paper which stated that:

"If benefits of extending energy to rural areas are to be maximized, a selective approach will be required. Electricity supply to undeveloped areas will be best viewed as a working component of a wider, co-ordinated rural economic development programme. The success of electricity within such a programme would depend on diverse factors including, for example, current trades, skills and the size of affected population, the proximity of the project to hydro or similar resources, the commitment of the overall programme to the development of the local economy, education, health, etc. The areas to be served in the near term would most likely be larger rural villages and towns which already have some form of industrial, commercial or administrative base."

Thus, project implementation should be undertaken in conjunction with other development initiatives and with specific efforts to promote end uses. Both social and economic end uses are valid consumers of power. But economic end uses create income which may be invested in further economic and/or social end uses. Thus, priority should be given to promoting economic rather than social end uses. Given the limited development of small-scale agro-industrial and manufacturing enterprises in rural areas, a load promotion/business extension programme will be vital to the success of most village micro hydro-power projects. This might include the provision of

technical, economic and management advice, the training of potential entrepreneurs and the provision of credit for the purchase of plant and machinery. Such a programme should be considered an integral part of the project and its costs considered as part of the overall project cost.

The shortage of technical and management skills in the rural areas of Papua New Guinea means that a substantial training input will also be needed, in conjunction with project implementation, to ensure that projects can be successfully operated and managed at village level. Again these costs should be considered as part of the overall project cost. There is also a strong case for establishing centralized facilities capable of providing spare parts and repair services at reasonable cost. In addition, care is needed to ensure that the project ownership and management structures established are appropriate to the village setting. Although their performance has often been poor, there is strong support for co-operative developments in Papua New Guinea. The village micro hydro-power schemes undertaken to date have proceeded on the basis that ownership of the project would be community-wide. Such general ownership is in many ways desirable, since it tends to minimize the extent of any divisions created within the community by the project. However, it has its disadvantages; in particular, it reduces the commitment of the individual and may mean that unpleasant or unpopular tasks necessary for maintaining project viability are left undone.

Few village micro hydro-power projects are likely to be financially viable in the medium term, and few are likely to be justified on the basis of their being the least cost method of providing specific benefits unless the specific costs of the installations can be significantly reduced from the level expected with current DPRP projects. Cost reductions of the scale required are not likely to be achieved while project design continues to be carried out by overseas consultants and while implementation is undertaken by contractors. There is a need to develop the skills within the country to carry out project design and to supervise the

construction and installation of projects using local labour. There is also scope for project simplification, equipment standardization and the development of designs that reflect local conditions. In the longer term the manufacture of some micro hydro-power equipment within the country may also become feasible.

8.3.2. Supporting Village Micro Hydro-Power Projects

Given the broad range of problems that will need tackling if a significant number of village micro hydro-power projects are to be successfully implemented and sustained, it would appear that there is a strong case for establishing in Papua New Guinea a micro hydro support agency along the lines proposed in Section 3.10. of this thesis.

Within the DME a programme has recently been established to train a group of national personnel who will eventually form the core of a Mini Hydro Development Unit. Initially the personnel of this Unit will be used to reduce the reliance of the existing programme upon overseas consultants. In the longer term the Unit may become directly involved in implementing village projects. The role of the Mini Hydro Development Unit has not yet been fully defined. However, it is currently envisaged that its role would be narrower than that of the proposed support agency and its responsibilities would be limited to (8.1, 8.2):

- a) undertaking initial surveys of hydro-power potential and possible end-uses of power for interested villages.
- b) economic evaluation of identified schemes and advice to community leaders.
- c) engineering design services for feasible and justifiable schemes.
- d) co-ordination of requests for outside funding.

- e) supervision of construction and commissioning of suitable schemes.
- f) training of locally recruited power station operators.

In the past little has been done in Papua New Guinea to link the provision of electricity to rural communities with other development initiatives. This has contributed to the poor performance of the limited rural electrification that has been undertaken to date. A Mini Hydro Development Unit established along the lines proposed above should be capable of physically implementing village micro hydro-power projects. This and the training of village operators might be sufficient for project success at the small number of villages where diesel generators are currently operated and where small-scale, power consuming agro-industrial enterprises have been established. But for the great majority of villages, the performance of projects is likely to be adversely affected unless specific steps are taken to link project implementation with other development initiatives and to promote end uses for the power generated.

Not all the functions of a micro hydro support agency as proposed in Section 3.10. need to be internalized to the Mini Hydro Development Unit and there is a case for making use of the skills and manpower of other rural development organizations in supporting projects. The Business Development Office, for example, has staff throughout the country who might profitably be used in any load promotion programme, in the training of local project managers and in providing on-going accounting support. But the BDO suffers from staff constraints and is likely to give its own projects priority. If organizations such as the BDO are to be successfully involved in supporting the activities of the Unit there is a clear need for the Unit to establish strong links with such organizations at the earliest possible date.

It has been argued that there is a strong case not only for encouraging the growth of existing 'C' centres, but also for increasing the number of rural central places (8.3, 8.4, 8.5). No integrated programme of encouraging such centres currently exists. Nevertheless, it is likely that some dynamic villages will develop at a faster rate than others and increasingly assume the role of service centres for the surrounding communities. It is at such villages that the potential for developing commercial and small-scale industrial enterprises is also likely to be highest. Given the relatively high cost of micro hydro-power projects and the fact that only limited resources are likely to be available for their development, it is important that those projects implemented should produce significant benefits. Such benefits are most likely to develop at villages that, through their own or provincial government effort, are considered as being (or likely to become) local central places. Such villages would tend to be characterized by:

- a) relatively large population,
- b) availability of land for further developments and expansion of the settlement,
- c) good communication links, preferably by road, with surrounding areas,
- d) the presence of facilities such as an aid post, community school, tradestore etc.,
- e) evidence of initiative and entrepreneurial drive by the inhabitants as shown by operation of a public motor vehicle (PMV) etc.,
- f) located in an area of relatively high population density,

- g) located in an area in which a high proportion of the people are well integrated in to the cash economy,
- h) the presence of an existing petrol or diesel generator set.

In further discussing the scope of an expanded programme of micro and mini hydro-power development it is suggested that projects should be considered as falling into three categories that partly reflect the rural electrification categories suggested in the 'Report of the Regional Rural Electrification Survey to the ADB' and discussed in Section 2.4. of this thesis.

Category One Projects

Category One schemes will be in the mini hydro range, ie. above 100 kW and typically of several hundred kW installed capacity. Demand on this scale currently exists only at government 'C' centres, at a few of the larger mission centres and at occasional agro-industrial enterprises. The 'C' centre projects fall within the scope of the current DPRP. Projects to be implemented are considered economically viable on a diesel replacement basis without complementary investments or load promotion programmes.

However, if the proposal to implement village micro hydro-power projects is serious, it is suggested that future projects be undertaken in conjunction with a range of business extension initiatives aimed at enhancing the role of the centres as central places and also improving the viability of the hydro-power projects themselves by promoting load growth and hence revenues accruing to the projects. Given the limited extent of small-scale agro-industrial and manufacturing enterprises in rural areas, a number of pilot enterprises should be established to demonstrate the viability of such enterprises in the rural environment. The links fostered with other government departments and the skills gained in this way would make the transition to village projects that much easier.

Because of their scale, Category One projects require a professional and reasonably conventional approach to project design, implementation and management. As the skills of the Mini Hydro Development Unit are developed it is likely that reliance upon overseas consultants will be reduced, although some input from them may continue. Similarly manpower limitations within the Unit are likely to mean that project implementation will remain in the hands of contractors or, at a later stage, a government agency such as the Department of Works. The scope for offering technical assistance in project design and implementation to missions or business enterprises is therefore limited.

Category Two Projects

Category Two projects may be considered as schemes within the micro hydro range and typically with installed capacities in the 15-60 kW range. This level of demand currently exists at some of the smaller 'C' centres and these centres are included within the scope of the current DPRP. However, the scale of these projects distinguishes them from those dealt with above and makes the adoption of a non-conventional approach to project design and implementation feasible. Enough low-cost projects have been implemented in the country to indicate that there is significant scope for reducing the costs of these projects by paying attention to simplifying project designs, using locally available materials and using labour intensive construction methods. As the Mini Hydro Development Unit is developed it is likely to become directly involved in project design and implementation, removing the need to rely upon consultants and contractors.

If the decision is taken to expand the scope of the DPRP to include village projects, it is likely that most projects selected for implementation will also be of this scale. The first projects are likely to be implemented at villages where small-scale, power consuming agro-industrial or manufacturing enterprises already exist. But the number of such villages is small.

As discussed, in selecting further projects for implementation, priority should be given to those that are judged to have the potential to act as local service centres, and to develop power consuming enterprises. Projects should be linked with other development initiatives and significant attention paid to establishing a viable management structure and to promoting load growth, particularly of an income generating nature. These aspects of the project should be considered of equal importance as implementation of the micro hydro-power scheme itself and the experience gained in implementing the earlier village projects and in establishing pilot enterprises in conjunction with 'C' centre projects is likely to prove invaluable at this stage.

Once firmly established the Mini Hydro Development Unit may also consider making its services available, probably on a cost-plus basis, to mission groups interested in implementing projects of an appropriate scale.

Category Three Projects

For many villages their remoteness, small size and the limited involvement of the population in the cash economy severely limit the possibilities for developing commercial and industrial power consuming enterprises.

Category Three projects comprise small micro hydro-power schemes that may be seen as suitable for the provision of power for lighting, and/or refrigeration, in schools and health centres etc., and for meeting primarily domestic needs in villages, where it is considered that commercial/industrial end uses are unlikely to develop. Such projects will generally have installed capacities of less than 10 kW and often less than 5 kW. A low technology approach to project implementation may be adopted by individuals. But the widespread implementation of such projects appears to be dependent upon the availability of small, low-cost, standardized turbine-generator units and the availability of sites where such units can be installed with minimal civil works or transmission network.

The Mini Hydro Development Unit could become directly involved in the implementation of such projects. However, the social benefits that have resulted from the implementation of the existing village micro hydro-power projects have been limited. It would appear that they could have been achieved at lower cost and in a more self-reliant manner by various other initiatives. It also seems clear that social benefits are more likely to develop where income generating end uses develop in conjunction with the project. This increases the ability of the community to pay for socially useful appliances and consumption. In addition, where demand for power is below about 5 kW it would appear that a system based upon photovoltaic panels will often offer a more attractive source of power than a hydro-power plant. Although such panels are high technology items, they have no moving parts and have a long life. They are unlikely to require outside assistance either in installation or in maintenance. Commercial units are readily available and the panels come in discreet sizes so that system expansion is possible. For household lighting, separate photovoltaic panels can be used to supply individual households so that no community-wide charge need be made to non-users of power. The panels can be used to charge portable fluorescent lanterns that, in many ways, better suit the lighting requirements of most villagers than the fixed lighting supplied by a hydro-power project and its distribution system.

The Mini Hydro Development Unit may become involved in implementing some Category Three projects. It may also act as a commercial agent for small standardized turbine-generator units and/or photovoltaic systems. But priority should normally be given to Category Two projects.

8.4. Conclusions and Recommendations

Expansion of the DPRP to include village projects is not likely unless the initial 'C' centre projects prove successful and unless the specific costs of micro hydro-power projects can be reduced significantly. High priority therefore needs to be given to ensuring

that the initial projects are completed on budget and on schedule and to developing the design and implementation skills of the proposed Mini Hydro Development Unit. It is also important that once completed these projects are effectively managed and that efficient tariff collection procedures are established.

However, success in these areas should not be taken as a positive indication that village micro hydro-power projects will also be successful and in the national interest. The development of the nation's micro hydro-power resources to serve rural communities does appear to fit in well with the national government's development philosophy as expressed in its 'Eight Aims'. But the financial and manpower inputs required to implement micro hydro-power projects are significant and projects can only be justified if they also create significant benefits. At the few village projects implemented to date insufficient attention has been paid to training and supporting project operators and managers and there has been only limited development of end uses for the power generated. This has meant that projects have been unreliable, operation and maintenance costs have not been covered and the benefits of the projects have been limited.

Given the commitment, there is little doubt that the Mini Hydro Development Unit can develop the skills to implement micro hydro-power installations in the villages of Papua New Guinea. But if village projects are to be successful this is but part of the problem that needs to be addressed. Unless specific training and support measures are taken to prevent it, it is likely that the fate of future village projects will be similar to that of those that have already been implemented.

Such support should be considered an integral part of any future projects and, if it is to be effectively provided, the role of the Mini Hydro Development Unit will need to be expanded. The Unit may not be solely responsible for providing all aspects of such project support and it is likely that financial and manpower constraints on the Unit will mean that significant reliance will be placed upon such organizations as the BDO for promoting end uses and providing

training of and support to project managers. However, there is a distinct danger that this will mean that these aspects of village projects will not be given the priority that they deserve. At a minimum the Unit will therefore need to develop a core of personnel skilled in these areas to establish the framework for the involvement of these organizations, to liaise with their staff and to monitor their activities. Links with relevant organizations need to be established at the earliest possible date, preferably while the DPRP is still concentrating on 'C' centre projects.

The difficulties and costs involved in establishing viable management structures and in promoting end uses for power generated are likely to be lowest at relatively large and dynamic villages that are judged to have the potential to act as service centres to surrounding communities. It is at such villages that the impact of micro hydro-power projects is likely to be greatest. Any future programme of implementing village micro hydro-power projects should concentrate on such villages.

Appendix A. Further Information on Elcom Systems

A. 1. The Ramu System

In 1985 the Ramu system had electricity sales of 155,700 MWh with a peak demand of 32.4 MW. The main source of generation is the Ramu No. 1 hydro-electric station with an installed capacity of 45 MW (3 x 15 MW), operating under a 220 m head. Further hydro generation is available from the Pauanda hydro-electric station, with an installed capacity of 12MW. Both schemes are of the run-of-river type and seasonal variations in flow mean that the firm capacity of the Ramu scheme is only 19 MW, whilst that of the Pauanda scheme is 5 MW.

There is supplementary diesel generation at Lae, Madang and Mendi. the total site rated capacity of these generators is 20.69 MW, and they are used to provide for peaking during the dry season and standby generation in case of transmission failure. Between 1 and 2 MW of hydro-power is also purchased from the non-Elcom Baiune hydro-power station and delivered via 66 kV line to Lae.

A 60 m high compacted, layered earth/rockfill dam is currently being constructed upstream of the Ramu hydro development. This will provide 332 cubic metres of storage, making possible the installation of a further 60 MW and secure a reliable supply, independent of fuel prices, for the Ramu system.

A. 2. The Port Moresby System

In 1985 the Port Moresby system had electricity sales of 191,400 MWh with a maximum demand of 43.8 MW. The Rouna hydro-power developments on the Laloki River provide the system's principal source of generation and the total installed capacity of these developments is currently 49 MW. The schemes have limited storage capacity and two 16 MW gas turbines and two 7.5 MW diesel generators are used to supply peak power during the dry season. To increase system capacity and reduce reliance upon fuel imports construction of a further

hydro-power development, Rouna-4, with two 6.75 MW units, was commenced in 1984. However, lack of storage capacity will continue to limit dry season output and completion of Rouna-4 will mean that the hydro-power potential of the Laloki River is fully developed. The most economic long term development of the Port Moresby system is inter-connection with the Ramu system once the Yonki dam has been completed. Construction of the required transmission lines is due to start in 1991 for commissioning in 1994. This connection should provide a reliable long term hydro-power supply to the capital and result in significant fuel savings. In the shorter term it is planned to install an additional 7.5 MW diesel unit in 1990.

A. 3. The Gazelle System

In 1985 the Gazelle system had electricity sales of 24,000 MWh with a peak demand of 5.2 MW. In November 1983 the Warangoi hydro-electric station, with an installed capacity of 10 MW, was commissioned and connected into the system via a 66kV transmission line. Design and administration of the Warangoi project was undertaken, on behalf of Elcom, by Norconsult. Funding had been provided by the Overseas Economic Co-operation Fund, the Asian Development Bank, the Norwegian government and the Papua New Guinean government. Final project cost was K 37.6 million. The hydro plant provides a firm hydro base for supplies to the area and has allowed a reduction in the use of fuel and installed capacity at the Rabaul and Keravat diesel power-stations. As of december 1985 installed diesel capacity (site rated) was 6.07 MW which is now used mainly to meet peak requirements and act as standby in case of transmission failure. The Warangoi hydro scheme is capable of supplying the system's main energy requirements for some time.

A. 4. Other Elcom Centres

Elcom's remaining 15 systems serve individual urban centres or conurbations. The extent to which distribution extends outside the urban area is limited. In all but two cases their supplies are

produced entirely by diesel generator sets, see Table A.1. for further details.

Table A.1. Information on Elcom's Isolated Power Systems

<u>System</u>	Installed Capacity in kW	1985 Peak Demand in kW	Energy Sales for 1985 in MWh	Hydro-Power Project Planned	Hydro-Power Project Under Investigation
Aitape	330	120	447		
Alotau	2,100	730	3,210		*
Buka	490	160	640		
Daru	1,050	470	2,000		
Finschhafen	440	130	420	*	
Kavieng	2,070	970	4,270		
Kerema	500	300	1,180		*
Kieta/Arawa	----- ¹	9,330	44,810		
Kimbe	2,080 ²	990	4,050		*
Lorengau/ Lombrum	1,950	910	4,265		*
Maprik	390	200	750		*
Popondetta	1,640	780	3,790	*	
Samarai	360	120	475		
Vanimo	760	450	1,930		*
Wewak	3,660	2,270	11,750		*

N. B. 1) The Kieta/Arawa conurbation is supplied with power purchased from Bougainville Copper Limited.

2) Of total installed capacity at Kimbe, 800 kW is hydro-capacity.

Source: Ten Year Plan 1986-1995, Elcom, 1985.

Appendix B. The Simbai Micro Hydro-Power Project

The Simbai micro hydro-power project utilizes flow from the Yinink River. The scheme incorporates a low rock filled gabion weir diverting flow into a trapezoidal section headrace channel 460 m in length. The power house site was situated 1.5 m above the normal river level and 15 m in elevation below the penstock intake. With a design flow of 315 litres/sec and gross head of 15 m, the scheme was designed for an output of 25 kW. A Gilbert Gordon and Gilkes turgo impulse turbine operates at 350 rpm and, via a step up to 1,500 rpm, drives a 3 phase, 4 wire Markon B354D brushless alternator rated 31.25 kVA at a power factor of 0.8 pm to provide a 50 Hz, 415/240 V supply. A Woodward governor (Type PG.D.) is belt driven from the turbine shaft and primary governing is by deflectors to limit pressure rise in the penstock during load rejection.

Appendix C. The Kabwum Micro Hydro-Power Project

The Kabwum micro hydro-power scheme was designed to utilize flow from the Pimuni River with a catchment area of 14 sq km above the weir site. The scheme had a capacity of 25 kW, but the headrace and penstock were over-sized to allow for a subsequent increase in capacity to 50 kW. It is not clear whether this was to be achieved by installing a second 25 kW unit or by replacing the installed unit with a single 50 kW unit and transferring the 25 kW unit to Tagarau (at which a micro hydro-power project was also being considered).

As completed, the micro hydro-power scheme incorporated a diversion weir and intake structure on the Pimuni River constructed of rock filled gabions. The intake structure diverted flow into a trapezoidal section, lime cement lined power canal approximately 600 m in length. From a forebay at the end of the power canal water entered the buried penstock which was about 250 m in length, 0.3 m in diameter and of steel construction. The penstock fed into an Ossberger cross flow turbine (Type SH35) which was designed for an output of 25 kW under a gross head of 45 m and a flow of 85 litres/sec. The 3 phase synchronous, brushless generator with a capacity of 31 kVA at 0.8 power factor and 50 Hz was driven via a flywheel, flexible coupling and step up gear box. Conventional mechanical/hydraulic governing was used.

The power house was located about 300 m from the end of the Kabwum airstrip and distribution from the scheme was at the generated 415/240 V. About 30 households were initially connected to the power supply, each being fitted with 3 x 40 W fluorescent tubes. In addition, several of these houses were provided with power points. Several other potential loads remained without power and there was some talk of eventually extending the distribution system to several nearby villages.

Appendix D. The Sohun Mini Hydro-Power Project

The Sohun scheme is sited on the Sohun River, 17 km from Namatanai. The catchment area of the river above the weir site is 20 sq km and it is a predominantly limestone area with significant groundwater flow. The natural head at the site is only 5.6 m, but a dam of compacted coronous was constructed to raise the gross head to 15 m. About 30,000 cubic metres of pondage allows some peaking operation above the 126 kW of power available under normal flow conditions. Hence the installation of two 100 kW units. However, during the dry season (June to October) the average power available can fall to about 50 kW. The penstock feeding water to the turbines is 150 m in length, has an internal diameter of 1.2 m and incorporates a small surge chamber to facilitate satisfactory governing of the turbines. Transmission to Namatanai is at 22 kV.

Appendix E. The Ru Creek Mini Hydro-Power Project

The lower reaches of Ru Creek lie to the west of Kimbe and flow into the Stettin Bay. The catchment area of the creek, above the weir is about 80 sq km and there is substantial groundwater flow. No stream gauging had been carried out on the creek prior to Elcom's proposal to build the mini hydro scheme. However, it had been estimated that minimum flow in the creek was 2.3 cubic metres/sec and that, combined with a potential head of 19 m (both gross and net) this gave a potential continuous power output of 328kW. A 67% flow was estimated at 5.5 cubic metres/sec to give a potential output of 783 kW. In fact the level of flow has consistently been below that used in project design and this has restricted output from the project.

The scheme involves the use of a low ogee type spill-weir designed for a flood discharge of 120 cubic metres/sec. Integral to the weir are the intake works and sandtrap. The headrace channel into which water passes is about 1,600 m in length, of trapezoidal section with a bottom width of 2.3 m and of reinforced concrete construction. From the headrace water was to be fed into the forebay and hence into two penstocks, each 45 m in length and 1.5 m in diameter.

Appendix F. The Lake Hargy and Tinputz Hydro-Power Projects

F. 1. Background to the Bialla Area

The proposed Lake Hargy mini hydro scheme was designed to serve the Bialla area of West New Britain. The economic life of the area centred around the activities of the Shin Asahigawa sawmill, the Bialla oil palm development and employment in the government services. At the time of the original project proposal the population of the area was about 2,500, but this was expected to have risen to about 7,500 by 1980.

Diesel generator capacity in the area was about 2,400 kVA of which 1,500 kVA was owned by the oil palm development and 750 kVA by the sawmill. In 1975/76 a total of 1,648,337 kWh of electricity was generated in the area. The cost, at the bus bars, of this energy was 11.1 toea/kWh in comparison with an estimated cost of at 0.5 toea/kWh from the proposed hydro scheme.

F. 2. Lake Hargy Hydro-Power Scheme Design

Lake Hargy has a catchment area of 80 sq km and drains into the Lobu River which had been stream gauged since 1969. The proposed scheme was a run-of-river project utilizing flow from the Lobu River and would have involved the construction of a low, mass concrete weir with a maximum height of 7.3 m and a length of 22 m. The weir was to incorporate an intake structure, with stop logs and screens, feeding water into a headrace channel 1,400 m in length and hence into the forebay.

The gross head created was 31 m giving a net head of 29 m. At a minimum flow of 5.5 cubic metres/sec this would give a potential power of 1,200 kW. At the 95% flow of 7.0 cubic metres/sec a potential 1,500 kW would be available and the scheme was to utilize 2 x 750 kW turbine-alternator units. The penstock taking water from the forebay to the power house was to have been 1.8 m in diameter and 55 m in length. The power house, sited 2 m above the normal

river level, was to house two horizontal axis francis turbine-generator units and a repair bay.

Development of the site would have involved the construction of a 22 kV transmission line, 15 km in length, to carry power to the load centre.

F. 3. Background to the Tinputz Area

The economy of the Tinputz area is based on cocoa production with smallholders and community groups being the major producers. There is also some coconut/copra production and saw-milling in the area. The area is accessible by road from Kieta and in 1977 the total population of the area was less than 1,000 and migration, particularly of young men, to the Kieta and to BCL's copper mine at Panguna was resulting in local shortages of labour.

F. 4. Tinputz Hydro-Power Scheme Design

As proposed the Tinputz hydro-power scheme would have involved the construction of a low, masonry weir to divert flow from the Tinputz River into a concrete lined, semi-hexagonal section power canal running along a bench cut into the left-hand side of a gorge through which the river flows. In this way a gross head of 20 m could be developed at the site. The catchment area above the weir site was 40 sq km. Little flow data was available, but rainfall in the area is fairly evenly spread throughout the year so that limited seasonal variations in flow rate were expected. Minimum flow was estimated at 0.92 cubic metres/sec which, combined with the available head, was expected to give a continuous power output of 131 kW.

Slopes at the proposed forebay site were excessive and would have required some flattening. From the forebay the steel penstock, 1 m in diameter and 36 m in length, was to feed two cross flow turbines located in a reinforced concrete power house structure sited 2 m above the normal river level.

Appendix G. The Tari Mini Hydro-Power Project

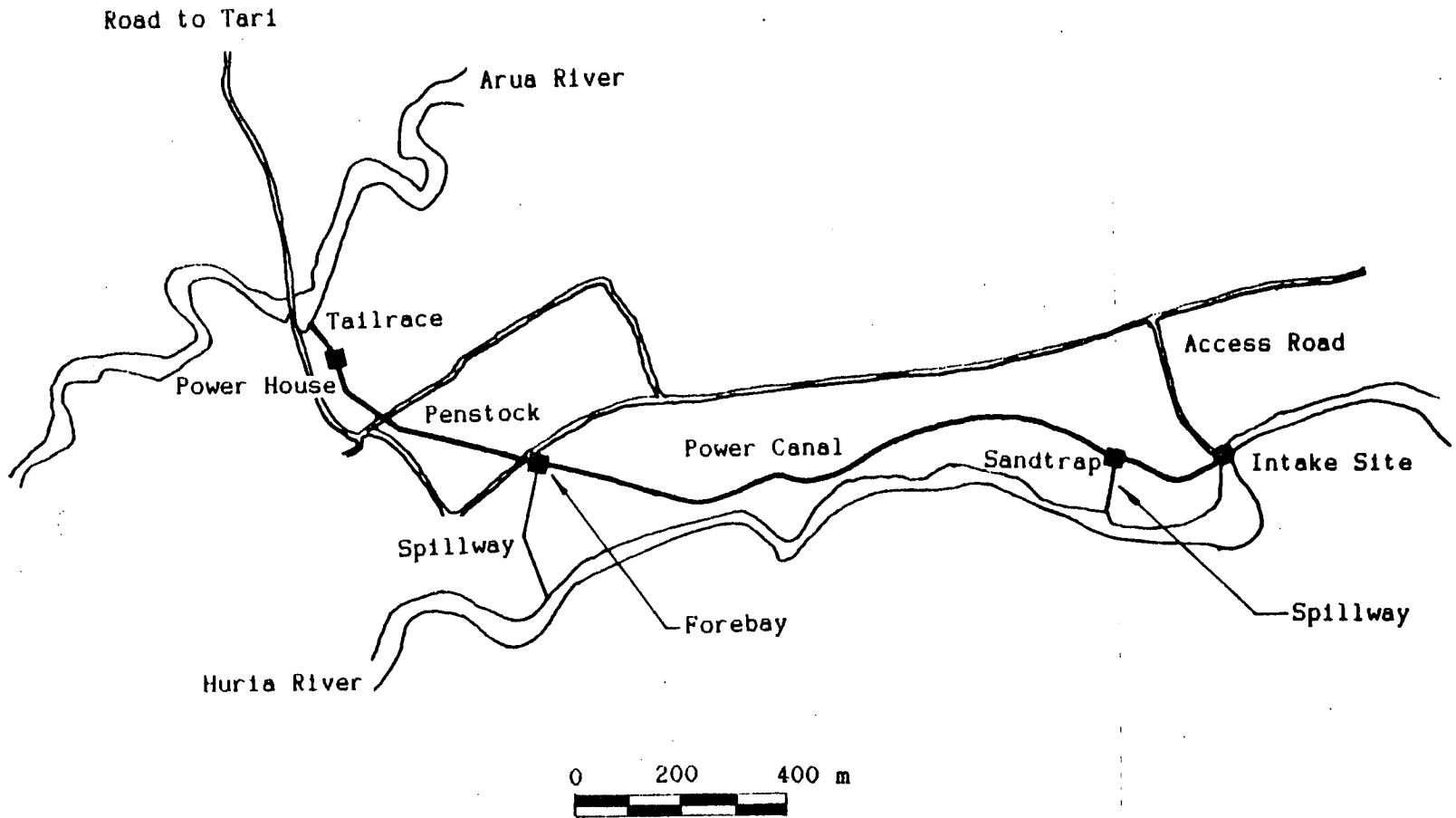
A schematic diagram of the Tari hydro-power project, currently under development, is shown in Figure G.1.. The completed project will operate under a gross head of 30 m and a maximum design flow of 1,330 litres/sec to give a maximum output of 315 kW.

The scheme will utilize a natural pool on the Huria River to obviate the need for a weir at the intake site. However, it is anticipated that the construction of a low weir might eventually prove necessary as load rises over the years. Provision has been made for this in the design.

From the intake a low pressure conduit of either 1,350 mm diameter corrugated iron or 1,050 mm diameter PVC is to be used to carry diverted flow across the alluvial flood plain to a sandtrap. The length of this conduit is 260 m and it is designed to withstand flooding and to provide some throttling action under such conditions. From the sandtrap, diverted flow will enter the 1,200 m long headrace channel being cut into the scarp slope. The channel is designed for a flow velocity of 0.4 m/sec and is of trapezoidal section with a base width of 3 m. The canal grade will be 1:400 and its construction is expected to involve 95,000 cubic metres of excavation. The final 163 m of the headrace feeding into the forebay will be lined and constructed on compacted fill.

The penstock is to be 511 m and of either 850 mm diameter steel or 800 mm diameter glass reinforced plastic. Several sections of the penstock will be buried, the remainder being mounted on concrete plinths. It will feed into a single cross flow turbine accommodated in a power house located 1.8 m above the flood terrace. The turbine is to be rated at 340 kW and will drive a 400 kVA synchronous machine to give an output of 315 kW at a power factor of 0.8. Transmission to Tari will be at 22kV with line construction being undertaken by Elcom.

Figure G.1. Schematic Layout of the Tari Hydro-Power Project



Appendix H. The Highlands Christian Mission Mini Hydro-Power Project

H. 1. Introduction

Okapa acts as the headquarters of Okapa District in the Eastern Highlands Province. The centre is accessible by road from both Goroka and Kainantu. It has a population of about 500 and contains services typical of a small 'C' centre including a small hospital, a community school, a garage, a bank, a police station, several trade-stores and the offices of the Department of Primary Industry, Business Development Office, Department of Works and the Local Government Council, (H. 1, H. 2, H. 3).

Located at Yagusa, about 14 km by road from Okapa, is the Highlands Christian Mission. In addition to its religious activities the mission runs a large tradestore, mechanical and carpentry workshops, a guest house, and a mobile sawmill. It also runs a community school for local children and is closely involved in the running of a high school with 560 students, all boarders, which is located immediately adjacent to the mission site. The mission is currently engaged in upgrading many of the high school buildings and plans to establish a separate vocational school to teach printing, welding and carpentry. The establishment of a health clinic and gymnasium on the mission site has also been proposed (H. 4, H. 5).

H. 2. Background to the Mini Hydro-Power Project

For many years the mission operated an 11 kVA diesel generator. By the late 1970's this was no longer adequate and it was suggested that the development of a mini hydro-power scheme was feasible utilizing flow from the Esapinti Creek which has its source in the steep slopes to the west of the mission site. The power output of this scheme was expected to be more than sufficient to meet the mission's needs and it was proposed that the mission sell excess power to the township of Okapa.

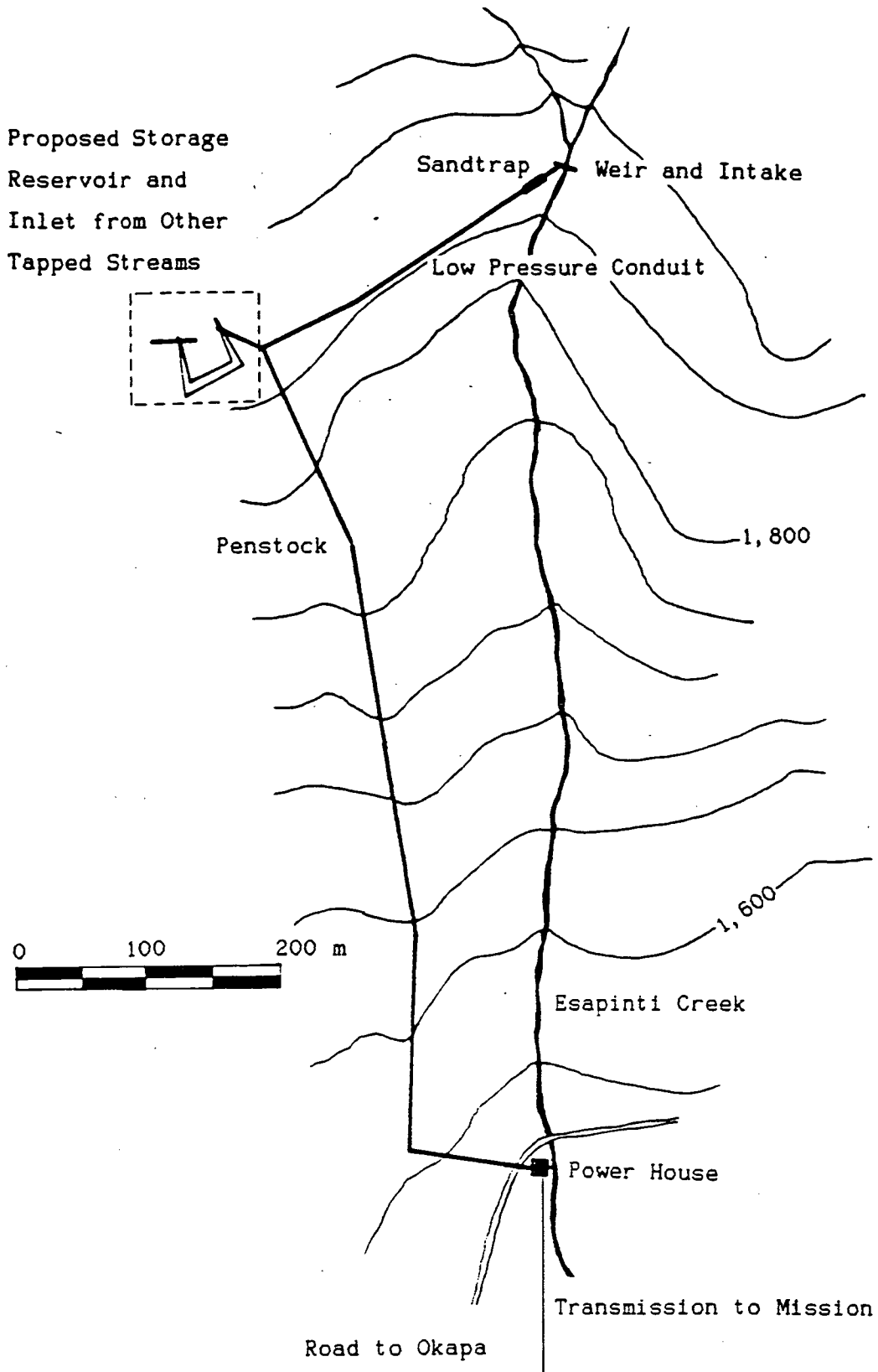
The mission had contacts in the U.S.A. and, during 1982, Sam Nelson of Hydro Light Inc. visited the site and proposed the construction of a 220 kW scheme. This was agreed, and subsequent design work was undertaken by Hydro Light Inc. The required funding was obtained from various charitable sources in the U.S.A. (H.6).

Construction of the project began in early 1983 and was supervised by Hydro Light Inc. who had also been responsible for procuring all equipment in the USA. Unskilled labour was provided locally, much of it by students at the high school. The project was commissioned in less than nine months (H.7).

H.3. Civil Works

The hydro-power scheme, a schematic diagram of which is shown in Figure H.1., utilizes flow in the Esapinti Creek. A low concrete diversion weir, sited 280 m in elevation above the power house, diverts flow, via a short length of pipe, into an enclosed concrete sandtrap. It then enters a low pressure pipeline which runs to the ridge down which the penstock is laid. It became clear during construction of the project that during the dry season there would be insufficient flow in the Esapinti Creek to fully utilize the scheme's capacity. Provision was made for the later construction of a storage reservoir on the ridge, and for tapping the flow from several smaller streams. Thus, at the top of the ridge a tee junction is provided to allow for future connection to the proposed reservoir. Below this glass fibre reinforced PVC pipe is used for the penstock. For the majority of its 700 m length the pipeline is buried and follows a fairly straight path down the ridge. Where angles exceed 4° ductile iron joints have been used in conjunction with concrete anchor blocks to resist the thrust. In several places sub-surface drainage has been provided and for about 70 m steel pipe is used where the penstock bridges a small gully (H.8, H.9).

Figure H.1. Schematic Layout of the Highlands
Christian Mission Project



H. 4.

Power House and Electro-Mechanical Equipment

The power house is of block-work construction and houses a twin jet pelton wheel turbine operating under a nett head of 268 m and designed for a maximum flow of 112 litres/sec. It was designed and manufactured by Hydro Light Inc and Hydro Stock Inc. A second hand Woodward P.G. 500 governor is installed and uses deflector plates on both nozzles to respond to rapid load changes. The lower of the two spear valves is also controlled by the governor. The upper valve is manually operated and since 110 kW is available using the lower nozzle, it is rarely used.

The turbine direct-drives the generator at 1,500 rpm through a heavy flywheel and flexible coupling. The generator is a four pole, brushless, revolving field, synchronous machine, rated at 275 kVA or 220 kW at a power factor of 0.8. It was supplied by Kato Engineering and is wired in star formation for three phase 240/415 V output at 50 Hz. The power control panel is fitted with two sets of breakers, one for the turbine-generator set and the other for a standby diesel generator. Provision is made for automatic shut down in the event of a) excessive rise in turbine bearing temperature, b) output frequency from the generator being outside prescribed limits, c) current in any phase exceeding 380 amps (H. 10, H. 11.)

H. 5.

Project Costs

The project was completed for a final cost of US\$ 225,000 implying a specific cost of about K 1,000/kW. This is significantly lower than the specific costs of the official schemes either completed or planned in the country. The following factors appear to be responsible for this (H. 12, H. 13):

- a) the scheme operates under a high head and this minimizes the need for civil works.
- b) construction was labour intensive and largely voluntary.

- c) significant use was made of second hand equipment.
- d) land compensation costs were limited since most of the land on which the hydro-power project was constructed was already controlled by the mission.
- e) the power house is located within the mission compound so that power distribution costs are minimized.

In addition, the output from the project is considerably restricted by lack of water for up to three months of the year. Significant further expenditure would be required to rectify this situation.

H. 6. System Operation and Problems

The scheme is operated by mission staff and is now proving reliable. However, several months after the scheme was commissioned the turbine runner disintegrated. As a result, the system was out of operation for several months before a replacement was delivered from the USA. A spare runner was also made up in Papua New Guinea. In operation both replacement runners are found to suffer from erosion to the back surfaces of the runner cups and periodic repairs are necessary.

On two separate occasions the penstock also failed soon after commissioning, once apparently as the result of soil erosion causing movement. In the second instance vibration of the penstock caused a small rock sitting against the pipeline to chafe through it (H. 14, H. 15).

Possible Connection to Okapa

Okapa's present official electricity supply is met by two diesel generators, each nominally of 40 kVA capacity. In addition, six tradestores operate small generators each of about 5 kVA capacity, and a 25 kVA diesel generator is owned by the Local Government Council.

Soon after the mini hydro-power scheme was commissioned the feasibility of constructing a transmission line to supply Okapa was investigated under the Mini Hydro Resource Inventory. Using Net Present Value analysis, the costs of the proposed extension were compared with the costs of continued diesel generation. It was assumed that capital costs for the transmission line, and expansion of the proposed hydro-power scheme would be met by the government. The mission was prepared to carry out the work itself using poles and transformers held in stock. But, this was not considered acceptable to the government or Elcom.

It appears unlikely that the connection between Okapa and the mission hydro-power scheme will go ahead. The main reasons for this being that (H. 16, H. 17):

- a) The mission is prepared to meet a maximum demand at Okapa of only 40 kW. The peak load at Okapa is expected to exceed this level by 1990. Thus, the transmission line will be under-utilized and either load management or supplementary generation will be required at Okapa.
- b) The analysis indicated that a transmission line was attractive if no charge was made by the mission for power supplied. But that it became unattractive if a charge of as little as 5 toea/kWh were to be made.
- c) The initially poor performance of the hydro-power scheme was judged to be a potential handicap to the proposal. It would appear that the scheme is now operating reliably, but its long term performance is heavily dependent upon the skills and interest of relatively short term volunteers.
- d) Load growth at the mission has been more rapid than expected, so that there is little scope for increasing the 40 kW peak demand limit imposed on Okapa.

H. 7.

Mission Power Use

All buildings in the mission and high school compounds (about 70 in all) are connected to the power supply. In addition street lighting is provided throughout the compound and in a nearby village.

All houses have electric lighting, many have electric cookers or hot plates, and/or 2,400 W electric shower heads. Several have television sets and video machines, refrigerators and/or electric heaters. Both the high school and community school have video machines. The tradestore operates several freezers and there is a range of electrical tools at the mechanical and carpentry workshops, which include an air compressor with hand tools, a bandsaw, an arc welder, several angle grinders, and several drills.

In July 1986 the average day-time load on the hydro-power scheme was about 50 kW rising to 75 kW in the evenings. This 75 kW peak demand is about the maximum that the scheme can sustain during the dry season and the mission staff were giving serious consideration to construction of the proposed storage reservoir to increase the scheme's dry season peaking capacity (H. 18).

H. 8.

Project Economics

The mission hydro-power scheme was not justified on financial criteria since its construction and engineering costs were not met by the mission, but from various grants (H. 19).

The scheme has increased the mission's income from its tradestore and workshops. However, both the tradestore and mission predominantly serve the mission so that this increase has been small (H. 20, H. 21). The main benefits of the hydro-power scheme take the form of improved facilities and services that it makes possible. These benefits affect mission staff, students at the two schools, and to a much lesser extent the surrounding rural population. Operation of the hydro-power scheme also avoids the costs that would otherwise be incurred if reliance was placed upon other energy

sources. An idea of these savings can be gained from looking at the relative costs of diesel generator and hydro-power project operation.

A stand-by 75 kVA Deutz diesel generator is located adjacent to the hydro plant's power house. During 1984, while waiting for a replacement turbine runner for the hydro scheme, the mission used this diesel generator to meet its power needs. This unit had been bought at a cost of K 16,000 and ran for a period of 9 months with a fuel cost of K 20,000 (H. 22).

Electricity use at the mission has grown significantly since then. However, it is reasonable to assume that steps would have been taken to prevent further increases in consumption, if the hydro-power project had not been repaired. It is therefore assumed that the fuel cost of continued diesel operation would be about K 26,000 p. a. . It is further assumed that the diesel plant would be operated by existing mission staff so that no additional expense would be incurred.

In comparison, the following costs were incurred in operating the hydro-power plant over a period of 30 months since its commissioning at the end of 1983 (H. 23):

-new turbine runner from the U. S. A	K 2,000
-extra turbine runner cups from the U. S. A.	K 1,000
-new hub for turbine	K 300
-new runner centre (mission built runner)	K 60
-new runner cups (mission built runner)	K 500
-welding rods for runner maintenance	K 250
-grinding discs for runner maintenance	K 100
-new flexible coupling	K 500
-new generator bearings	K 800
-new turbine bearings	K 300
-miscellaneous @ 20% of above	K 600

TOTAL	K 6,410

In addition, three Papua New Guinean employees at the mission are employed on a part-time basis to help operate the scheme at an annual cost of about K 1,000. Total operating costs of the hydro-power plant, to date, have therefore been about K 3,600 per annum.

Ignoring the initial costs of the hydro-power project, which were not met by the mission, it would therefore appear that its operation does result in very significant cost savings to the mission and in a higher standard of electricity supply.

Appendix I. The Umbang-Baindoang Micro Hydro-Power Project

I. 1. Introduction

Umbang Regional Centre acts as the focal point for the 14 rural villages that surround it and comprise the Umbang Community Group. The centre is located in the Sarawaged mountains and, although only about 50 km north west of Lae, the area has rugged terrain and the villages are relatively isolated and 'undeveloped'. Nevertheless, by late 1975 the Community Group had constructed an airstrip at the Centre, a permanent materials community school was under construction and two tradestores were in business. It was hoped that the Centre would be expanded to include an Aid Post, an emergency radio, an agricultural depot and a community workshop or vocational centre. It was also anticipated that there would be some re-settlement of people from the surrounding villages to Umbang (I.1).

In late 1975 a one day seminar on rural electrification was held at the Papua New Guinea University of Technology. This was followed by a broadcast over the local radio during which it was suggested that any rural groups interested in the possibility of developing a micro hydro-power project contact the University's Department of Electrical and Communication Engineering. Mr Yang a teacher at the Umbang community school heard this broadcast and subsequently discussed the possible benefits of Umbang obtaining an electricity supply with members of the Community Group. On their behalf, he then wrote to Unitech expressing interest in the possibility of developing such a project to serve Umbang (I.2).

I. 2 Project Motivation

Unitech staff contacted and subsequently visited the Community Group to investigate and discuss the technical feasibility and desirability of developing a micro hydro-power project to serve the Centre. During discussions, it rapidly became clear that the Community Group had little understanding of the technicalities or implications of the proposed micro hydro-power project. They had not

considered electricity as a development option until Mr Yang brought the subject to their attention after hearing the radio broadcast. The leaders of the Community Group therefore relied heavily upon the judgement of Mr Yang, in whom they had a great deal of trust. Nevertheless, the people were enthusiastic about the project, perceiving that the provision of lighting to the school and teachers houses would make it possible to attract higher calibre staff to the school with beneficial effect upon their childrens education. It was also hoped that some productive use could be made of the power at the tradestores and that the project would prove to be a profitable venture. It was anticipated that an emergency radio link would be established as part of the project and interest was also expressed in the possibility of lighting being provided at the church in the nearest of the villages, Baindoang (I.3).

For their part, those involved from Unitech, were keen to see a pilot low-cost, reliable and community sustainable project developed which would lead to increased community self-sufficiency and improved local development. To this end, it was seen as important that the community be fully involved in project planning and implementation. The project was seen as providing valuable practical experience, both for the staff involved and for final year students. It was also hoped to combat a perceived urban bias among some students by demonstrating that their technical training could be usefully used in the rural environment (I.4) .

I.3. Details of the Design of Stage One of the Umbang Project

It was decided to proceed with the development of a micro hydro-power project to serve Umbang. The provision of lights at Baindoang church was not considered feasible, because of the transmission distance involved, and it was anticipated that the load at the Umbang would be about 5 kW, see Table I.1.. Design proceeded on the basis that a low-cost and simple project was desirable. However, it was felt that good operational reliability of the completed project was of over-riding importance since major repairs in such an

isolated location would be both difficult and expensive and because unreliable performance would jeopardize project acceptance.

Table I. 1. Electrical Load Forecast for Uimbang Regional Centre

<u>Site</u>	<u>Items</u>	<u>Load in kW</u>
School	Lights (12 x 40W)	0.48
	Power Point For Projector etc.	1.0
Aid Post (Proposed)	Lights (2 x40 W)	0.08
	Fridge	0.2
	Water Heater	0.5
Tradestore	Lights (3 x40 W)	0.12
	Freezer	0.5
Houses (20)	Lighting Only (4 x 25 W Each)	2.0

TOTAL		4.88

Source: Rural Electrification in Papua New Guinea: Assessment of a Pilot Micro Hydro-Electricity Project, Kaye Bowman, Ph. D. Thesis, Australian National University, 1985.

As completed the project utilized flow from the Menemateun Creek. A low dam was constructed across the creek about 170 m in elevation above the power house. It is of earth construction with an impermeable membrane of corrugated roofing sheet and incorporates a scour drain and concrete spillway. From the submerged intake 600 m of 80 mm diameter heavy duty PVC pipe was laid to the power house site in a trench that was subsequently back-filled with sieved soil. Concrete anchor blocks were used at 12 m intervals. Because the lower section of the penstock was being used at above its rated pressure a bursting disc was installed outside the power house to

relieve pressure in the event of a pressure surge caused by rapid valve closure etc.

The power house foundation, its lower walls, the machine plinth and the first few metres of the tailrace were of reinforced concrete construction. The super-structure was timber framed and iron clad. Because of the heavy emphasis placed upon project reliability, a single jet Gilbert Gilkes and Gordon pelton unit was installed to operate under a full flow of 8.35 litres/sec and net head of 152 metres. The unit was directly coupled to a Markon 240 V single phase alternator rated at 7.2 kW at a power factor of 0.9. No conventional governor was purchased since this was seen as being expensive, complex, and likely to prove unreliable. Initially, a constant base load of 3.6 kW was applied to the generator and the voltage and frequency of the generator output were found to remain within reasonable limits as minor lighting loads were switched in and out. An electronic load controller developed at Unitech was later installed to provide better system control. To prevent turbine run-away, a relay was installed at the power house which was designed to switch in an emergency dump load if for any reason the normal load fell below a set threshold. Both a spear and gate valve were installed in the power house to control flow to the turbine.

Distribution from the power house to Umbang was at the generated voltage and by buried cable. The constant base load was provided by a water heater in the wash house and shower block constructed as part of the project (I.5, I.6, I.7).

I.4. Project Implementation

Implementation of the project commenced in November 1976 on the basis that the Community Group was to provide the water and land resources involved in the project, 10% of the equipment costs, and voluntary labour during the construction period. Unitech were to design the scheme, procure the necessary equipment and provide the technical skills and supervision needed for its implementation. They would also obtain 90% of the project costs from various overseas

sources. It was agreed that all 14 villages making up the community group would own, control and have access to the power at the centre.

Two project managers were appointed to organize work on the project. Mr Yang (the school teacher) acted as the local manager with responsibility for organizing labour from the villages and for supervising much of the non-critical manual work, such as excavation of the trenches for the penstock and distribution cables. Allen Inversin acted as the Unitech based manager. He was a staff member at ATDI and, not having a teaching role to fulfil, he had a more flexible time-table than other interested staff. Much of the work of designing, organizing and implementing the project was undertaken by him. He was responsible for obtaining the materials and equipment necessary in constructing the scheme, for arranging air-freight to the centre, and for on-site supervision of many of the more technically demanding aspects of the project. However, a significant contribution was made by other Unitech staff and by students especially during the vacation periods.

No strict work schedule was used and implementation proceeded at an easy pace with intermittent haltages. The scheme was completed in May 1979. The materials and equipment cost of the completed project was K 10,720, see Table I.2.. This did not include any provision for the input from Unitech staff and students or the cost of their travel to and from the site (I.8, I.9).

I.5. A Proposal to Expand the Micro Hydro-Power Project

At about the time that the project, as originally envisaged, was completed, the Department of Minerals and Energy became interested in the possibility of extending power to the nearest and largest of the 14 villages, Baidoang. The DME was of the opinion that the provision of electricity to villages was not a high development priority, but it was keen to undertake a before and after study of its impact upon a rural village to confirm their judgement. The installation of a transmission line to supply power to Baidoang seemed an ideal way of doing this.

Table I.2. A Breakdown of Material and Equipment Costs for Stage One of the Ubang-Baindoang Project

<u>Item</u>	<u>Cost in Kina</u>
Penstock and Dam	1,160
Power House	230
Turbine and Generator	5,440
Cable from Power House to School	1,190
Cable from School to Airstrip	590
Electrical Components	390
Water Pipe	210
Washing Facilities	530
Miscellaneous	290
Airfreight	690

TOTAL	10,720

Source: Technical Notes on the Baindoang Micro-Hydro and Water Supply Scheme,
 Allen. R. Inversin,
 Appropriate Technology Development Unit, 1980.

The DME was prepared to pay for the construction of a high voltage transmission line to Baindoang. During April 1979 a meeting between staff from the DME and leaders from the 14 villages comprising the Ubang Community Group was held at Ubang to discuss this proposal. It was made clear to the village leaders that the limited power of the micro hydro-power project and the high cost of transmission ruled out the possibility of further villages receiving power. After much discussion, the village leaders agreed to the extension of power to Baindoang provided that the Baindoang community committed itself to contributing both labour and finance to any future micro hydro-power projects that might be developed to serve the other villages (I.10).

I.6.

Implementation of Stage Two of the Micro Hydro-Power Project

With the decision to proceed, the Department of Electrical and Communication Engineering at Unitech was appointed as the DME's agent to design the transmission system, procure necessary equipment and supervise its installation. The people of Baidoang were to provide unskilled labour on a voluntary basis.

Baidoang is located about 2 km from the existing power house and power was to be delivered to the village via an 11.7 kV Single Wire Earth Return (SWER) Line. Survey of the transmission route, design and equipment procurement proceeded through late 1979 and early 1980. Installation of the line commenced in March 1980 and a member of staff from the Department of Electrical and Communication Engineering was allocated full-time to the project at this stage. He was supported by further inputs from other staff and students at weekends. The transmission line was completed towards the end of April and lights were installed in the Aid Post to demonstrate the system to the villagers.

At this point it became clear that poor communications between the DME, Department of Electrical and Communication Engineering and village had resulted in some confusion over the final form of the project. The Department of Electrical Engineering had understood that the project was to include the provision of reticulation to the village houses, whilst the intention of the DME was to supply the village with an equal access electricity supply. This was not provided by the high voltage line alone, and some form of low voltage distribution within the village was necessary. But, the DME was not prepared to fund household connections.

Baidoang village comprises the main village area and a smaller sub-village, Norkalang, located several hundred metres from the main village. As a compromise the DME suggested that:

- a) that they would fund a low voltage distribution system to both the main village and Norkalang. In which case the villagers would themselves have to fund any household connections.
- b) that the low voltage distribution system be restricted to the main village and that the money saved by not supplying Norkalang be used to fund household connections within the main village.

The village leaders agreed that, to avoid any intra village disunity, the distribution system should encompass Norkalang. However, this decision had been made without full consultation of the village members among whom it created widespread resentment. Nevertheless the project proceeded on this basis and an overhead distribution system was completed in September 1980. The equipment cost of the completed transmission and distribution system was K 8,663 and a further K 3,310 was paid to the Department of Electrical and Communication Engineering, by the DME, for its design and installation services (I.11, I.12).

I.7. The Performance of the Uambang-Baindoang Project

The Uambang-Baindoang micro hydro-power project remains operational. However, it continues to be reliant upon support from Unitech and it has not been uncommon for the scheme to be out of operation for extended periods. In particular an extensive re-habilitation of the project was undertaken during 1985/86. There has been limited development of end uses for the power generated, and none of them have offered any income generating potential. The researcher funded by the DME to investigate the impact of the Baindoang connection has suggested that the funds used to implement both stages of the project could have been better used if allocated to other development initiatives (I.13).

I. 7. 1. Power Use at Umbang

As completed, Stage One of the project included the provision of light fittings and several power points in the classrooms of the community school. The five teachers houses were also provided with lighting. An emergency radio set was installed at the headmaster's house with a battery and trickle charger to ensure continued operation should the hydro system fail. The wash house was the centre of the reticulation system and was fitted with a water heater (which acted as the system's constant base load), shower units, lights, a power point and switch board. Reticulation was also extended to two tradestores (and at a later date to a third), but these paid a connection fee of K 50 each. A similar connection fee was also paid for the installation of two street-lights within the school grounds and by the only village house connected to the supply. There had been some interest in installing freezers at the tradestores, but in the event none were purchased. It appears that two of the tradestores were operating at a loss and that profits from the third were used by the owner to finance construction of a permanent materials house. No other uses for power at Umbang had developed by mid-1986.

The washing facilities and hot showers are well used and have resulted in a reduction in the level of skin disease found, especially among children attending the community school. The lighting installed in the teachers housing is also well used, as is the radio. But, little use is made of the lights provided at the school or in the tradestores (I. 14, I. 15).

I. 7. 2. Operation and Management of Stage One of the Project

Unitech and ATDI envisaged that, after completion, the project would be handed over to the Community Group which would operate, and carry out basic maintenance and repair work on it. Tariffs collected from power consumers would be sufficient to pay for major repair services provided by either Unitech, or later the Morobe Provincial Mini Hydro Programme.

During implementation, Mr Yang and Dopeke (another school teacher local to the area) had been given some on-the-job training in the operation and technicalities of the project. Because of his closer involvement, Mr Yang's understanding of the project was significantly better than that of Dopeke and with completion responsibility for operating and maintaining the project was largely assumed by him. But Mr Yang was not local to the project area and had already accepted a demotion in order to remain in the community to see the project completed. He was aware that he would shortly be leaving and therefore encouraged Dopeke and another man from Baidoang to become more involved in project operation.

As the project neared completion K 600, collected from members of the community, had been deposited in a savings account to cover future operating and maintenance costs. An informal system of tariff collection, from power consumers, was also established under which the school was to be charged K 15.00 pa, the teachers K2.50/month and the tradestores and village house were expected to make a contribution reflecting their power use. Mr Yang also assumed responsibility for the financial management of the project. He unsuccessfully sought volunteers to take over this task, the role subsequently being forced upon the executive members of the schools Parents and Teachers Committee (I. 16, I. 17).

Mr Yang left Umbang towards the end of 1980. After his departure revenue collection from power consumers became erratic. The reliability of the project also suffered and its continued operation became both technically and financially dependent upon the support of the Department of Electrical and Communication Engineering at Unitech (I. 18, I. 19).

I. 7. 3. Power Use at Baidoang

With completion of the low voltage distribution system at Baidoang the villagers paid for the installation of lights in their church. One street light was also installed in the village by Unitech free of charge. Funds were required for further connections. A submission

for such funds was made to the Local Government Council, but was refused. In an attempt to obtain funds for further lighting installations the people of Baidoang village took control of the weekly market held at the community school at Umbang. Stall-holders at the market paid a fee of 20 toea to the school. But the land on which Umbang was sited had originally been controlled by the people of Baidoang and in late 1980 they decided to re-locate the market and use the money collected from stall-holders to pay for communal appliances in the village. Understandably this move was not popular with people from the remaining villages and the revenue generated was limited. Further sums were raised from donations by the people of Baidoang, but the Umbang Electricity Fund Account provided the main source of finance for further appliance purchases. The use of these funds was again unpopular.

By January 1982 the funds raised had been used to pay for the installation of a further 6 street-lights (making a total of 7) in the village, additional lights had also been installed in the church. The village aid post had been provided with lights and a power point by Unitech and 4 houses had been supplied with lights after paying a connection fee of K 50 each. No effective system of tariff collection was in operation. Towards the end of 1982 a major fire at Baidoang destroyed much of the village. Much of the low voltage distribution system was also damaged. Rebuilding of the village was a slow process and the most of the village remained disconnected from the hydro-power supply until 1986 (I.20, I.21, I.22).

I.8. Recent Project Re-Habilitation

A new member of staff, Charles Kiewiet, joined the Department of Electrical and Communication Engineering in 1985. He became interested in the Umbang-Baidoang project and subsequently became involved in a major re-habilitation of the project aimed at making it more reliable, and less reliant upon Unitech for future support. At the power house a new brushless generator was installed and the turbine bearings replaced.

At Umbang the underground distribution system had persistently created problems, the insulation being eaten through by ants on several occasions. The underground line from the power house to the wash house was therefore replaced with an 11.7 kV overhead line. Within the centre much of the distribution system was also replaced by overhead line. The load controller has been removed and the system again operates on a constant load: constant flow basis.

At Baindoang the low voltage distribution system was repaired, damaged street-lights replaced and several additional units installed. In addition, the installation of a water supply and wash-house with hot showers is currently underway.

Efforts were made to train two young men from Baindoang in project operation and maintenance. Two teachers from the school had also enthusiastically become involved, but, since neither is local to the area they cannot be relied upon in the longer term. Efforts were also being made to establish a formal system of tariff collection from consumers of power (I.23, I.24, I.25).

I.9. Conclusions

The Umbang-Baindoang project is technically the most successful of the village micro hydro-power schemes. But its impact on the communities served has not been dramatic or entirely beneficial. No income generating end uses for the power generated have been developed so that the project has not resulted in any real development. The use of lighting at both Umbang and Baindoang has resulted in some social benefits, but it is worth noting that;

- a) if regular tariff collections from consumers had been made, then at the level of lighting used, kerosene lamps would have provided a cheaper source of light.
- b) the installation of street-lights at Baindoang was largely motivated by the need to be seen to be utilizing

the power provided, and so avoid the ridicule of neighbouring villages.

The project, especially the extension of power to Baindoang has been divisive. The land on which the hydro-power project is built and on which Umbang is sited was originally controlled by Baindoang. In a number of instances this fact has created difficulties. Thus, Baindoang has effectively vetoed the establishment of any business ventures at Umbang not initiated by themselves. The extension of power to Baindoang and the subsequent activities of the village in trying to raise funds for street-lights further divided the Community Group. Within the village the project has also been divisive. The fact that only the four wealthiest households within the village could afford to have lighting installed introduced a status distinction into an otherwise egalitarian community (H. 26, H. 27, H. 28, H. 29, H. 30).

The continuing reliance of the project upon support from Unitech highlights the need for an effective training programme covering, project operation, maintenance, repair, and financial management, and for the establishment of an appropriate management structure, if projects are to be sustainable at village level. Unitech has made several efforts to provide such training. But training takes time and much of Unitech's support work has been provided in short weekend visits when the pressure to complete a particular repair has often meant that time could not be spared to involve the would be trainee effectively. No real attention has been given to management structures.

The project also demonstrates the need to provide information on and encourage the use of a range of power consuming devices, preferably with income generating potential. Projects are more likely to be sustainable where end uses contribute to the economic welfare of the community.

Appendix J. The Ogeranang Micro Hydro-Power Project

J.1. Background Information on Ogeranang

Ogeranang is a remote community located towards the centre of the Huon Peninsula and is the site of the first and only micro hydro-power project implemented under the Morobe Provincial Mini Hydro Programme. The Bulum valley lies within the Pindiu Local Government Council area and has a total population of about 5,000. Ogeranang lies above, but is the most important of the valley's 19 villages. Ogeranang has an airstrip, around the north end of which there are several tradestores, a small hospital and several clusters of housing. Along the north eastern side of the airstrip are several more tradestores, a post office, a bank agency, some coffee stores, a church, the council offices and more housing. At the southern end of the airstrip lies most housing, beyond that the school, and beyond that another area of housing where a workshop with a small diesel driven saw bench is located (J.1, J.2).

During the mid-1970's Ogeranang was under-going a period of rapid change. A government primary school had been established there during 1973/4 and the airstrip was opened in 1975. In the same year Tingnau Mandan, formerly a Curriculum Adviser with the Education Department and local to Ogeranang, was appointed as headmaster of the school. He was a dynamic character and under his influence the Bulum Valley Development Association was formed. All coffee trees of the members were pooled and an attempt to harvest the complete crop made. This allowed some revenue to be used on a number of projects aimed at benefiting the community. Thus, by October 1976 the school facilities had grown significantly to include several weather and corrugated iron teacher's houses, two substantial bush material teachers house's, four bush material classrooms, store-rooms, a saw bench shelter, a community centre, student living quarters, plus basketball and soccer playing fields. A two storey classroom building was also being constructed and the community had hired a Dolmar saw to cut the necessary timber. Several further projects were planned including (J.3, J.4):

- a) a permanent materials community centre
- b) a large workshop
- c) additional permanent teacher housing
- d) a post-primary community education centre
- e) the purchase of a coffee hulling machine to raise the value of the crop.

J. 2. Micro Hydro-Power Investigations

At the invitation of Tingnau Mandan, C. W. Perrett from the Department of Electrical and Communication Engineering, Unitech, made three visits to Ogeranang during 1977 to investigate the feasibility of constructing a micro hydro-power project to supply the village. A suitable site was identified about 3 km from Ogeranang where the Kemaip river, with a measured flow of 400 l/sec, enters short a steeply descending gorge. Flow diverted from the river could be fed into a power canal constructed along a bench on the righthand wall of the gorge. At the far end of the gorge a penstock could be routed down a steep rock face to create a head of about 20 m. Thus, in excess of 20 kW could be developed at the site (J.5).

The decision to proceed with the Ogeranang project was largely influenced by the evident dynamism of the centre at that time. This dynamism included the operation of a small diesel generator-set to provide lighting at the school and teacher's houses. A film projector, hand drill and grinder were also in use and it was anticipated that future loads would include lights and freezers in several of the tradestores, lighting at the church and community centre, coffee drying and processing, a small saw-mill and planer, water supply and water heating. At a later date it was anticipated that the transmission system would be extended to include several other nearby villages (J.6).

During late 1979 and early 1980 survey and design work for the project had been proceeding from Unitech. Construction work began, in earnest, after Easter 1980 with David Talbot acting as on-site supervisor. A work programme was drawn up in which it was envisaged that the project's civil works would be completed by the end of November 1980, followed by commissioning of the project during 1981 (J. 7).

In fact the project civil works were not completed until the end of 1983 and the scheme was not commissioned until January 1985. Not only was completion of the project significantly delayed, but a large cost over-run was also experienced. Thus, the original cost estimate for construction of the project, including transmission to Ogeranang had been K 15,000, whilst the final cost has been estimated at over K 100,000 (J. 8). The reasons for the delays and cost over-runs incurred in implementing the project include the fact that:

- a) both the original cost estimate and work programme were probably unrealistically optimistic.
- b) the project was intended to be, but in fact was not, undertaken on a community self-help basis. The people of Ogeranang had been expected to contribute voluntary unskilled labour, locally available materials and K 4,000 towards implementation of the project. Although initially there was enthusiasm for the project and some voluntary labour was forthcoming, this situation rapidly changed and it became necessary to pay labourers working on the scheme. It has been estimated that the cost of this labour was about K 25,000 and the K 4,000 contribution from the people of Ogeranang was never collected (J. 9).
- c) the effective village leader, Tingnau Mandan, was elected to the provincial government during 1980. No strong

leader took his place and this contributed to the decline in village co-operation. It has also been suggested that, having supported the election of Tingnau Mandan, the people of Ogeranang expected some display of gratitude from him, in the form of payment for their work on the hydro-power project (J. 10, J. 11).

- d) because the provincial government did not recruit or allocate staff to the programme Unitech was forced to accept greater responsibility for the project than it could effectively handle. This, particularly the lack of a permanent on-site supervisor, not only slowed progress but soured relations, especially after the departure of David Talbot (J. 12).
- e) slow progress at implementing the project further reduced the enthusiasm of the people of Ogeranang (J. 13).
- f) detail project design was not completed before implementation commenced. Particular aspects of the project had to be designed as implementation proceeded. Because of this, equipment and materials could not be ordered sufficiently in advance to avoid delays (J. 14).
- g) this situation was exacerbated by the fact that responsibility for design and implementation passed through several hands each with their own idea of how best to proceed (J. 15).
- h) lack of suitable on-site supervision for much of the implementation period, meant that productivity was low, that often work undertaken did not follow the design with the result that on several occasions jobs needed re-doing, or designs modifying (J. 16, J. 17).

As completed the micro hydro-power project features a low rock and mortar construction dam, designed to raise the level of water behind its crest sufficiently to allow diversion of flow into the power canal constructed along the bench in the gorge wall. From the intake at the dam a semi-circular flume, 20 m in length and constructed of galvanized iron sheet supported on parallel box section steel beams and circular steel posts carries diverted flow to the main power canal.

The main power canal is rectangular in section and of reinforced concrete construction. It runs along the bench in the gorge wall and although it incorporates a settling tank, with drain, at a wider section of the bench, it has no appreciable forebay area. The power canal runs to the end of the gorge and from there the penstock steeply descends a rock face. The penstock is of 300 mm internal diameter PVC pipe, with a wall thickness of 10 mm and is mounted on concrete anchor blocks.

The turbine is a cross flow unit designed by Rik Hothersall at Unitech and manufactured in Lae for K 1,000. It is designed for a flow of 250 litres/sec and head of 20 m. It and the generator are mounted on an angle iron base. The generator is a 415/240 V, 50 Hz, 3 phase Markon brushless unit, Type B354B, rated at 25 kVA at a power factor of 0.8. The unit is driven at 1,500 rpm by a 2:1 step-up flat belt drive. Output from the generator is fed into a control panel in the power house incorporating 3 over-current trips and circuit breakers. From there power is carried by 2 twin core underground cables approximately 350 m to the top of a nearby ridge. Here a cardomom drying shed was constructed and a load controller installed. It was intended that the controller would use heater elements in the cardomom drying shed as dump loads. However, the load controller has never been commissioned. Instead the heater elements of the drier act as a constant base load and the voltage and frequency are allowed to fluctuate in response to changing consumer load.

From the cardomom drying shed, two phases are carried by buried cable to the centre of Ogeranang. Here a 415/240 V step-down transformer is installed and distribution and reticulation within Ogeranang is also by buried cable. Power is distributed to 5 tradestores, the school, parish office, health centre, teachers houses and several other houses (J.18, J.19, J.20, J.21,).

The decision to transmit power to Ogeranang at low, rather than high, voltage was taken in the light of the large cost over-run that had occurred in completing the civil works. It had also been planned that a small scale industries centre would be developed in conjunction with the hydro scheme. This has not happened because:

- a) the delays and cost over-runs involved in completing the project meant that both funding and patience were in short supply by the time of its completion.
- b) the manpower necessary to establish the proposed centre and train people to operate and manage the various enterprises was not readily available.
- c) since Tingnau Mandan had been elected to the provincial government, the community had been lacking the type of strong leadership to which it had become accustomed and had lost much of its earlier dynamism.

J.5. Project Operation

Since commissioning the scheme has operated intermittently. Cracks developed in the welds on the turbine runner soon after it was commissioned and it was returned to Lae for repairs. Several months after these repairs had been completed the runner was again damaged, this time beyond repair, by debris entering the penstock. A replacement was fabricated and installed at a cost of K 1,000. However, in mid-1986 this new runner was damaged when the turbine ran away after failure of the belt drive. This caused failure of the turbine's bearings which allowed the runner to run off centre and

wear against a guide vane. The damage was substantial and consideration was being given to replacing the unit with a commercially available alternative. As a result of these, and several other minor problems, as of August 1986 the scheme had been out of operation for almost half of the period since commissioning (J. 22, J. 23, J. 24).

As the scheme approached completion there was some debate about what arrangements should be made for its operation and maintenance. It was suggested that the provincial government should recoup some of the capital costs sunk, by taking a percentage of any revenue collected from consumers. But, this proposal was not accepted and the scheme was handed over to the Community Government which is now the official owner of the project. It is responsible for providing the funds for maintaining the scheme and financing any further developments of it. As such it should be collecting revenue from consumers of power, however, it is claimed that the scheme has been so unreliable that this has been neither justified or possible (J. 25, J. 26).

The scheme has not been used at full capacity and only about 6 kW is normally generated. Of this about 4 kW is dumped into the heaters in the cardomom drier. The lighting and re Fridgeration load at Ogeranang is normally only about 1 kW. The drier has been used on several occasions, but is not well designed with a lack of ventilation and tendency to scorch the crop and produce an unevenly dried sample. At present most of the cardomom produced is therefore sun dried and of low quality. At the current level of power use, even if the scheme were operating reliably, the tariff collected from consumers would not be sufficient to cover plant operation and maintenance costs. These costs have so far had to be met by the Community Government and, rather than being seen as a benefit to the community, the scheme is seen as a financial burden, at least to the Community Government. Enthusiasm for the scheme is fairly low and no individual has been prepared to commit themselves to seeing that it is properly managed. Tingnau Mandan, although dis-satisfied with the scheme, remains keen to see it developed (J. 27, J. 28, J. 29).

The immediate priorities are to improve the project's reliability and develop commercial loads at Ogeranang and at the drying shed site. Several proposals are under consideration to this end. Cardomom has relatively strict drying requirements and premium grade cardomom commands a significant premium. However, prices are variable and during 1986 the market price for premium grade produce fell from K 25/kg to K 5/kg. The value of sun-dried cardomom fell to K1.00/kg. However, local cardomom plantings increased significantly in anticipation of the electrical drier becoming operational and an efficient drier, if developed, would still have a significant impact upon the income of local producers, and improve the economics of the hydro-power project through revenues collected from drier users.

The possibility also exists of setting up a cardamom oil extraction operation. The value added in the processing operation and the reduced bulk and transport costs of oil would help to maximize the growers income from low grade sun-dried cardamom. The small saw bench and planer still exist at Ogeranang. In addition a 'Wokabout Somil' (portable sawmill) has been ordered and there has been some talk of establishing a furniture making workshop close to the existing drying shed. Initially it would supply the local market only, but as skills developed it might become practical to export output to the Lae and Finschhafen markets (J. 30, J. 31).

J. 6. Conclusions

The delays and cost over-runs incurred in implementing the Ogeranang project discouraged the Morobe Provincial Government from further investments in micro hydro-power projects. At Ogeranang two results of this were that; a) the project was not satisfactorily completed and b) the proposed small-scale industries centre was not established. The present low voltage transmission system and lack of governing limit the potential for load growth at Ogeranang. Unless income generating end-uses for the power generated can be developed at the present cardomom drier site it seems unlikely that the project will generate significant benefits for the community, and may act as a drain on Community Government resources.

The problems encountered with the project highlight the need for an appropriate support agency to become involved not only in project implementation, but also project establishment. The lack of such support at Ogeranang has hindered the development of a suitable management system and, given the projects unreliability, has prevented the collection of tariffs from consumers. Without further support it appears unlikely that the income generating end-uses for the power generated will be developed.

Appendix K. The Anga Region: Micro and Mini Hydro-Power Projects
and Investigations

K. 1. Background to the Anga Region

The Anga region is centred on the Menyamya and Aseki areas of Morobe Province, but extends to Watut on the Slate Creek and includes areas of the Eastern Highlands and Gulf Provinces. It is predominantly inhabited by the Kukuku people and in 1978 the region's total population was estimated at 77,000. The region is extremely rugged and mountainous with steep slopes and deeply incised valleys. This fact, combined with the fierce independence and fighting skills of the Kukuku people meant that colonial exploration and contact with the region did not occur until a fairly late date (K. 1).

With the development of the Wau-Bulolo gold-fields, prospectors began to penetrate the area. In 1933 a temporary patrol post and airstrip were established at Menyamya to allow prospecting to go ahead under Administration protection. However, results of the prospecting were disappointing and the camp was subsequently abandoned. There was little further ex-patriate activity in the area until after the Second World War when some patrolling of the area was carried out from the newly established post at Mumeng. In 1950 Menyamya was re-established as a permanent station and a further patrol post was established at Aseki in 1962/63 (K. 2).

Lutheran mission stations were also set-up in the area, at Menyamya in 1951, and at Aseki in 1958, prior to the establishment of the patrol post there. Further Lutheran mission stations were subsequently established around Menyamya at Kwapalim, Concordia and Kapo. A Seventh Day Adventist mission was also established at Menyamya. The mission stations were ex-patriate staffed and between them became largely self contained with schools, health facilities, stores, workshops, power supplies etc..

At present the district is administered from Menyamya with Aseki being a Sub-District Office. The Anga people of the Upper Watut

Valley and Slate Creek are administered from Wau. The area is one of the least developed of Morobe Province in terms of economic activity and the provision of social services..

During the late 1960's work started on the construction of a road to link Aseki to Bulolo and hence Lae. The project was funded through the Rural Improvement Programme and labour intensive methods were used with construction proceeding from both ends of the road. By 1974 less than 50 km had been constructed and it was not until 1980 that a penetration road to Aseki was finally completed. A year later the Anga Development Authority (ADA) was established by the provincial government to act as its rural development agent in the area. It's objectives were to improve the regions social and economic infrastructure, broaden its economic base, and increase the self-reliance of the area and it's people. The ADA has offices in both Menyama and Aseki and, to date, it's principal effort has been directed towards up-grading and maintaining the road link from Aseki to Bulolo. The track to Menyama has also been up-graded and there are plans to construct or up-grade several further roads within the area. In addition to this activity, ADA (K.3, K.4, K.5):

- a) operates a small saw-mill to provide timber for its construction projects.
- b) operates mechanical and carpentry workshops.
- c) operates a nutrition and agricultural extension service aimed at improving subsistence gardening and introducing small livestock projects.
- d) operates a trading arm and coffee buying operation intended to reduce costs of bought in items and offer a higher price to growers than commercial buyers would offer.
- e) is involved in the provision of basic health care.

- f) plans to establish a coffee processing enterprise to retain the value added processing within the region.
- g) plans to establish a high school at Menyamya.

K. 2. Micro and Mini Hydro-Power within the Region

There has been significant interest in micro hydro-power in the region. A mission micro hydro-power project has been developed at Kwapalim and several feasibility studies have been carried out for projects to supply power to Menyamya and Aseki.

K. 2. 1. The Kwapalim Micro Hydro-Power Project

Kwapalim is located about 13 km west of Menyamya and is accessible from there by a rough track which is suitable for four wheel drive vehicles only. A Lutheran mission station was established at Kwapalim during the early 1960's and was closely linked with the other mission stations in the area. To meet the mission's power needs a micro hydro-power project was implemented at Kwapalim during the late 1960's. The scheme incorporated a rock fill dam with a clay core to divert flow from a tributary of the Tauri River into an unlined power canal about 280 m in length. This led into a large settling pond from which the 370 mm diameter steel penstock led to the power house. Installed in the power house was a twin jet pelton unit operating under a gross head of about 20 m. The turbine drove a 25 kVA 3 phase generator. The power house was located only about 50 m from the mission station so that distribution within the station was at the generated voltage.

The micro hydro-power project successfully met the mission's power needs until 1975 when the ex-patriate missionary from Kwapalim, together with several others from the other local mission stations, left the country. Shortly after this the hydro-power project fell into dis-repair as did many of the other mission facilities in the area. However, the church and many of the mission buildings remain in use at Kwapalim and a health centre has been established there by ADA. The ADA is keen to install an electricity supply at Kwapalim to

supply power to the health centre and they have expressed an interest in renovating the micro hydro-power project. Although the derelict scheme had an installed capacity of 25 kW, the current demand is for only about 2 kW and this is not expected to increase significantly. Renovation of the existing scheme would be a major project involving construction of an intake structure, renovation of the power canal, replacement of the penstock and power house, generator, governor, switch gear, and distribution system. It would therefore be more appropriate to proceed on the basis of constructing a scheme designed to meet the required load only. The ADA are also interested in developing micro hydro-power projects of similar scale to serve their other health centres. However, the scale of the project indicates that photovoltaic cells may well provide a viable alternative to the development of hydro-power resources. During 1987, Charles Kiewiet from Unitech was approached by ADA to investigate the feasibility of several of these projects (K. 6, K. 7, K. 8, K. 9).

K. 2. 2. Aseki

Aseki currently acts as the sub-district headquarters of Menyama District. It has a range of government facilities, a community school associated with the Lutheran mission and is also the location of the ADA's mechanical workshop, portable saw-mill, and one of its tradestores. It is a 'C' centre with two 25 kVA diesel generator sets installed to meet its electricity needs (K. 10, K. 11, K. 12).

The Onangi creek which runs along the edge of the township has several potential micro hydro-power sites within reasonable distance of the centre. The possibility of developing one of these to supply the centre was first investigated by Elcom in 1972/73. At that time there was no official electricity supply at Aseki, but the Lutheran mission ran a 6 kVA diesel generator set and the Officer in Charge of the station also operated a private 2.2 kVA generator. A 10 kW scheme was proposed to serve the centre alone, but it was suggested that, if the mission were interested in purchasing power from the hydro-power project, a 25 kW project be developed. Funding from the

national government's Capital Works Programme was with-held while it was ascertained whether the mission was interested in buying power from the proposed project. The result of this investigation is not known but the proposal for the micro hydro-power was subsequently dropped and a diesel generator set installed (K. 13).

During 1980 another micro hydro-power project feasibility study was undertaken at Aseki under the Morobe Provincial Micro Hydro Programme. The proposed scheme utilized flow from the Aseki river, a tributary of the Onangi Creek and a scheme of up to about 15 kW could be developed at the site. This would have satisfied Aseki's existing peak demand of about 11 kW, but left little scope for future expansion (K. 14).

No immediate action was taken over this report, largely because of the problems being experienced with the provincial government programme (K. 15). But in 1982, a further feasibility study was undertaken. This study looked at a site where the Onangi Creek descends over a series of waterfalls. The head available was 102m and flow was estimated at 250 l/sec. This gave the potential to develop 150 kW at an overall efficiency of 60%. However, from an examination of rainfall records covering the period 1960 to 1971 it was estimated that only 53 kW would be available for much of the dry season (K. 16).

By this time ADA's saw-mill, tradestore and mechanical workshop had been established at Aseki and the road construction unit was also based there. As a result, the load on the centre's 25 kVA diesel generator set had increased and it was operating at close to capacity. The station was continuing to expand and there were plans to install a second diesel generator. In addition, the ADA had plans to develop a coffee mill at Aseki to process the region's coffee crop and to expand its saw-milling and timber processing operations. If developed these projects were expected to add significantly to the centre's power demand and the construction of a 100 kW hydro-power project was therefore proposed to meet demand over a reasonable period. Development of the site would involve

construction of a diversion weir feeding water, via a headrace channel 200m in length, into a forebay and hence into a penstock, 300 mm in diameter and 140 m in length. It was proposed that a locally manufactured cross flow turbine be used to direct drive an imported alternator. However, it is suggested that it would also have been feasible to re-habilitate and install the pelton unit currently installed at Kwapalim.

The cost of the project was estimated as being between K 55,000 and K 80,000 depending on the extent of the distribution system. To reflect the probability that only a limited amount of capital would be available for micro hydro development in the province and that the development of further sites would depend on revenue from electricity sales at the initially funded sites, it was assumed that it would be necessary for the scheme to pay back its capital costs over a 5 year period at an interest rate of 13%. It was concluded that the scheme appeared to be financially viable if a significant industrial load could be developed to improve the load factor. It was recommended that the installation at Aseki should be proceed given the centre's projected increase in demand, particularly from ADA's proposed power consuming industries. Other factors favourable to the project were the fact that it had existing road access, that it was a relatively cheap site to develop, that in ADA there was a suitable organization to look after scheme operation and maintenance (and possibly to develop it), and that in addition to its potential economic viability the project operated as a diesel replacement scheme (K.17).

The Aseki project was therefore adopted by the Morobe Provincial Micro Hydro Programme as its next site for development. A submission for funding of the project was made to the Executive of the Provincial Government in 1983, but the difficulties being encountered at Ogeranang and the subsequent collapse of the Morobe Provincial Micro Hydro Programme meant that implementation of the project did not proceed (K.18).

Menyamya, with a population of about 300, acts as the headquarters of Menyamya District. In 1980 the official electricity supply at Menyamya was met by two 25 kVA diesel generator sets, but the area west of the airstrip which included the DPI and Forestry offices and the vocational centre were not connected to this supply. Both the Lutheran and Seventh Day Adventist missions operated their own generator sets. The official generator was over-loaded meeting existing demand and the installation of two 40 kVA units was being proposed. However, it was estimated that including the two missions there was a total latent demand at the station of about 100 kVA (K. 19, K. 20, K. 21).

By 1986 the ADA's main workshops had been established at Menyamya and a high school was under construction. Power demand had therefore continued to grow and further growth was expected. A 75 kVA and two 40 kVA diesel generators had been installed to meet the official supply (K. 22, K. 23, K. 24).

A potential hydro-power site capable of meeting the centre's power demand had been identified by 1979 and was the subject of feasibility studies in 1984 and 1986. Both studies examined a site located about 5 km from Menyamya near the Concordia mission and proposed similar layouts. Thus, it was proposed that flow diverted from the Menya Creek would be fed into an open headrace channel contouring the valley side and through a saddle into the valley of the Tauri River. In this way a head of 80 m could be developed. The 1984 study was undertaken by Dick Burton, director of ATDI. Based on estimates of available flow, he proposed the development of a 100 kW scheme. This would be sufficient to meet Menyamya's forecast load in the initial years only and supplementary diesel generation would later be required. The 1986 study was carried out by MacDonald Wagner Pty Ltd under the Mini Hydro Resource Inventory and, using higher estimates of available flow, proposed the development of a 150 kW scheme which would be capable of meeting Menyamya's forecast power demand over a 20 year period (K. 25, K. 26).

Project costs were estimated by MacDonald Wagner Pty Ltd using a conventional engineering approach, with the detail design prepared by consultants and the project implemented by contractors. The study by Dick Burton, was based on the use of labour intensive techniques with much of the unskilled labour and basic supervision being provided by staff and students of the vocational centre at Menyamya. Professional engineering input would be limited to site survey, detail design, marking out the site, and supervision of critical aspects of the work such as installation of the penstock and electro-mechanical equipment. As a result (K.27, K.28), there was a significant difference in the specific costs of the two projects, see Table K.1..

Economic analysis of the 100 kW scheme, over a 20 year period, indicated that on a diesel replacement basis it offered a positive Net Present Value of K 283,810 (including the discounted residual value of the scheme) (K.29). Details of any economic analysis of the larger scheme were not available to the author. However, if for the 150 kW scheme it is assumed that:

- a) the overall load growth forecast will be the same as that used in the analysis of the 100 kW scheme.
- b) annual energy production will be 90% hydro-based.
- c) the remaining 10% will be generated by supplementary diesel generators at a cost of K 0.45/kWh (the same figure as used in the analysis of the 100 kW scheme).
- d) a new 64 kVA diesel generator set be installed in year 4 of the project and replaced in year 14.
- e) the cost of diesel generation (in the event of the hydro-power project not being developed) is the same as that used in the analysis of the 100 kW scheme.

Then it would appear that the NPV of the project after a 20 year period is K 32,486 (including the discounted residual value

of the scheme), see Table K.2.. The project is therefore marginally attractive. However, if continued stream gauging confirms that sufficient flow is available, the development of the scheme on the same basis as that proposed for the smaller scheme would generate significantly greater savings.

Table K.1. A Cost Comparison of Two Potential Mini Hydro-Power Projects to Supply Menyanya

<u>Item</u>	<u>MHRI Study</u> <u>Cost in Kina</u>	<u>ATDI Study</u> <u>Cost in Kina</u>
Weir, Intake and Settling Tank	27,700	3,000
Headrace	40,000	8,000
Forebay	9,500	3,200
Penstock	13,200	40,000
Power House	30,000	4,000
Access Road	8,000	8,000
Sum of Civil Costs	146,400	66,200
Civil On Cost	90,000	-----
20% Contingency	47,000	13,250
Electro-Mechanical Equipment	130,000	18,000
10% Contingency	13,000	1,800
Transmission	98,000	60,000
Total Works	524,700	159,250
Engineering Cost	40,000	18,000
Overall Total	564,700	177,250
Installed Capacity in kW	150	100
Specific Cost in Kina/kW	3,765	1,773

Figure K.2. A Net Present Value Analysis of the Proposed Government Mini Hydro-Power Project

Year	Forecast Annual Generation in kWh	Proposed Hydro-Power Project with Diesel Back Up					Alternative Diesel Generation				Difference in Cost	Discount Factor	Present Value
		Diesel Generation @ 10% of Total	Capital Cost in Kina	Operation and Maintenance Costs	Fuel Cost in Kina @ K 0.45/kWh	Total Cost in Kina	Capital Cost in Kina	Operation and Maintenance Costs	Fuel Cost in Kina @ K 0.45/kWh	Total Cost in Kina			
1	78,840	7,884	564,700	11,00	3,548	579,248	25,000	4,000	35,480	64,480	-514,768	0.909	-467,924
2	105,120	10,512		11,00	4,730	15,730		4,000	47,300	61,300	35,570	0.826	29,380
3	131,400	13,140		11,00	5,913	16,913	25,000	8,000	59,130	92,130	75,217	0.751	59,497
4	134,028	13,403	25,000	11,000	6,031	42,031		8,000	60,310	68,310	26,279	0.683	17,948
5	136,656	13,666		11,000	6,150	17,150	20,000	8,000	61,500	89,500	72,350	0.621	47,413
6	139,284	13,928		11,000	6,268	17,268		8,000	62,680	70,680	53,412	0.564	30,124
7	141,912	14,191		11,000	6,386	17,386		8,000	63,860	71,860	54,474	0.513	27,945
8	144,540	14,454		11,000	6,504	17,504		8,000	65,040	73,040	55,536	0.467	25,935
9	148,482	14,848		11,000	6,682	17,682		8,000	66,810	74,810	57,128	0.424	24,222
10	151,110	15,111		11,000	6,800	17,800	50,000	8,000	68,000	126,000	108,000	0.386	41,765
11	153,338	15,374		11,000	6,919	17,918		8,000	69,180	77,180	59,268	0.350	20,744
12	157,680	15,768		11,000	7,096	18,096		8,000	70,960	78,960	60,864	0.319	19,416
13	160,308	16,031		11,000	7,214	18,214	25,000	8,000	72,140	105,140	86,926	0.290	25,208
14	162,936	16,294	25,000	11,000	7,332	43,332		8,000	73,320	81,320	37,988	0.263	9,991
15	166,876	16,688		11,000	7,509	18,509		8,000	75,100	83,100	64,591	0.239	15,437
16	169,508	16,951		11,000	7,628	18,628		8,000	76,280	84,280	65,892	0.218	14,312
17	173,448	17,345		11,000	7,805	18,805		8,000	78,050	86,050	67,245	0.198	13,316
18	177,390	17,739		11,000	7,983	18,983		8,000	79,380	87,830	68,847	0.180	12,392
19	180,018	18,002		11,000	8,101	19,101		8,000	81,010	89,010	69,909	0.164	11,489
20	183,960	18,396		11,000	8,278	19,278		8,000	82,780	90,780	71,502	0.149	10,653
Residual Values			-299,350				-7,500				-291,850	0.149	43,486
Net Present Value Including Discounted Residual												32,729	

Conclusions

No road connection currently exists between Lae and Port Moresby. But, such a connection will eventually be developed and it is likely to pass through the Anga region and probably through or close to Aseki (K. 30, K. 31). The construction of this road will have a major impact upon the area and the extent to which this impact is beneficial will largely depend upon the extent to which the region has developed a strong economy and identity. The ADA has had a significant impact in the area. The organization appears well-managed and the benefits of development can be expected to become more widespread as ADA's initiatives continue and as the local road network is developed.

Given the importance of strengthening the regional economy prior to the development of the Port Moresby to Lae road link, the case for encouraging the growth of one of the two regions main centres (ie, Aseki or Menyamya) is strong. It has been argued that the limited capacity and high cost of electricity at both centres has restricted their growth. Thus, at Aseki the centres generators are over-loaded, while at Menyamya the missions, vocational centre, and several of the governments offices are not connected to the electricity supply. In addition, power is not available 24 hours/day at either centre and this restricts power use for productive purposes at the ADA workshops etc.. The development of industrial and commercial uses for power is more likely at either Aseki or Menyamya than many other 'C' centres because of ADA's direct involvement in enterprises and because of the stimulus it provides to the area. Although the ADA has not yet developed their proposed coffee mill, by late 1986 they had received government approval to proceed with the project. However, the project is now to be developed at Watut on the edge of the Anga region (K. 32). This location offers short term advantages, in terms of savings in transport costs. But, location of the mill at Aseki or Menyamya would be more effective at strengthening the core of the region and it seems likely that its development would have gone ahead at Aseki if the hydro-power project had been developed there.

The Morobe Provincial Micro Hydro Programme is now defunct and development of the Aseki hydro-power project is unlikely in the near future. In addition, Menyama is the larger of the two centres and is the target of further development initiatives. Given these facts it seems desirable that a hydro-power project to serve Menyama be developed under the DPRP if its economic viability is confirmed.

Appendix L. The Nawong Micro Hydro-Power Project

L.1) Introduction

Nawong village lies approximately one hours walk from Mindik airstrip in the centre of the Huon Peninsula. The village is relatively small, comprising about 25 households, and is closely tied to the larger nearby village of Hamoronong. The village is the site of the second of three micro hydro-power projects installed in the Pindiu area during the mid-1970's (L.1, L.2).

L.2) Project Details

The scheme was initially surveyed by Ian Bean during August 1977. Work on the scheme started soon afterwards and was completed in February 1978. The total cost of materials involved in its construction was K 1,180, of which K 680 was collected from members of the community. As originally constructed the scheme incorporated a temporary boulder weir diverting flow from a nearby stream into a natural channel running roughly parallel to the original stream course. After a distance of about 100 m an earth dam was constructed across this channel, raising the water level behind it sufficiently for an unlined power canal to be led off along a bench cut into the hillside. This power canal was about 250 m in length and fed into a large settling pond (originally stocked with fish). From the settling tank water entered the penstock of 100 mm diameter PVC pipe and exited through a 25 mm PVC reduction fitting set in cement. The scheme operated under a gross head of 21 m and a design flow of 12 l/sec. The turbine used was a crude pelton unit constructed at the Finschhafen vocational centre. It operated in a constant load, constant flow mode and drove a 1 kW generator via a belt drive utilizing an intermediate shaft. The power house was of bush material construction and a timber turbine and generator mounting frame was used.

The power house was located about 250 m from the centre of the village and power transmission to, and distribution within, the

village was at the generated 240 V. An underground system, without conduit, was used and all houses within the village were provide with light fixtures (L.3, L.4).

L.3. Scheme Operation

Initially Ian Bean was responsible for maintenance of the project although it was intended to train village operators to carry out routine maintenance and minor repairs. But, Ian Bean left Papua New Guinea towards the end of 1979 before any serious training had been undertaken. A request was made to Unitech that they undertake to look after the management of the schemes. In addition, Risieve Mumengte the DPI Officer based at Pindiu had a better understanding the project than anyone in the village and was able to undertake some basic repair and maintenance work (L.5, L.6).

Unitech did become involved in some maintenance and up-grading work at Nawong and the other two projects implemented by Ian Bean and it was hoped that the centralized repair and maintenance facility proposed under the Morobe Provincial Micro Hydro Programme would eventually take over this role. However, this facility was never established and the provincial government did not provide any financial support for Unitech's maintenance activities.

The scheme operated fairly successfully until late 1979. It would not appear that any system of tariff collection from consumers had been initiated to pay for future system repairs or expansion. After Ian Bean's departure, the Department of Electrical and Communication Engineering undertook to provide occasional technical assistance to the project. However, it was concerned that the low standard of the projects distribution and reticulation system had serious implications with respect to the Department's liability should an accident occur. In addition, poor communications with the village and other commitments of the Department's staff meant that there were often substantial delays in responding to requests for assistance. Combined with the limited technical training of the villagers this meant that the reliability of the project suffered.

Shortly after Ian Bean's departure the installed Honda generator is reported to have burnt out, burning down the power house in the process. A new power house was subsequently constructed and a new generator installed by Unitech staff in early 1980. In May 1980, during a visit to the project by Unitech staff the villagers expressed an interest in supplying power to the community school at Hamoronong, about 2 km in distance, and in connecting several further lighting loads within the village. But, given the restricted output of the scheme, the supply of power to the school was not considered feasible. At the time the output of the scheme was restricted to 220 W at about 175 V by partial clogging of the trash rack. As a result, there was some doubt that the project would be capable of meeting any further lighting load in Nawong, especially as the fixtures obtained by the villagers were fluorescent and so would not start if voltage was to remain significantly below 240 V.

By November 1981 the Nawong scheme was out of operation. The power canal had been blocked by a landslide which had not been cleared and seepage problems were being encountered along that section of the canal that still contained water. The roof of the power house had largely collapsed and as a result the interior was damp and moss covered: the bearings had not been greased, the belts were slack and the generator was out of order. The generator was removed by Unitech staff and returned to Lae where it was overhauled as a 4th year student project. It was suggested that if the villagers were prepared to clear the landslide, re-habilitate the power canal, and repair the power house, then Unitech would arrange a subsequent work party to re-install the generator, repair and up-grade some sections of the distribution system and fit over-voltage and over-current protection at the power house.

Closure of the Mindik airstrip prevented further visits to the project by Unitech staff or students during much of 1982. But, by the end of 1982 the power canal had been re-habilitated and a new bush material power house had been constructed by the villagers. Unitech staff and students installed the overhauled generator in the new power house and removed a partial blockage of the penstock. In

early 1983 it was found that excessive field current was overheating the generator. A modified excitation system was subsequently installed in which field current was directly controlled by a variac. Much of the project's distribution and reticulation system was also up-graded at this stage.

With this work complete it was agreed that the people of Nawong would open a bank account, the contents of which would be used to pay for future maintenance and repair costs and to fund any further extensions of the project, there still being several houses within the village that were not connected to the power supply. There is no record of the method by which the community intended to raise the cash to meet these future costs. However, shortly after the modified excitation system was fitted, the generator again failed. Failure of the generator was followed by flooding that completely destroyed the earth dam and partially destroyed the banks of the natural channel feeding water towards it. Since that time the scheme has remained out of operation (L.7, L.8).

L.4. Conclusions

In mid-1986 the author and Noel Mohiba (from the Department of Electrical Engineering, Unitech) visited the village, at the request of two village leaders, to look into the feasibility of rehabilitating the project. By this time the power house had again collapsed, much of the distribution and reticulation system had been damaged beyond repair and the light fittings lost. Re-habilitation of the scheme would have required its almost complete re-construction at an estimated cost of about K5,500 (L.9). Given the problems previously encountered with this and other village micro hydro-power projects its re-construction does not seem warranted given:

- a) the lack of a support agency to supervise re-construction and provide on-going maintenance and repair support.

- b) the limited output, and hence limited scope of the project, especially with respect to income generating end uses.
- c) the apparently limited enthusiasm for the project of many of the village inhabitants (L. 10).
- d) the cost of re-construction, much or all of which would have to be met by the villagers.

M. 1. Introduction

Faseu village lies in the interior of the Huon peninsula. The village consists of two settlements Old and New Faseu separated by about half a kilometre. New Faseu is the larger of the two and contains about twenty houses, a church, aid post and a disused school building. Old Faseu contains about ten houses. The village economy is semi-subsistence. Some coffee is grown and more recently a small amount of cardamom has been planted. The village is about one hours walk from the newly opened Finschhafen to Pindiu road. Previously access was by walking track from either the Masa or Pindiu airstrip. There is a proposal to build a road from Korbau on the Finschhafen to Pindiu road through Faseu to Masa. This road would be partially community financed with additional funds coming from the Rural Improvement Programme (R. I. P.) (M. 1, M. 2, M. 3).

Nearby Korbau is the site of the first of the Pindiu micro hydro-power projects and Faseu is the home village of Mr Yang, the headmaster of the community school at Umbang over the period that the micro hydro-power project was implemented there. As a result of the Korbau micro hydro-power project and Mr Yang's enthusiasm for the Umbang-Baindoang project, the people of Faseu became interested in the idea of developing a micro hydro-power project to serve their village. They contacted Unitech about the idea and a feasibility study for a micro hydro-power project was subsequently carried out under the Morobe Provincial Micro Hydro Programme. A potentially suitable site was identified, but as the programme became more concerned with the economic viability of projects, interest in supporting the scheme declined (M. 4, M. 5, M. 6, M. 7).

The villagers, supported by Mr Yang and a Business Development Officer from the village but based in Lae, have nevertheless remained interested in the idea of developing a micro hydro-power project. They see the project as serving several objectives and in interview were not prepared to give any one of these objectives

priority. Their stated objectives are to obtain a source of power for domestic lighting, for operating a small sawmill and for operating an electric cardamom drier. The villagers see both the possible road and the hydro scheme as providing opportunities for improving their standard of living through increased economic activity (M. 8, M. 9).

The villagers continued interest in developing a micro hydro-power project led to further feasibility studies being undertaken in 1984 and 1986 by Professor Woodward, previously head of the Department of Electrical and Communication Engineering at Unitech (M. 10), and the author respectively.

M. 2. Hydro-Power Project Details

The schemes proposed in both studies used the same site and were very similar in most respects. The scheme would utilize flow diverted from the nearby Woninzozo stream by a low rock and mortar weir sited immediately above the point where the stream descends steeply through a small gorge to join the Gobang river. From the weir flow would be diverted into a settling tank and hence into a 150 mm diameter PVC low pressure pipeline approximately 70 m in length and routed along a level bench to the top of a fairly steep bank. From this point heavy duty pipe of the same diameter would be used to carry water about 60m down the bank and into the power house. The power house would be built on a terrace above the Gobang river. After flowing through the turbine the diverted water would be returned to the Gobang river.

The gross head available at the proposed site is 31.5m. Readings over several months from a primitive notch weir, and several spot flow measurements from earlier visits indicate a mean flow of about 14l/sec at the site with recorded flows varying between 8 and 24 l/sec. Using the mean flow and assuming a turbine efficiency of 70% and an overall efficiency of 55% the expected power output of the project would be 2.9 kW mechanical or 2.3 kW electrical (M. 11, M. 12, M. 13, M. 14).

The terrace on which the power house would be built is located about 700 m from New Faseu. The proposed sawmill would be mechanically driven by the turbine and so would be located in, or adjacent to, the power house. To minimize transmission costs the proposed cardamom drier would also be located adjacent to the power house. Transmission to both New and Old Faseu would be for domestic purposes only and would be at 240V, using locally cut timber poles (M. 15).

The materials, equipment and transport costs that would be incurred in completing the project were estimated in 1986 as K 17,000. However, it would be possible to undertake the project in three phases. The first of these would involved construction of the weir, settling tank and power house and installation of the low pressure pipeline, penstock, turbine and saw-bench. With this section of the scheme completed the saw-mill could be operated, and if successful the revenues generated used to fund subsequent installation of the cardomom drier and transmission to, and reticulation within, Old and New Faseu (M. 16).

M. 3.

Project Feasibility

From a technical point of view the proposed micro hydro scheme is feasible and fairly straightforward. The relatively low rate of flow in the Woninzozo stream does, however, impose limits to the scope of the scheme. the limited power available means that diversification of end uses beyond those outlined would be difficult. In spite of its limitations the villagers are enthusiastic about the scheme and it would undoubtedly offer opportunities for improving their standard of living. By June 1986 they had raised in excess of K1,200 to fund either the micro hydro-power project or the road construction project. However, implementation of the micro hydro-power project is likely to be dependent upon the support of an outside agency prepared to assist in fund-raising and in supplying the necessary technical and management skills. These services are unlikely to be made available by Unitech and no other agency is

currently actively involved in supporting village micro hydro-power projects within the country (M. 17, M. 18, M. 19, M. 20, M. 21).

Should the scheme be implemented the problem of project maintenance, repair and financial management remains. For the scheme to be viable further inputs would be necessary to ensure that an adequate management structure was established within the village. At Faseu it has been suggested that a registered business group would be set up with responsibility for the hydro-power installation, the cardamom drier and the saw-mill. This group would maintain the project and collect tariffs from power users (M. 22).

M. 4. An Alternative Proposal

It may be argued that the potential benefits of the micro hydro-power project could be better met by other means. Thus, a simple, low-cost, wood-fired cardamom drier, as developed by the Appropriate Technology Development Institute, could be constructed. This would cost only about K 200 to construct, and could be financed from the villagers existing resources. The drier would require minimal outside input and should produce dried cardamom of an equivalent quality to that of an electric drier and would result in a significant increase in income to members of the community. The drier might be managed by a business group established for the purpose and a charge made to individual users. Some of the proceeds from operating the drier could then be used to help finance other community projects (M. 23).

One of these community projects might be the purchase and operation of a 'Wokabout Somil' from Village Equipment Supplies (VES), Lae. This is a hand portable sawmill which uses an 18 hp petrol engine to drive vertical and horizontal circular blades with replaceable tips. Its maximum cut is 250 mm by 100 mm and it offers several advantages over the hydro-power driven alternative. Being more powerful it would have a significantly greater output. But, perhaps more importantly it is portable and so can be moved to where supplies of, and demand for, timber exist, thus partially overcoming the problem

of Faseu's remoteness from a market. It could thus be used to meet the demand for sawn timber in several other villages within the locality and would allow the utilization of timber felled during garden clearing operations. The 'Wokabaut Somil' therefore has significantly greater income generating potential than the hydro-power driven alternative and while based at Faseu would provide enough waste material to fire the cardamom drier.

In mid-1986, the cost of a new 'Wokabaut Somil' was K 5,500 (slightly less than the cost of installing the first phase of the hydro-power project) and commercial loans were available for their purchase. Although the Wokabaut Somil is a relatively complex piece of machinery, its purchase price includes a three week training course for two operators. A comprehensive spares and back up service is also available. Mr Yang currently owns and operates two such sawmills in the Lae area, and several men from Faseu have gained experience of the sawmill by working with him. These factors combine to suggest that the Wokabaut Somil could successfully be managed by the villagers (M. 24, M. 25, M. 26).

The third objective of the micro hydro-power project, the provision of domestic lighting in Old and New Faseu, could be satisfied by using photovoltaic panels in conjunction with rechargeable hand held fluorescent lanterns. 10 W panels roof mounted at each house would charge hand held 6 W single tube fluorescent lanterns fitted with ni-cad cells. The ATDI has conducted a two year field trial of such a system with encouraging results. The photovoltaic panels are well proven and should have an indefinite life. Ni-cad cells can be expected to have a life of three years and the fluorescent lanterns six years. The lanterns produce about half the light of a Coleman lamp and daytime charging is sufficient to operate the lantern for 3-4 hours each evening. This has been found to be sufficient for most needs and the portability of the lanterns is appreciated by users.

The estimated costs of installing photovoltaic panels and lanterns at each household in Faseu is about K 5,000. This would be a major

expense to the villagers and it is unlikely that either agency funding or a commercial loan would be available. However, income generated by the cardamom drier and the sawmill could be used. The system could be installed gradually as funds become available either on a community or individual basis (M.27, M.28).

M.5. Conclusions

Both the micro hydro-power project and the alternative proposal are technically feasible. However, the alternative proposal is felt to be preferable. It is the lower cost option and has the potential to generate greater economic benefits for the community.

By developing the project progressively, starting with the cardamom drier, the project could be implemented without any significant reliance upon outside technical or financial support. In addition, the project is more likely to be sustainable by the villagers for the following reasons:

- a) the cardamom drier is simple and its construction and operation should be within the capabilities of the villagers.
- b) unless the cardamom drier is successfully managed both physically and financially it is unlikely that the second stage of the project will proceed. In the event of failure the losses incurred by the community will, thus, be minimized.
- c) with the training course provided, the operation and management of the sawmill should also be within the capabilities of the villagers.
- d) VES operates a spares and back-up service for the sawmill and repair costs should be covered by profits generated by the sawmill and cardomom drier.

- e) the maintenance requirements of the photovoltaic lighting system would be minimal. Faults often call for equipment replacement rather than repair.

- f) since the cardamom drier, saw-mill and lighting facilities are developed as independent systems a fault in one will not affect the operation of the others. In addition, a fault in one households lighting system would have no affect upon the remainder. The complete project need not therefore come to standstill because of some minor fault beyond the ability of the villagers to repair.

The need for significant technical and financial support in developing the micro hydro-power project is, in the absence of an appropriate support agency, likely to preclude its implementation for the foreseeable future. The development of the alternative proposal depends much more upon its acceptance by the villagers and upon their dynamism.

Appendix N. The Ambua Lodge Micro Hydro-Power Project

N. 1. Introduction

Ambua Lodge is a new hotel located on the edge of the Tari Basin, approximately 15 km outside Tari on the road to Mendi. The hotel offers accommodation in 20 individual chalets containing either two single or double and single rooms. The main building offers restaurant facilities, lounge area and bar. All buildings are constructed using semi-traditional techniques (N.1).

A micro hydro-power scheme has been installed to supply power to the hotel. It was designed by Bob Bates, manager of the company (N.2).

N. 2. Hydro-Power Scheme Details

The scheme operates under a gross head of 77 m with a design flow of 50 l/sec. A temporary loose boulder weir is used to divert flow from a large stream into the scheme's intake structure. From this point a stone and mortar lined power canal, 320 m in length, leads to the penstock intake which incorporates no appreciable settling area and only a crude trash rack. The penstock is of 150 mm diameter PVC and about 400 m in length. It follows a shallow gully to the power house site and is mounted in several concrete anchor blocks. The power house incorporates a large concrete anchor block and the power house floor and machine plinth are also of concrete construction. The structure is timber framed and clad with corrugated iron.

The scheme utilizes a Tamar Design turgo impulse turbine, which operates with a single jet, but has provision for the addition of a second jet should additional power be required. In this case installation of an enlarged or second penstock would be required. The turbine directly drives a single phase Markon brushless generator of 26 kVA capacity. The power house lies only 150 m from the main hotel building and power transmission is at 240 V by buried cable that follows the penstock route for much of its length. System

control is achieved with an electronic load controller which is situated in the main hotel building (N. 3, N. 4).

N. 3. Scheme Operation and Problems

A number of teething problems have been encountered with the scheme. Initially, turbine output was restricted by the inability of the tailrace to pass full load flow. Subsequent enlargement of the tailrace increased output to about 14 kVA, but this remains below the design output of 17 kVA. In an attempt to further increase output, installation of a modified nozzle is planned. It has also been necessary to install a damping resistor in the load controller to prevent power surges under full load conditions.

Erosion along the penstock route has exposed several of the anchor blocks. This has resulted in some movement of the penstock and the failure of one of the joints. If the problem is not to re-occur remedial action is required (N. 5, N. 6, N. 7).

N. 4 System Loads

The hydro plant normally acts as the sole power source for the Lodge. The scheme provides power for all the hotel's internal and external lighting. Electric cooking facilities are also used, and a normal cooking load is about 7 kW. In addition two large freezers, three fridges, a large washing machine and a clothes drying room draw power from the scheme.

Two hot water systems are installed in the main hotel building. One of these supplies the building's hot water requirements, while the other supplies an under-floor heating system to the main restaurant, lounge and bar areas. Hot water elements in both these systems constitute the dump loads that are switched in and out by the load controller in response to changes in consumer load. The main hot water system in the building also has elements that can be switched in or out independent of the load controller.

Six independent hot water systems, each with a 400 W immersion heater, supply hot water to the chalets. Electric blankets are also provided. The chalets are at present unheated, but installation of heaters is planned should the capacity of the scheme be expanded.

The output of the hydro-power scheme is insufficient to cope with the simultaneous connection of all loads and some load shedding is necessary. Thus, for example, when the cookers are in use, it is necessary to dis-connect the water heating load in the central building. Similarly, it is not possible to cook and use the clothes drying room at the same time.

A 10 kVA diesel generator has been installed to act as a standby in case of system failure. One gas cooker has also been installed and a large open fire in the hotel's lounge area is capable of keeping that area warm (N.8, N.9).

N.5. Project Economics

The viability of the micro hydro-power project must be assessed on the basis of a comparison with alternative energy sources. An attempt is made below to compare the hydro-power scheme costs with those of a diesel generator.

The original budget for implementing the hydro-power scheme was K 20,000. A full breakdown of real costs was not available, however, Chris Rose, who was responsible for supervising work on the project, estimates that the eventual cost was about K 30,000 (N.10, N.11).

When the hotel was first opened, the hydro scheme was incomplete and the 10 kVA standby diesel generator was used as the main power source. It was operated from 6.30 to 10.30 am and again from 4.00 pm to 10.30 pm. The limited generator capacity and the lack of 24 hours/day power created significant inconvenience to both staff and guests at the hotel (N.12).

If diesel was to provide the main source of power to the hotel, it is assumed that a larger diesel generator with a capacity of 20 kVA would be purchased, at an estimated cost of about K 7,500, to minimize inconvenience (N.13). In addition, the number of hours of operation would be increased. The assumed hours of operation are from 6.30 am to 12.00 pm. Using these hours of operation, an average load of 10 kVA and a diesel generator conversion rate of 2.6 kWh/litre of fuel consumed, the daily fuel consumption of the unit would be about 70 litres (N.14).

In June 1986 a 200 litre drum of diesel at Tari cost K 112 (N.15). The resulting annual fuel cost of diesel generator operation would therefore be about K 14,500. For both the hydro and the diesel options plant operation would be carried out by existing hotel staff so that no costs are ascribed to this.

The above analysis indicates that the hydro-power scheme should prove to be a cost effective source of power for the hotel. It should have a payback period of less than three years when compared with the diesel generation based alternative. In addition, the hydro-power scheme should have a significantly longer useful life than a diesel set.

Appendix O. Basic Information on Other Micro and Mini Hydro-Power Projects

O. 1. Other Mission Schemes

Bema, Gulf Province, 20 kW.

Bena Bena, Eastern Highlands, Supplies power to a school.

Bundi, Madang Province. This Catholic Mission scheme supplies power to the mission compound which includes, accommodation, a community school, a tradestore, mechanical and carpentry workshops, a social centre and a carpentry training centre (not in use). The scheme was implemented in the early 1970's and operates under a head of 49.5 m, with a design flow of 210 l/sec and has an installed capacity of 90 kVA. The scheme remains in use but lack of water restricts output to about 40 kVA for much of the year. Problems have been experienced with the collapse of head creating dam, subsidence of the forebay and unreliability of the governor. Project funding came principally from charitable sources.

Busama, Morobe Province, 20 kW, not operational, but in the past supplied power to a mission and mission run vocational training centre.

Det, Southern Highlands Province, 51 kW.

Heldsbach, Morobe Province, Lutheran Mission. A 48 kW scheme using a cross flow turbine and a second scheme using a 15 kW pelton unit are run in parallel to supply power to the mission facilities and a mission run plantation and its workshops.

Kagua, Southern Highlands, 7 kW.

Kaintiba, Gulf Province, 15 kW, not operational.

Kamulai, Central Prvince, 3 kW.

Kanabea, Gulf Province, 100 kW, supplies power to a mission run hospital.

Kegsugl, Chimbu Province, Catholic Mission. The 50 kW scheme supplies power to the mission compound which includes a carpentry training centre. Power is also sold to a sawmilling operation run by the Local Government Council. The scheme has been in operation for 20 years.

Kerau, Central Province, 6 kW.

Kuli, Western Highlands, Catholic Mission. The hydro scheme no longer exists.

Kudjip, Western Highlands. The 100 kW scheme supplies power to a mission run hospital.

Lae, Morobe Province, St Joseph's Technical College, 7 kW.

Mendi, Southern Highlands Province, Catholic Mission.

Mougulu, Southern Highlands Province, Evangelical Church of Papua. This 10 kW scheme was implemented in 1986 using a turgo impulse turbine and electronic load controller. Specific cost K 2,000/kW.

Minj, Western Highlands, Swiss Mission, water wheel.

Par, Enga Province.

Pureni, Southern Highlands, 3 kW.

Rugli, Western Highlands, Christian Radio Fellowship, 25 kW, implemented 1955.

Sapos, Enga Province, 30 kW, supplies power to a hospital.

Tari, Southern Highlands Province, Evangelical Church of Papua. A 37kW scheme operates under a head of 5.6 m and design flow of 840 l/sec. It utilizes a head creating dam and an Ossberger cross flow turbine. The scheme was implemented in 1974 using principally charitable sources of funding and Australian volunteer engineers. The specific costs of the scheme was about K 1,500 and it supplies

power to the mission offices and accommodation, two schools, and mechanical and carpentry workshops.

Tari, Southern Highlands Province, Catholic High School. The 36 kVA scheme operates under a head of 6 m and a design flow of 710 l/sec. It utilizes an Ossberger cross flow turbine and was implemented in 1976. The scheme supplies power to the school compound which has facilities for about 450 pupils (mostly boarders).

Tari, Southern Highlands Province, Hoyabia United Church Centre, 35 kW, not operational.

Togaba, Western Highlands, Seventh Day Adventist, 30 kW, not operational.

Ulap, Morobe Province.

Wapenamanda, Enga Province, Lutheran Mission, 100 kW, supplies power to a mission run hospital.

Wabag, Enga Province, 76 kW, supplies power to a high school.

Wasu, Morobe Province, 25 kW, supplies to a health centre.

Watut, Morobe Province, 200 kW, not operational. Yaibos, Southern Highlands, 97 kW.

O.2. Other Village Projects

Agaun, Milne Bay Province, 0.4 kW. Implemented by Father Clement Bateman who is resident in the village, the project utilizes a home built turbine (based on a tractor wheel) and supplies power to his home and the offices of a group of young villagers who have established a business group.

Gemaheng, Morobe Province, 1.5 kW. An Ian Bean project.

Korbau, Morobe Province. The 2.5 kW project was the first of those implemented by Ian Bean. It is no longer operational.

Kipu, Morobe Province. This 5 kW scheme was implemented by the Summer Institute of Linguistics. The project was intended to supply power to a carpentry workshop but has never been fully operational.

Molmoi, Morobe Province, 0.8 kW. Implemented by the Summer Institute of Linguistics the project is no longer operational.

Romsis, North Solomons Province. This 10 kW project was undertaken with assistance from the Univeristy of Technology, but never completed.

O.3. Other Private and Commercial Projects

Zenag, Morobe Province. This 20 kW scheme supplies power to a large chicken farm. Although still in use, diesel generators now provide the main source of power.

Barapa, Eastern Highlands Province, 20 kW. In the past the scheme powered a sawmill, but it has not been in use for a numbwr of years.

References

1. 1) The Economics of Development,
Gillis, Perkins, Roemer and Snodgrass,
W. W. Norton and Co,
1983.
1. 2) Locational Analysis in Human Geography,
P. Hagget, A. D. Cliff and A. Grey,
Edward Arnold,
Edition 2, 1977.
1. 3) Report on Development Strategies for Papua New Guinea,
Prepared by M. Faber, A. McFarquhar, J. Hart and
J. Diddens of the Overseas Development Group, University
of East Anglia for the World Bank and United Nations
Development Programme,
Papua New Guinea Office of Programming and Co-ordination,
1974, p. 22.
1. 4) Ibid. p. 23.
1. 5) 1. 2, op. cit.
1. 6) The Poverty of Development Economics,
Deepak Lal,
Hobart Paperback No. 16,
1983.
1. 7) 1. 2, op. cit.
1. 8) Agropolitan Development: Towards a New Strategy for
Regional Planning in Asia,
J. Friedman and M. Douglass (University of California),
Seminar on Industrialization Strategies and Growth Pole
Approach to Regional Planning and Development: The Asian
Experience,
United Nations Centre For Regional Development, Japan,
4th-13th November 1975.
1. 9) Rural Inequality and Regional Planning,
Richard Peet,
Systems of Cities: Readings on Structure, Growth and
Policy.
Editors: L. S. Bourne and J.W. Simmons,
Oxford University Press,
1978.
1. 10) The Organization of Space in Developing Countries,
E. A. J. Johnson,
Harvard University Press,
1978.

1. 11) The Village Entrepreneur: Change Agents in India's Rural Development,
W. G. Broehl Jnr,
Harvard University Press,
1978.
1. 12) The Community and Village Industries Programme of Papua New Guinea: A New Approach to Rural Small-Scale Industry Development,
Mursalin New,
Regional Seminar on 'Dissemination of Technology to Rural Communities',
UNESCO, FEISEAP, EIT, Chulalongkorn University,
16th-20th August 1982.
1. 13) Industrialization and Rural Development,
UNIDO, ID/215,
1978.
1. 14) Industrialization of Developing Countries: Problems and Prospects: Small-Scale Industry,
UNIDO, Monograph No 11,
1969.
1. 15) Industrial Location Theory: Its Relevance to an Industrializing Nation,
A. Gilbert,
Spatial Aspects of Development,
Editor; B. S. Hoyle,
John Wiley and Sons,
1974.
1. 16) 1. 10, op. cit.
1. 17) The Effectiveness of Industrial Estates in Developing Countries,
UNIDO, I. D. 216,
1978.
1. 18) Growth Poles in Spatial Planning,
M. J. Moseley,
Pergamon Press,
1974.
1. 19) Inertia of Spatial Structure of the Economy of the Colonial Type and Geographical Problems of its Overcoming,
Galina V. Sdasyuk,
Proceedings of the Third Polish-Soviet Seminar
Geographical Studies No. 141,
Warsaw 1979.

1. 20) Industrialization and Rural Development,
Report of the Expert Group Meeting on Industrialization
in Relation to Integrated Rural Development,
UNIDO, ID/WG.257/23,
1978.
1. 21) Small Business in the Third World,
M. Harper,
John Wiley and Sons,
1984.
2. 1) Necessary Conditions for the Success of Micro Hydro,
Professor J. L. Woodward,
Proceedings of the UNESCO Sponsored Workshop on Micro
Hydro Installations,
Papua New Guinea University of Technology,
8th -10th July 1986.
2. 2) The Power Guide; A Catalogue of Small-Scale Power
Equipment,
Compiled by Peter Fraenkel,
Intermediate Technology Publications,
1979.
2. 3) Energy Strategies for Developing Countries,
J. Dunkerley, W. Ramsay, L. Gordon and E. Cecelski,
A Book for Resources for the Future,
John Hopkins University Press,
1981.
2. 4) Electricity for a Developing World: New Directions,
C. Flavin,
World Watch Institute, Paper No 70,
1986, p. 5.
2. 5) Ibid. p. 34.
2. 6) 2, 3, op. cit.
2. 7) Energy in the Developing World: The Real Energy Crisis,
Editors Vaclav Smil and W. E. Knowland,
Oxford University Press,
1980.
2. 8) Rural Electrification in Developing Countries:
Development Discussion Paper No. 122,
Lalit K. Sen,
Harvard Institute for International Development,
October 1981.
2. 9) The Role of Rural Electrification in Development,
E. Cecelski and S. Glatt,
Centre for Energy Policy Research: Resources for the
Future/ Washington D.C.,
1982.

- 2.10) Report of the Regional Rural Electrification Survey to the Asian Development Bank, D. V. Smith, D. B. Menta, P. J. Hayes, Asian Development Bank, Manila, 1983.
- 2.11) 2.4, op. cit. p. 33.
- 2.12) Ibid. p. 34.
- 2.13) The Philippines: Rural Electrification Project Impact Evaluation, United States Agency for International Development, USAID No. 15 PN-AAH-976, 1980.
- 2.14) 2.9, op. cit.
- 2.15) 2.8, op. cit. p. 7.
- 2.16) 2.10, op. cit.
- 2.17) Ibid.
- 2.18) 2.8, op. cit. p. 2.
- 2.19) Evaluating Electrification Experience: A Guide to the Social Evaluation of Small Hydro-Electric Units in Lesser Developed Countries, AMARU IV Co-operative, National Rural Electric Co-operative Association, 1982.
- 2.20) Ibid. p. 23.
- 2.21) 2.10, op. cit.
- 2.22) 2.8, op. cit. p. 13.
- 2.23) 2.10, op. cit.
- 2.24) 2.8, op. cit. p. 12.
- 2.25) Ibid. p. 13.
- 2.26) 2.4, op. cit. p. 39.
- 2.27) 2.10, op. cit. p. VII.39.
- 2.28) Ibid. p. VII.29.
- 2.29) 2.9, op. cit. pp. 58-60.
- 2.30) 2.10, op. cit. pp. VII 7-19.
- 2.31) Ibid. p. VII. 13.

- 2.32) Ibid.
- 2.33) Ibid.
- 2.34) Ibid.
- 2.35) 2.4, op. cit.
- 2.36) 2.10, op. cit.
- 2.37) 2.8, op. cit.
- 2.38) Ibid.
- 2.39) Rural Electrification in South East Asia: A Comparative Study,
A. H. Finnegan,
Edinburgh University,
May 1985.
- 2.40) Rural Electrification in Papua New Guinea,
E. S. Dryer,
Papua New Guinea Electricity Commission,
1975.
- 3.1) Third World Electrification,
H. W. Whittington,
Proceedings of the Institution of Electrical Engineers
Special Issue: Engineering and Society,
Institution of Electrical Engineers,
1988.
- 3.2) 2.2, op. cit.
- 3.3) 2.3, op. cit.
- 3.4) 3.1, op. cit.
- 3.5) Renewable Energy Prospects,
Editors W. Bach, W. Manshard, W. Matthews and H. Brown,
Pergamon Press,
1980, p. 711.
- 3.6) 2.4, op. cit.
- 3.7) Energy and Human Needs,
S. C. Curran and J. S. Curran,
Scottish Academic Press,
1979.

3. 8) An Economic and Technical Appraisal of Micro Hydro for Rural Electrification,
A. R. Wallace, K. Whittaker, H. W. Whittington and D. E. Macpherson,
Proceedings the conference 'Power for National Development',
Kuala Lumpur,
April 1987.
3. 9) Appropriate Technology for Micro Hydro Generation,
A. R. Wallace,
Proceedings of the 21st Universities Power Conference,
Imperial College, London,
April 1986.
3. 10) Trends in Third World Hydro Development,
C. Flavin,
International Water Power and Dam Construction,
October 1986.
3. 11) Small-Scale Power Generation,
United Nations,
1968.
3. 12) 2. 2, op. cit. pp. 94-97.
3. 13) Small Hydro Needs Its Own Experts,
International Water Power and Dam Construction,
December 1982.
3. 14) Hydropower Engineering,
C. C. Warnick,
Prentice-Hall Inc.,
1984, p. 281.
3. 15) Ibid.
3. 16) Equipment for Small Hydro Schemes: A Review of Progress,
B. W. Leyland,
International Water Power and Dam Construction,
April 1987.
3. 17) Micro Hydro Sourcebook: A Practical Guide to Design and Implementation in Developing Countries,
Allen R. Inversin,
NRECA International Foundation,
1986, pp. 1-5.
3. 18) Mechanics of Fluids,
B. S. Massey,
Van Nostrand Reinhold Co.,
1976.
3. 19) 3. 13, op. cit.

- 3.20) Local Experience with Micro Hydro Technology,
Ueli Meier,
SKAT,
1981.
- 3.21) 3.17, op. cit.
- 3.22) Ibid.
- 3.23) Micro Hydro-Power Training Course for Engineers and
Technicians, Pokhara, Nepal,
Intermediate Technology Development Group,
1987, p. 4-1.
- 3.24) 3.17, op. cit.
- 3.25) Energy for Rural Development: Renewable Resources and
Alternative Technologies for Developing Countries,
Report of an Ad Hoc Panel of the Advisory Committee on
Technology Innovation, Board on Science and Technology of
International Development, Commission on International
Relations,
National Academy of Sciences,
1976.
- 3.26) 3.18, op. cit. pp. 456-460.
- 3.27) Micro Hydro Development for Papua New Guinea: M. Phil.
Thesis,
R. J. Hothersall,
Papua New Guinea University of Technology,
1984.
- 3.28) 3.25, op. cit. p. 38.
- 3.29) Small and Mini Hydropower Systems,
Editor J. J. Fritz,
McGraw-Hill,
1984.
- 3.30) Small Hydro Continues to Grow,
F. Acker,
International Water Power and Dam Construction,
February 1984.
- 3.31) 3.14, op. cit. p. 284.
- 3.32) Historical Overview of the Cross-Flow Turbine,
S. Khosrowpanah, M. L. Albertson and A. A. Fiuzat,
International Water Power and Dam Construction,
October 1984.
- 3.33) 3.20, op. cit.

- 3.34) Francis Turbines for Small-Scale Applications,
N. Roncke and J. J. Victory,
International Water Power and Dam Construction,
December 1982.
- 3.35) Hydro-Electric Engineering Practice,
Editor J. G. Brown,
Blackie and Son,
1965.
- 3.36) Appropriate Speed and Frequency Control for Micro Hydro
Plants,
J. L. Woodward,
Proceedings of the UNESCO sponsored 'Workshop on Micro
Hydro Installations',
Papua New Guinea University of Technology,
July 1986.
- 3.37) Generator Design for Small Hydro Applications,
F. J. Parker,
International Water Power and Dam Construction,
February 1982.
- 3.38) 3.23, op. cit. pp. 21-44.
- 3.39) Ibid.
- 3.40) The Stabilization of a Self-Excited Induction Generator
for Small Hydro Power Applications,
N. P. A. Smith, J. M. K. Pratt, and P. G. Holmes,
Proceedings of the 21st Universities Power Engineering
Conference,
Imperial College, London,
April 1986.
- 3.41) 3.35, op. cit. p. 204.
- 3.42) 3.14, op. cit.
- 3.43) 3.23, op. cit.
- 3.44) 3.35, op. cit.
- 3.45) Energy, Volume II,
S. S. Penner and L. Ickerman,
Addison Wesley,
1975, p. 500.
- 3.46) Mini Hydro-Power in the U. S. A.,
R. O. Haroldsen, and F. B. Simpson,
International Water Power and Dam Construction,
November 1981.

3. 47) Mini Hydro Power Stations: A Manual for Decision Makers, Prepared jointly by the UNIDO Technology Programme and the Latin American Energy Organization (OLADE), UNIDO/IS.225, 1981.
3. 48) 3. 30, op. cit.
3. 49) 3. 47, op. cit.
3. 50) 2. 10, op. cit.
3. 51) 3. 47, op. cit.
3. 52) Machinery and Equipment for Micro Hydro Plants, R. Holland, International Water Power and Dam Construction, November 1986.
3. 53) Nepal: Private Sector Approach to Implementing Micro Hydro-Power Schemes: A Case Study, Allen R. Inversin, National Rural Electric Co-operative Association, 1982.
3. 54) Pakistan: Villager Implemented Micro Hydro-Power Schemes: A Case Study, Allen R. Inversin, National Rural Electric Co-operative Association, 1983, p. 13.
3. 55) 3. 8, op. cit.
3. 56) 3. 10, op. cit.
3. 57) Prospects for Large and Small Hydro Development in Peru, P. Wicke, International Water Power and Dam Construction, July 1987.
5. 58) The Economic Limits of Small and Low Head Hydro, J. L. Gordon and R. C. R. Noel, International Water Power and Dam Construction, April 1986.
3. 59) Standard Design for Six Mini Hydro Sites in Indonesia, S. Crighton, G. L. Barker and J. M. Magyari, International Water Power and Dam Construction, April 1986.
3. 60) The Optimum Size of Run-of-River Plants, P. R. Gingold, International Water Power and Dam Construction, November 1981.

- 3.61) Recent Developments in Hydropower,
J. L. Gordon,
International Water Power and Dam Construction,
September 1983.
- 3.62) 3.35, op. cit. p. 191.
- 3.63) 2.8, op. cit.
- 3.64) Electrification Study of Gazelle Peninsula, New Britain,
H. L. Brush and A. A. Swanson,
National Rural Electric Co-operative Association,
1976.
- 3.65) Evaluating Electrification Experience,
AMARU IV Co-operative,
NRECA,
1982.
- 3.66) Ibid.
- 3.67) 3.17, op. cit. p. 4.
- 3.68) Ibid. p. 5.
- 3.69) 3.9, op. cit.
- 3.70) 3.20, op. cit. p. 148.
- 3.71) 3.17, op. cit. p. v.
- 3.72) 3.47, op. cit.
- 3.73) 3.20, op. cit. p. 142.
- 3.74) Manual for Industrial Project Analysis in Developing
Countries,
Little and Mirlees,
Organization for Economic Co-operation and Development,
1969.
- 3.75) Financial Requirements for Micro Hydro Projects,
Hans P. Schoener,
Proceedings of the UNESCO sponsored 'Workshop on Micro
Hydro Installations',
Papua New Guinea University of Technology,
July 1986.
- 3.76) Manual for Evaluation of Industrial Projects,
Prepared jointly by UNIDO and the Industrial Development
Centre of Arab States,
UNIDO ID/244,
1980.

- 3.77) Design and Installation Considerations for Micro Hydro-Electric Generating Systems,
K. R. Offord and P. Bryce,
Proceedings of the conference 'Power for National Development'
Kuala Lumpur,
April 1987.
- 3.78) 3.53, op. cit.
- 3.79) 3.77, op. cit.
- 3.80) 3.75, op. cit.
- 3.81) 3.75, op. cit.
- 3.82) 3.65, op. cit.
- 3.83) 3.75, op. cit.
- 4.1) Papua New Guinea,
Mursalin New and Paul R. Warpeha,
Proceedings of the UNESCO/FEISEAP/EIT/Chulalongkorn University Regional Seminar on 'Dissemination of Technology to Rural Communities',
August 1982.
- 4.2) Geology,
D. B. Dow,
Papua New Guinea Resource Atlas,
Editor E. Ford,
Jacaranda Press,
1974.
- 4.3) Paradise Lost? Rural Development in an Export Led Economy: The Case of Papua New Guinea,
Bryant J. Allen,
from Rural Development and the State,
Editors: D. A. M. Lee and D. P. Chaudhri,
Methuen, London,
1883.
- 4.4) Encyclopaedia of Papua and New Guinea,
General Editor P. Ryan,
Melbourne University Press in association with the University of Papua and New Guinea,
1972, pp. 479-485.
- 4.5) The Handbook of Papua and New Guinea,
Editor J. Tudor,
Pacific Publications,
1966, pp. 8-9.

- 4.6) Landforms,
E. Loffler,
Papua New Guinea Resource Atlas,
Editor E. Ford,
Jacaranda Press,
1974.
- 4.7) 4.4, op. cit. pp. 182-184.
- 4.8) New Guinea: The Territory and its People,
D. A. M. Lee and P. G. Irwin,
Oxford University Press,
1967.
- 4.9) An Investigation of Some Aspects of Tropical Lightning
and its Effect on the Design of Transmission Lines,
P. Greenwood, Ph.D. Thesis,
The Papua New Guinea University of Technology,
March 1982.
- 4.10) Rainfall in the Tropical South-West Pacific,
H. C. Brookfield and D. Hart,
Australian National University Press,
1966.
- 4.11) 4.4, op. cit. pp. 1163-1169.
- 4.12) Ibid. pp. 1065-1078.
- 4.13) Ibid.
- 4.14) Papua New Guinea: Problems and Prospects,
P. Hastings,
Australian Institute of National Affairs,
1973.
- 4.15) New Guinea on the Threshold: Aspects of Social, Political
and Economic Development,
Editor E. K. Fisk,
Longmans,
1966, pp. 150-152.
- 4.16) 4.14, p. cit. pp. 31-68.
- 4.17) The Small Towns and Outstations of Papua New Guinea,
David King,
Geography Department Occasional Paper (New Series No. 3),
University of Papua New Guinea,
1983.
- 4.18) The Role of the Private Sector in the Economic
Development of Papua New Guinea,
M. J. Trebillock,
Institute of National Affairs, Discussion Paper No. 13,
1983, pp. 2-12.

4. 19) The Challenge of New Guinea,
A. Grenfell Price,
Angus and Robertson,
1965, pp. 1-23.
4. 20) The Politics of Dependence: Papua New Guinea,
Editors A. L. Epstein, R. S. Parker and M. Reay,
Australian National University Press,
1971, pp. 20-30.
4. 21) Rural Electrification in Papua New Guinea: Assessment of
a Pilot Micro Hydro-Electricity Project,
Kaye Bowman, Ph.D. Thesis,
Australian National University,
1985.
4. 22) 4. 18, op. cit.
4. 23) 4. 3, op, cit.
4. 24) South Pacific Agriculture: Choices and Constraints: South
Pacific Agricultural Survey 1979,
Editors R. Gerard Ward and Andrew Proctor,
Asian Development Bank in association with the Australian
National University Press,
1980.
4. 25) Industrialization, Growth and Development in Papua New
Guinea,
Helen Hughes,
Institute of National Affairs, Discussion Paper No. 17,
1984.
4. 26) 4. 18, op. cit.
4. 27) 1. 3, op. cit.
4. 28) Rural Electrification a Comparative Study,
P. Greenwood, M.Sc. Thesis,
University of Stirling,
1977.
4. 29) Statistical Year Book for Asia and the Pacific,
United Nations Economic and Social Commission for Asia
and the Pacific,
Bangkok,
1985.
4. 30) 4. 18, op. cit.
4. 31) National Manpower Assessment 1982-92,
Department of Finance and Planning,
1986.
4. 32) 4. 18, op. cit.

4. 33) The National Expenditure Plan 1982-85,
National Planning Office,
1981.
4. 34) 4. 18, op. cit.
4. 35) 4. 24, op. cit.
4. 36) Ibid.
4. 37) World Fact Book,
Central Intelligence Agency,
1986.
4. 38) 4. 24, op. cit.
4. 39) 4. 18, op. cit.
4. 40) Papua New Guinea: Selected Development Issues,
World Bank,
1981.
4. 41) 4. 24, op. cit.
4. 42) 4. 40, op. cit.
4. 43) 4. 24, op. cit.
4. 44) 4. 33, op. cit.
4. 45) 4. 25, op. cit.
4. 46) 4. 18, op. cit.
4. 47) Public Sector Enterprises in Papua New Guinea,
M. J. Trebilock,
Institute of National Affairs, Discussion Paper No. 9,
1983.
4. 48) 4. 17, op. cit.
4. 49) Village Survey,
National Statistical Office,
1975.
4. 50) 4. 1, op. cit.
4. 51) Assessment of Run-Off and Hydro-Electric Potential,
Snowy Mountains Engineering Corporation,
1970.
4. 52) The World's Hydro Resources,
International Water Power and Dam Construction,
October 1986.

- 4.53) The Role of Engineering Geology in the Selection and Assessment of Sites for Mini Hydro-Power Schemes, Jonathan King, Proceedings of the UNESCO sponsored 'Workshop on Micro Hydro Installations', Papua New Guinea University of Technology, July 1986.
- 4.54) Hydropower Development Study of Papua New Guinea, Prepared by S. W. E. Pepler and S. I. Ramsahoye of the Shawinigan Engineering Co. Ltd., For the Asian Development Bank and the Government of Papua New Guinea, 1980.
- 4.55) Affordable Micro Hydros: A Critical Appraisal of Civil Works Costs, A. R. Yadav and R. N. Welsford, Proceedings of the UNESCO sponsored 'Workshop on Micro Hydro Installations', Papua New Guinea University of Technology, July 1986.
- 5.1) Energy Policy and Planning for Papua New Guinea, A White Paper from the Department of Minerals and Energy, 1979, p. 30.
- 5.2) Ibid. p. 25.
- 5.3) Medium Term Development Strategy: Energy Strategy: Discussion Papers, National Planning Office, 1984, pp. 34-35.
- 5.4) Ibid. p. 12.
- 5.5.) Ibid. p. 12.
- 5.6) 5.1, op. cit. pp. 9-10.
- 5.7) Doing Business in Papua New Guinea, Price Waterhouse, 1984.
- 5.8) 4.47, op. cit.
- 5.9) Ibid.
- 5.10) 1.12, op. cit.
- 5.11) 5.1, op. cit. pp. 15,26.
- 5.12) 5.3, op. cit. p. 30.
- 5.13) Ibid. pp. 20-47.

- 5.14) 21st Annual Report,
Papua New Guinea Electricity Commission,
1983.
- 5.15) Unpublished Material from Papua New Guinea Electricity
Commission File E72-2-5 Pt 2.
- 5.16) 5.3, op. cit.
- 5.17) Ibid.
- 5.18) 4.47, op. cit.
- 5.19) 5.3, op. cit.
- 5.20) 5.1, op. cit.
- 5.21) Papua New Guinea Electricity Commission Planning Criteria
for Mini Hydro Schemes,
A. L. Davies,
Proceedings of the UNESCO sponsored 'Workshop on Micro
Hydro Installations',
Papua New Guinea University of Technology,
1986.
- 5.22) Papua New Guinea Electricity Commission Ten Year Plan
1977-1986,
Papua New Guinea Electricity Commission,
1976, p. 43.
- 5.23) Ibid. p. 43.
- 5.24) Ten Year Plan 1986-1995,
Papua New Guinea Electricity Commission,
1985.
- 5.25) Rural Electrification,
Medium Term Planning Group, Energy Planning Unit,
Department of Minerals and Energy,
1984, p. 4.
- 5.26) Ibid.
- 5.27) Ibid.
- 5.28) Ibid.
- 5.29) 5.14, op. cit.
- 5.30) 5.25, op. cit.
- 5.31) 5.23, op cit.
- 5.32) Unpublished Material
- 5.33) 5.3, op. cit.

- 5.34) 5.14, op. cit.
- 5.35) 5.3, op. cit.
- 5.36) Ibid.
- 5.37) 5.25, op. cit.
- 5.38) 'C' Centre Power Supply Survey,
Cameron McNamara Kramer Consulting Engineers,
Department of Finance,
1982.
- 5.39) A National Government Mini Hydro Construction Programme
for Diesel Power Replacement,
C. Cheatham and F. Gooneratne,
Proceedings of the UNESCO sponsored 'Workshop on Micro
Hydro Installations',
Papua New Guinea University of Technology,
July 1986.
- 5.40) Mini Hydro Resource Inventory: Talasea-Kimbe: West New
Britain Province,
Beca Worley International,
1984, Appendix B.
- 5.41) 5.39, op. cit.
- 5.42) Ibid.
- 5.43) Interviews with District Cashiers at Tari and Menyamy.
- 5.44) Interviews with C. Cheatham, Power Systems Planner,
Department of Minerals and Energy.
- 5.45) 5.40, op. cit.
- 5.46) Interviews with businessmen at Tari.
- 5.47) 5.3, op. cit.
- 5.48) 5.40, op. cit.
- 6.1) 5.25, op. cit. p. 1.
- 6.2) Unpublished Internal Report from Papua New Guinea
Electricity Commission File 119-17-7
Pt 2; Rural Electrification Schemes.
- 6.3) Rural Electrification in Papua New Guinea,
E. S. Dryer,
Papua New Guinea Electricity Commission,
1975, pp. 1-2.
- 6.4) Ibid. pp. 8-14, 35-34.

- 6.5) Ibid. pp. 12-22.
- 6.6) Ibid. pp. 32, 34, 54-55.
- 6.7) Rural Electrification for the People of Papua New Guinea:
Rural Electrification Phase One Study,
National Rural Electric Co-operative Association,
1975, p. 1.
- 6.8) Ibid. p. 50.
- 6.9) Ibid. pp. 26, 36, 39.
- 6.10) Ibid. pp. 4-6, 17-35.
- 6.11) 3.64, op. cit.
- 6.12) Ibid.
- 6.13) Ibid.
- 6.14) Operational Programme Grant,
National Rural Electric Co-operative Association,
1976.
- 6.15) Unpublished Internal Report from Papua New Guinea
Electricity Commission File E119-17-8.
- 6.16) Unpublished Extract from Elcom Meeting No. 1/77,
Papua New Guinea Electricity Commission File E119-17-8.
- 6.17) Unpublished Internal Report from Papua New Guinea
Electricity Commission File E119-17-8.
- 6.18) 5.22, op. cit.
- 6.19) 5.1, op. cit.
- 6.20) Ibid.
- 6.21) Internal Correspondence,
Papua New Guinea Electricity Commission File E119-17-7.
- 6.22) 5.24, op. cit. pp. 119-121.
- 6.23) Ibid. pp. 128-130.
- 6.24) Ibid. p. 130
- 6.25) Ibid. p. 30.
- 6.26) 5.25, op. cit. Annex 2, p. 1.
- 6.27) Internal Report from Papua New Guinea Electricity
Commission File E119-17-4: Power supply to Villages:
General.

- 6.28) Unpublished Internal Report from Papua New Guinea
Electricity Commission File E119-17-7.
- 6.29) Hey, Dad I Wish We Could Get Power at Our Place,
Information Pamphlet Published by the Public Relations
Section of the Papua New Guinea Electricity Commission,
1978.
- 6.30) 5.22, op. cit.
- 6.31) Ten Year Plan 1978-1987,
Papua New Guinea Electricity Commission,
1977.
- 6.32) Internal Report from Elcom File E72-20-1: Hydro-Electric
Scheme: Simbai Patrol Post.
- 6.33) Internal Correspondence from Papua New Guinea Electricity
Commission Files E72-8-1 and 1a.
- 6.34) 6.32, op. cit.
- 6.35) 6.33, op. cit.
- 6.36) 3.27, op. cit.
- 6.37) Appraisal of the Provincial Mini Hydro-Power Project in
Papua New Guinea,
Asian Development Bank,
October 1977.
- 6.38) Ibid.
- 6.39) Appraisal of Four Mini Hydro-Electric Schemes in Papua
New Guinea,
Shawinigan Engineering,
May 1977.
- 6.40) 6.37, op. cit.
- 6.41) 6.39, op. cit.
- 6.42) Ibid.
- 6.43) 2.10, op. cit. Appendix 1-2, AIV-15.
- 6.44) 6.39, op. cit.
- 6.45) 3.27, op. cit.
- 6.46) Extract from Commission Meeting No 5/81,
Papua New Guinea Electricity Commission File E119-17-7:
Rural Electrification Policy.
- 6.47) 5.24, op. cit.

- 6. 48) Ibid.
- 6. 49) Internal Progress Report from Papua New Guinea Electricity Commission File E72-2-5 Pt 2: Lake Hargy Hydro.
- 6. 50) Internal Correspondence from Papua New Guinea Electricity Commission File E72-2-5 Pt 2.
- 6. 51) Ru Creek Mini Hydro-Electric Scheme; Financial and Economic Reappraisal, Papua New Guinea Electricity Commission, June 1980,
- 6. 52) Ru Creek Mini Hydro - 800 kW Papua New Guinea, Fiji - Papua New Guinea Special, SHP News No. 2, 1987, Newsletter of the Asia-Pacific Network for Small Hydro-Power, Hangzhou Regional Centre for Small Hydro-Power,
- 6. 53) Tinputz and Lake Hargy Mini Hydro-Power Projects; Economic and Financial Reassessment, Tom Crouch, Elcom May 1981,
- 6. 54) Ibid.
- 6. 55) Extract from Commission Meeting No 5/81, Papua New Guinea Electricity Commission File E119-17-7: Rural Electrification Policy.
- 6. 56) Economic Evaluation of Lake Hargy Mini Hydro Project, Papua New Guinea Electricity Commission, October 1983.
- 6. 57) Internal Correspondence from Papua New Guinea Electricity Commission File E72-125: Tinputz Hydro.
- 6. 58) Unpublished Material from Papua New Guinea Electricity Commission File E72-2-5 Pt 2.
- 6. 59) Evaluation of Tinputz Hydro Project, Papua New Guinea Electricity Commission, October 1986.
- 6. 60) Economic and Financial Evaluation of Tinputz Mini Hydro Project, Papua New Guinea Electricity Commission, April 1986.
- 6. 61) Interview with Chris Cheatham, Power Systems Planner, Energy Planning Unit, Department of Minerals and Energy.
- 6. 62) 4. 54, op. cit.

- 6.63) 5.25, op. cit.
- 6.64) 5.38, op. cit.
- 6.65) 5.25, op. cit.
- 6.66) 5.39, op. cit.
- 6.67) Mini Hydro-Power Resource Inventory; Explanatory Report, Beca Worley International, September 1983.
- 6.68) A National Small Hydro-Power Construction Programme for Rural Electrification in Papua New Guinea, C. Cheatham, SHP News No. 2, 1987, Newsletter of the Asia-Pacific Network for Small Hydro-Power, Hangzhou Regional Centre for Small Hydro-Power.
- 6.69) Personal Correspondence with C. Cheatham, Power Systems Planner, Energy Planning Unit, Department of Minerals and Energy.
- 6.70) 5.39, op cit.
- 6.71) Interview with C. Cheatham, Power Systems Planner, Energy Planning Unit, Department of Minerals and Energy.
- 6.72) 5.25, op cit.
- 6.73) Interview with the Assistant Commissioner of Tari, and various other inhabitants of the centre.
- 6.74) Visit to Tari power house, and interviews with the power house operator and various businessmen in Tari,
- 6.75) DPRP Mini Hydro-Electric Power Scheme for Tari, Southern Highlands Province; Design Report, Beca Worley International, 1985.
- 6.76) Ibid.
- 6.77) Tari Mini Hydro; Review of Economic, Financial and Management Issues, Policy Unit, Department of Minerals and Energy, February 1986.
- 6.78) Interview with C. Cheatham, Power Systems Planner, Energy Planning Unit, Department of Minerals and Energy.
- 6.79) Personal Correspondence with C. Cheatham, Power Systems Planner, Energy Planning Unit, Department of Minerals and Energy.

- 6.80) Ibid.
- 6.81) 5.39, op cit.
- 6.82) 6.68, op cit.
- 6.83) Ibid.
- 6.84) Personal Correspondence with C. Cheatham, Power Systems Planner, Energy Planning Unit, Department of Minerals and Energy.

- 7.1) 4.17, op. cit. pp. 1-8.
- 7.2) 4.5, op. cit. pp. 196-198.
- 7.3) 4.18, op. cit. p. 8.
- 7.4) The Papua New Guinea Micro Hydro Sourcebook, Rik Hothersall, Papua New Guinea University of Technology, 1982.
- 7.5) Micro Hydro: An Appropriate Technology for Villages in Papua New Guinea?, R. Burton, Proceedings of the UNESCO sponsored 'Workshop on Micro Hydro Installations', Papua New Guinea University of Technology, July 1986.
- 7.6) Postal Questionnaire Responses.
- 7.7) Interviews with various mission personnel.
- 7.8) 7.6, op. cit.
- 7.9) Ibid.
- 7.10) 7.4, op. cit.
- 7.11) Interview with Father Clement Bateman.
- 7.12) 7.6, op. cit.
- 7.13) Ibid.
- 7.14) 7.7, op. cit.
- 7.15) Balindoang Micro Hydro Project 1980-84: Departmental Report No. 3/84, P. Robinson, Department of Electrical and Communication Engineering, Papua New Guinea University of Technology, 1984.

- 7.16) Integrated Development of Energy Sources: Departmental Report,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology,
1979.
- 7.17) Technical Notes on the Baindoang Micro Hydro and Water Supply Scheme,
Allen R. Inversin,
Appropriate Technology Development Unit,
1980.
- 7.18) Report on the Current Status of Micro Hydro Project at Romsis, North Solomons Province,
J. L. Wodward,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology,
1984.
- 7.19) Survey of Micro Hydro Schemes in Pindiu Area:
Departmental Report No. 1/82,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology,
1982.
- 7.20) 3.27, op. cit.
- 7.21) Electronic Control of Small Hydroelectric Schemes Using a Microcomputer,
S. Kormilo and P. Robinson,
Proceedings, Volume 131; Pt. E, No. 4,
Institution of Electrical Engineers,
July 1984.
- 7.22) A Pelton Micro Hydro Prototype Design,
Allen R. Inversin,
Appropriate Technology Development Institute,
1980.
- 7.23) Preliminary Micro Hydro-Electric Survey of Opai Village, Siassi Island, Departmental Report No. 1/81,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology,
1981.
- 7.24) Unpublished Material from File No. H.E.5.,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology.
- 7.25) Unpublished Material from File No. M.E.12.3.,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology.
- 7.26) 3.27, op. cit.

- 7.27) Unpublished Material from the Morobe provincial Government's Micro Hydro Files.
- 7.28) Unpublished Material from File No. R.E.1.8., Department of Electrical and Communication Engineering, Papua New Guinea University of Technology.
- 7.29) 4.21, op. cit.
- 7.30) Project Proposal for a Five Year Development Plan for Micro Hydro Generators, P. Greenwood, Unpublished Material from File No. R.E.1.8., Department of Electrical and Communication Engineering, Papua New Guinea University of Technology.
- 7.31) 7.16, op. cit.
- 7.32) Unpublished Material from the Morobe provincial Government's Micro Hydro Files.
- 7.33) Ibid.
- 7.34) Ibid.
- 7.35) Unpublished Material from File No. M.E.12.1., Department of Electrical and Communication Engineering, Papua New Guinea University of Technology.
- 7.36) Unpublished Material from File No. R.E.1.8., Department of Electrical and Communication Engineering, Papua New Guinea University of Technology.
- 7.37) Unpublished Material from the Morobe Provincial Government's Micro Hydro Files.
- 7.38) Ibid.
- 7.39) Unpublished Material from File No. M.E.12.3., Department of Electrical and Communication Engineering, Papua New Guinea University of Technology.
- 7.40) Morobe's Micro Hydro: Reality and Potential, J. Arneaud-Clarke and M. New, International Water Power and Dam Construction, October 1984.
- 7.41) Personal Correspondence with Ian Bean.
- 7.42) Ibid.
- 7.43) Ibid.
- 7.44) Ibid.

- 7.45) Unpublished Material from File No. R.E.6.,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology.
- 7.46) Unpublished Material from File No. R.E.1.8.,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology.
- 7.47) Unpublished Material from File No. M.E.12.3.,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology.
- 7.48) 7.20, op. cit.
- 7.49) 7.21, op. cit.
- 7.50) 7.22, op. cit.
- 7.51) Village Micro Hydro: Which Generator: Departmental Report
No. 3/81,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology,
1981.
- 7.52) Micro Hydro Project in Anditale, Enga Province,
J. L. Woodward, A. R. Yadav, R. Welsford and F. Bullen,
Papua New Guinea University of Technology,
1985.
- 7.53) Micro Hydro Project in Maramuni, Enga Province,
J. L. Woodward, A. R. Yadav, R. Welsford and F. Bullen,
Papua New Guinea University of Technology,
1985.
- 7.54) Agaun Micro Hydro-Power Scheme: Feasibility Study Report,
K. Whittaker, A. R. Yadav and W. C. Kiewiet,
Papua New Guinea University of Technology,
1986.
- 7.55) 7.5, op. cit.
- 8.1) Personal Correspondence with C. Cheatham, Power Systems
Planner, Energy Planning Unit, Department of Minerals and
Energy.
- 8.2) 6.68, op. cit.
- 8.3) 1.3, op. cit.
- 8.4) 4.24, op. cit.

8. 5) Growth Centres and Area Improvement in the Eastern Highlands District,
R. Gerard Ward, N. Clark, C. Kissling and H. C. Weinand,
Department of Human Geography, Research School of Pacific Studies, Australian National University,
1974.
- H. 1) Mini Hydro-Power Resource Inventory: Okapa: Eastern Highlands Province,
Beca Worley International,
Energy Planning Unit, Department of Minerals and Energy,
1985.
- H. 2) 4.17, op. cit. p. 68.
- H. 3) Field Work Observations.
- H. 4) Interviews with mission personnel.
- H. 5) H. 1, op. cit.
- H. 6) Ibid.
- H. 7) Interview with Richard Deeds responsible for operation and maintenance of the hydro-power project.
- H. 8) H. 1, op. cit.
- H. 9) Unpublished technical information on, and Manual for, the hydro-power project supplied by Hydro Light Inc..
- H. 10) Ibid.
- H. 11) H. 7, op. cit.
- H. 12) H. 9, op. cit.
- H. 13) H. 4, op. cit.
- H. 14) H. 7, op. cit.
- H. 15) Personal Correspondence with Richard Deeds responsible for operation and maintenance of the hydro-power project.
- H. 16) H. 1, op. cit.
- H. 17) H. 4, op. cit.
- H. 18) Ibid.
- H. 19) Unpublished Material.
- H. 20) Interview with the manager of the mission tradestore.
- H. 21) Interview with the manager of the mission workshops.

- H. 22) H. 7, op. cit.
- H. 23) Ibid.
- I. 1) The Baindoang Micro Hydro-Electric Installation,
Charles Kiewiet,
Proceedings of the UNESCO sponsored 'Workshop on Micro
Hydro Installations',
Papua New Guinea University of Technology,
July 1986.
- I. 2) 4.21, op. cit.
- I. 3) Ibid.
- I. 4) Ibid.
- I. 5) Ibid.
- I. 6) 7.17, op. cit.
- I. 7) 7.15, op. cit.
- I. 8) I.2, op. cit.
- I. 9) 7.17, op. cit.
- I. 10) 4.21, op. cit.
- I. 11) Ibid.
- I. 12) 7.15, op. cit.
- I. 13) 4.21, op. cit.
- I. 14) Ibid.
- I. 15) Interviews with inhabitants of Umbang and Baindoang.
- I. 16) 4.21, op. cit.
- I. 17) Interview with Mr Yang.
- I. 18) Interview with P. Robinson, Lecturer at the Department of
Electrical and Communication Engineering from 1980 to
1984.
- I. 19) 7.15, op. cit.
- I. 20) 4.21, op. cit.
- I. 21) Interview with Kaye Bowman.
- I. 22) Site Inspection.

- I. 23) Field Trip Report from Baindoang, J. L. Woodward,
Unpublished Material from File No. R.E. 1.8.
Papua new Guinea University of Technology.
- I. 24) H.1, op. cit.
- I. 25) Site Inspection.
- I. 26) 4.21, op. cit.
- I. 27) Update on the Baindoang Micro Hydro Project,
J. L. Woodward and M. Woodward, 1984,
Unpublished Material from File No. R.E. 1.8.
Papua new Guinea University of Technology.
- I. 28) 7.15, op. cit.
- I. 29) H.21, op. cit.
- I. 30) Interviews with various inhabitants from Baindoang,
Umbang and the neighbouring villages of Kotien and Tuep.

- J. 1) Field Work Observations.
- J. 2) Project Survey Report: Ogeranang, Bulum valley,
Leigh Baker,
Community Service Committee, Rotary Club of Lae,
1976.
- J. 3) Ibid.
- J. 4) Burum and its Development: Problems and Suggestions,
K. Olkkonen and S. Olkkonen,
Summer Institute of Linguistics,
1983.
- J. 5) Report on Potential Hydro-Electric Site Near Ogeranang,
Morobe Province,
C. W. Perrett,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology,
1978.
- J. 6) Unpublished Material of the Morobe Provincial
Government's Micro Hydro Files.
- J. 7) Unpublished Material from File No. O.E. 3.,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology.
- J. 8) J.6, op. cit.
- J. 9) Interview with Mursalin New, Provincial Industrial
Development Officer.

- J. 10) Ibid.
- J. 11) Interview with P. Robinson, Lecturer at the Department of Electrical and Communication Engineering from 1980 to 1984.
- J. 12) Unpublished Material from File No. O.E. 3., Department of Electrical and Communication Engineering, Papua New Guinea University of Technology.
- J. 13) Interview with the Honourable Tingnau Mandan, Morobe Provincial Government Minister for Forests and formerly Headmaster of Ogeranang Community School.
- J. 14) Unpublished Material from the Morobe Provincial Government's Micro Hydro Files.
- J. 15) Ibid.
- J. 16) J. 9, op. cit.
- J. 17) Interview with Ben Kavi, one of the supervisors working on the Ogeranang project.
- J. 18) Field work Observations.
- J. 19) Unpublished Material from File No. O.E. 3., Department of Electrical and Communication Engineering, Papua New Guinea University of Technology.
- J. 20) Unpublished Material of the Morobe Provincial Government's Micro Hydro Files.
- J. 21) J. 17, op. cit.
- J. 22) Interview with one of the hydro-power plant operators.
- J. 23) Interview with the Ogeranang Community Government Leader.
- J. 24) J. 13, op. cit.
- J. 25) Ibid.
- J. 26) J. 23, op. cit.
- J. 27) J. 9, op. cit.
- J. 28) J. 13, op. cit.
- J. 29) J. 23, op. cit.
- J. 30) J. 9, op. cit.
- J. 31) J. 13, op. cit.

- K. 1) Anga Regional Development (Menyamya District): A Proposal for Funding, Policy Secretariat, Morobe Provincial Government, 1980.
- K. 2) Unpublished Material from Morobe Provincial Government File 6-3-6c.
- K. 3) Ibid.
- K. 4) K. 1, op. cit.
- K. 5) Interviews with staff of the Anga Development Authority.
- K. 6) Field Work Observations.
- K. 7) K. 1, op. cit.
- K. 8) K. 5, op. cit.
- K. 9) K. 2, op. cit.
- K. 10) Ibid.
- K. 11) K. 1, op. cit.
- K. 12) Field Work Observations.
- K. 13) Unpublished Material from Papua New Guinea Electricity Commission File E72-8-3: Aseki Hydro.
- K. 14) Preliminary Micro Hydro-Electric Survey for Aseki Station: Departmental Report No. 2/80, Mirisa Danjeng, Department of Electrical and Communication Engineering, Papua New Guinea University of Technology, 1980.
- K. 15) Unpublished Material from the Morobe Provincial Government's Micro Hydro Files.
- K. 16) Ibid.
- K. 17) Ibid.
- K. 18) Ibid.
- K. 19) K. 1, op. cit.
- K. 20) K. 2, op. cit.
- K. 21) Unpublished Material from Morobe Provincial Government File 6-11-2D.
- K. 22) Interview with the Menyamya District Officer.

- K. 23) K. 5, op. cit.
- K. 24) Field Work Observations.
- K. 25) Pre-Feasibility Study of a Small Hydro Scheme for
Menyama Station, Morobe Province,
R. Burton,
Department of Mechanical Engineering, Papua New Guinea
University of Technology,
1984.
- K. 26) Unpublished Material from Files at the Energy Planning
Unit, Department of Minerals and Energy.
- K. 27) Ibid.
- K. 28) K. 25, op. cit.
- K. 29) Ibid.
- K. 30) 5. 24, op. cit.
- K. 31) Aseki Road Impact Study,
Carl T. Mahoney,
Department of Architecture and Building, Papua New Guinea
University of Technology,
1980.
- K. 32) K. 5, op. cit.

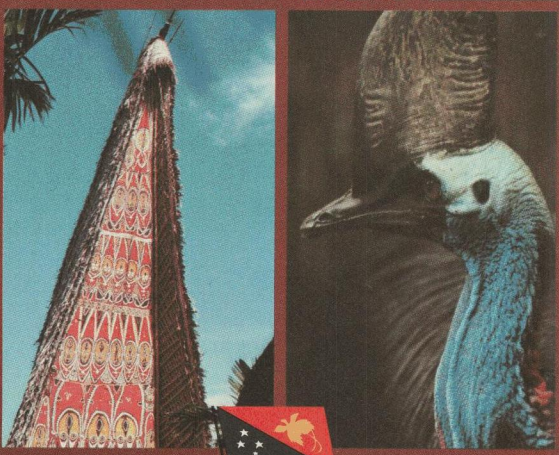
- L. 1) Field Work Observations
- L. 2) Personal Correspondence with Ian Bean who was responsible
for project implementation.
- L. 3) Ibid.
- L. 4) L. 1, op. cit.
- L. 5) Ibid.
- L. 6) Unpublished Material from File No. ME. 12. 2.,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology.
- L. 7) Ibid.
- L. 8) Interviews with various inhabitants of Nawong.
- L. 9) Nawong Micro Hydro: Re-habilitation Feasibility Study,
Unpublished report prepared by Keith Whittaker.
- L. 10) L. 8, op, cit.

- M. 1) Field Work Observations.
- M. 2) Proposal for a Micro Hydro Plant at Faseu Village,
J. L. Woodward,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology,
1984.
- M. 3) Interview with Mr Yang.
- M. 4) Ibid.
- M. 5) Preliminary Hydro-Electric Survey: Faseu,
David Talbot,
Unpublished Material from File No. R. E. 8.,
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology.
- M. 6) Interview with Mr Stanley, a Business Development
Officer.
- M. 7) Unpublished Material from Morobe Provincial Government's
Micro Hydro Files.
- M. 8) M. 2, op. cit.
- M. 9) Interviews with various inhabitants of Faseu.
- M. 10) M. 2, op. cit.
- M. 11) Faseu Micro Hydro-Power Feasibility Study,
Unpublished report prepared by Keith Whittaker.
- M. 12) M. 2, op. cit.
- M. 13) M. 5, op. cit.
- M. 14) Personal Correspondence with Mr Yang.
- M. 15) M. 2, op. cit.
- M. 16) M. 11, op. cit.
- M. 17) M. 3, op. cit.
- M. 18) M. 6, op. cit.
- M. 19) Interview with Charles Kiewiet, Lecturer at the
Department of Electrical and Communication Engineering,
Papua New Guinea University of Technology.
- M. 20) Interview with R. Burton, Director of the Appropriate
Technology Development Institute.

- M. 21) Interview with Professor D. Harris, Head of the Department of Electrical and Communication Engineering, Papua New Guinea University of Technology.
- M. 22) M. 9, op. cit.
- M. 23) M. 20, op. cit.
- M. 24) M. 3, op. cit.
- M. 25) Interview with Mursalin New, Provincial Industrial Development Officer.
- M. 26) Interview with Paul Unwin, an engineer working on the 'Wokabout Somil' with Village Equipment Supplies.
- M. 27) M. 20, op. cit.
- M. 28) Photovoltaic Powered Lanterns for Village Use, R. Burton, G. D. Gafiye and U. G. A. Stimming, Papua New Guinea University of Technology. 1985.
- N. 1) Field Work Observations.
- N. 2) Personal Correspondence with Bob Bates, manager of Trans Nuigini Tours.
- N. 3) Ibid.
- N. 4) N. 1, op. cit.
- N. 5) Ibid.
- N. 6) Interview with John Bates, manager of the Ambua Lodge.
- N. 7) Interview with Chris Rose, supervisor of work on the hydro-power project.
- N. 8) Ibid.
- N. 9) N. 6, op. cit.
- N. 10) N. 2, op. cit.
- N. 11) N. 7, op. cit.
- N. 12) N. 6, op. cit.
- N. 13) Unpublished Material from the Morobe Provincial Government's Mini Hydro Files.
- N. 14) 5.40, op. cit.
- N. 15) Interview with the manager of Huli Motors, Tari.



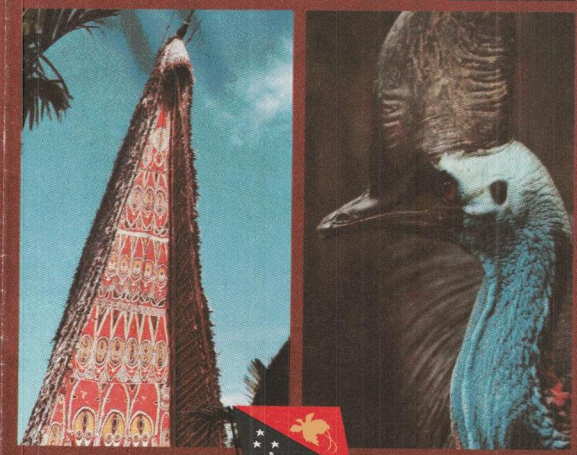
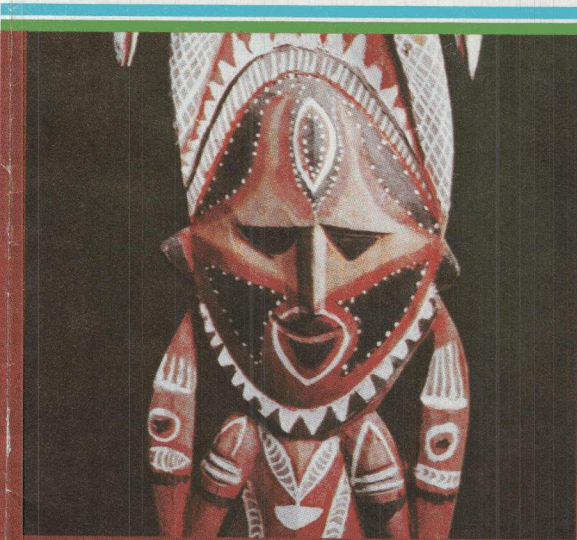
Tourist guide to Papua New Guinea



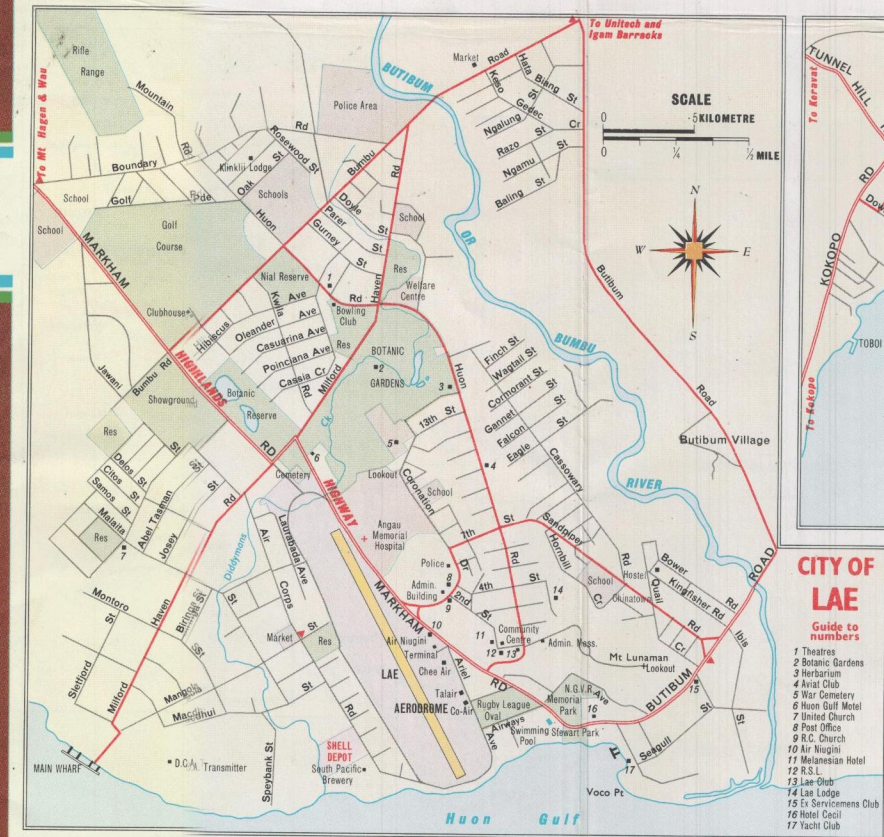
Produced by Shell Papua New Guinea Pty. Ltd. and the P.N.G. Office of Tourism



Tourist guide to Papua New Guinea



Produced by Shell Papua New Guinea Pty. Ltd. and the P.N.G. Office of Tourism



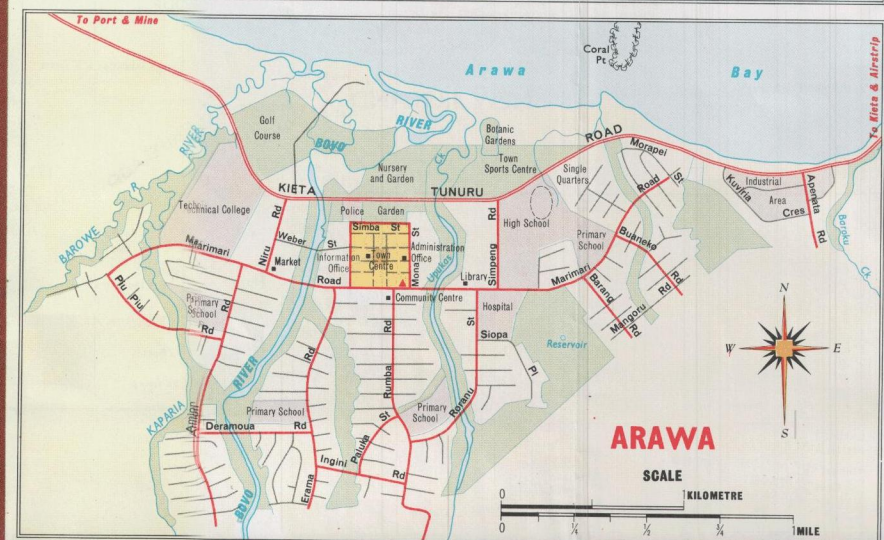
CITY OF LAE

- Guide to numbers**
- 1 Theatre
 - 2 Botanic Gardens
 - 3 Parliament
 - 4 Airstrip
 - 5 War Cemetery
 - 6 Race Club
 - 7 Post Office
 - 8 R.C. Church
 - 9 Air Hospital
 - 10 Japanese Hotel
 - 11 Lae Club
 - 12 Lae Lodge
 - 13 Lae-Club
 - 14 Lae Lodge
 - 15 St. Servatius Club
 - 16 Race Club
 - 17 Yacht Club



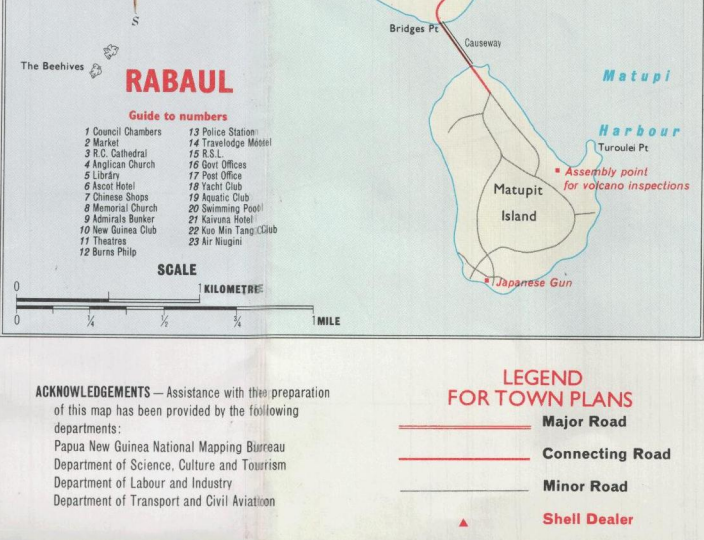
RABAUL

- Guide to numbers**
- 1 Council Chambers
 - 2 Market
 - 3 R.C. Cathedral
 - 4 Anglican Church
 - 5 Library
 - 6 Race Club
 - 7 Chinese Shops
 - 8 Memorial Church
 - 9 Amamba Butler
 - 10 New Guinea Club
 - 11 Theatre
 - 12 Police Station
 - 13 Telephone Exchange
 - 14 R.S.L.
 - 15 Post Office
 - 16 Golf Club
 - 17 Post Office
 - 18 Post Office
 - 19 Post Office
 - 20 Swimming Pool
 - 21 Japanese Hotel
 - 22 New Mita Hotel
 - 23 Japanese Club
 - 24 Japanese Club
 - 25 Japanese Club
 - 26 Japanese Club
 - 27 Japanese Club
 - 28 Japanese Club
 - 29 Japanese Club
 - 30 Japanese Club



ARAWA

- Guide to numbers**
- 1 Council Chambers
 - 2 Market
 - 3 R.C. Cathedral
 - 4 Anglican Church
 - 5 Library
 - 6 Race Club
 - 7 Chinese Shops
 - 8 Memorial Church
 - 9 Amamba Butler
 - 10 New Guinea Club
 - 11 Theatre
 - 12 Police Station
 - 13 Telephone Exchange
 - 14 R.S.L.
 - 15 Post Office
 - 16 Golf Club
 - 17 Post Office
 - 18 Post Office
 - 19 Post Office
 - 20 Swimming Pool
 - 21 Japanese Hotel
 - 22 New Mita Hotel
 - 23 Japanese Club
 - 24 Japanese Club
 - 25 Japanese Club
 - 26 Japanese Club
 - 27 Japanese Club
 - 28 Japanese Club
 - 29 Japanese Club
 - 30 Japanese Club



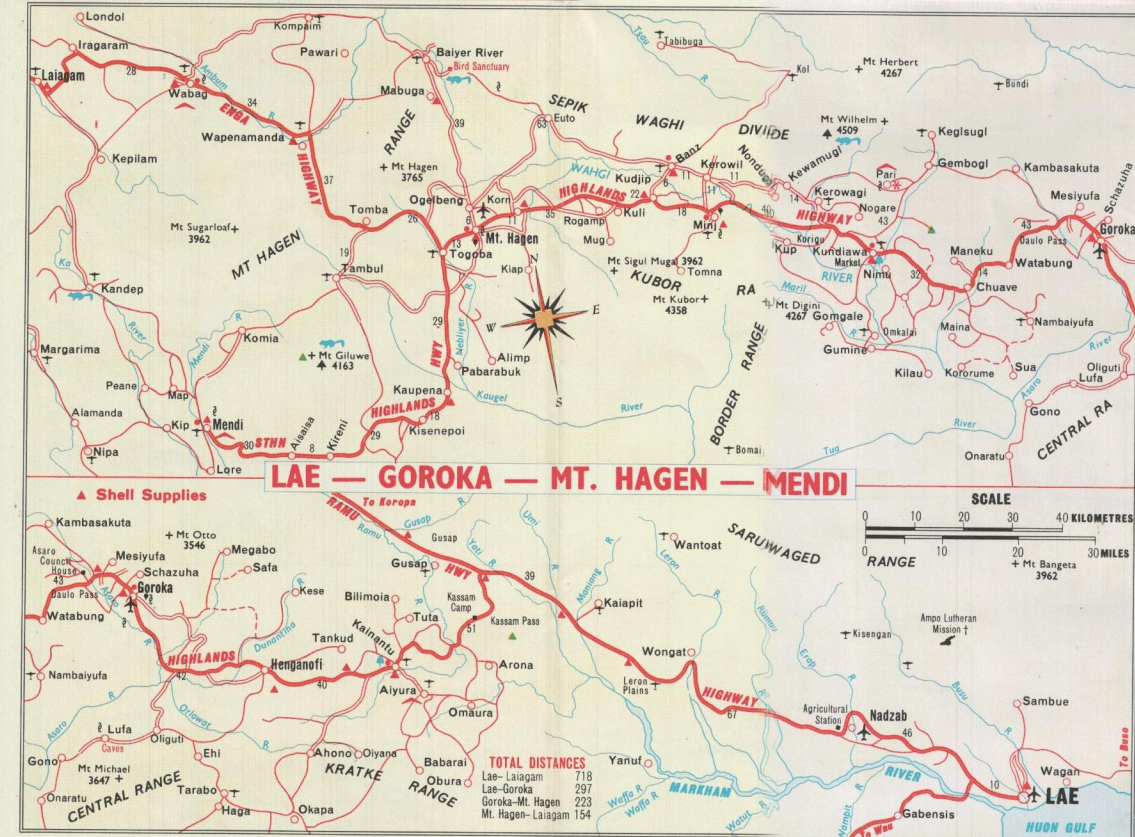
MADANG

- Guide to numbers**
- 1 Council Chambers
 - 2 Market
 - 3 R.C. Cathedral
 - 4 Anglican Church
 - 5 Library
 - 6 Race Club
 - 7 Chinese Shops
 - 8 Memorial Church
 - 9 Amamba Butler
 - 10 New Guinea Club
 - 11 Theatre
 - 12 Police Station
 - 13 Telephone Exchange
 - 14 R.S.L.
 - 15 Post Office
 - 16 Golf Club
 - 17 Post Office
 - 18 Post Office
 - 19 Post Office
 - 20 Swimming Pool
 - 21 Japanese Hotel
 - 22 New Mita Hotel
 - 23 Japanese Club
 - 24 Japanese Club
 - 25 Japanese Club
 - 26 Japanese Club
 - 27 Japanese Club
 - 28 Japanese Club
 - 29 Japanese Club
 - 30 Japanese Club

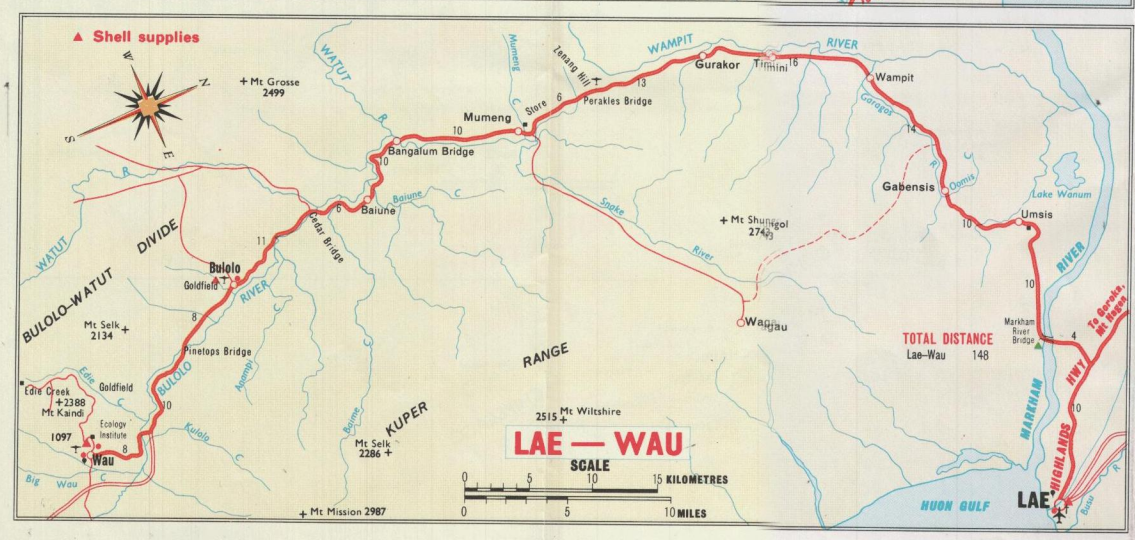
ACKNOWLEDGEMENTS — Assistance with the preparation of this map has been provided by the following departments:
 Papua New Guinea National Mapping Bureau
 Department of Science, Culture and Tourism
 Department of Labour and Industry
 Department of Transport and Civil Aviation

LEGEND FOR TOWN PLANS

- Major Road
- Connecting Road
- Minor Road
- Shell Dealer



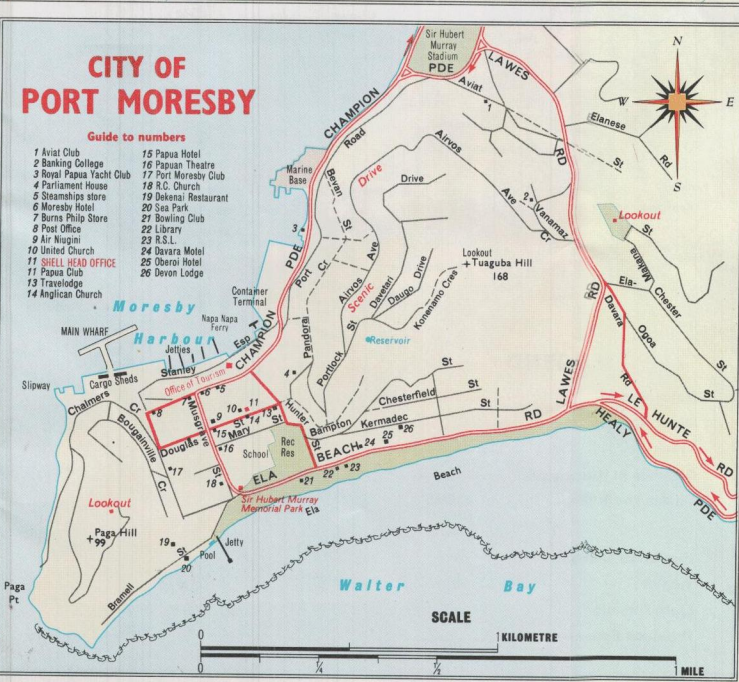
LAE — GOROKA — MT. HAGEN — MENDI



LAE — WAU



ARAWA DISTRICT



CITY OF PORT MORESBY

- Guide to numbers**
- 1 Airstrip
 - 2 Parliament House
 - 3 Parliament House
 - 4 Parliament House
 - 5 Parliament House
 - 6 Parliament House
 - 7 Parliament House
 - 8 Parliament House
 - 9 Parliament House
 - 10 Parliament House
 - 11 Parliament House
 - 12 Parliament House
 - 13 Parliament House
 - 14 Parliament House
 - 15 Parliament House
 - 16 Parliament House
 - 17 Parliament House
 - 18 Parliament House
 - 19 Parliament House
 - 20 Parliament House
 - 21 Parliament House
 - 22 Parliament House
 - 23 Parliament House
 - 24 Parliament House
 - 25 Parliament House
 - 26 Parliament House
 - 27 Parliament House
 - 28 Parliament House
 - 29 Parliament House
 - 30 Parliament House



guide to PORT MORESBY SUBURBS

