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ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC
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Part One

REPORT OF THE MEETING

I. ORGANIZATION OF THE MEETING

1. The Meeting on Water Resources Development in the South Pacific was held at Suva from 14 to 19 March 1983.

Attendance

2. The Meeting was attended by representatives of the following ESCAP members and associate members: Fiji, Niue, Samoa, Solomon Islands, Tonga and Trust Territory of the Pacific Islands (Federated States of Micronesia, Republic of the Marshall Islands and Commonwealth of the Northern Mariana Islands).

3. The following United Nations bodies and specialized agencies were represented: ESCAP, United Nations Department of Technical Co-operation for Development (DTCD), Food and Agriculture Organization of the United Nations (FAO), International Labour Organisation (ILO), United Nations Educational, Scientific and Cultural Organization (UNESCO), World Health Organization (WHO) and World Meteorological Organization (WMO).

Opening of the Meeting

4. The Meeting was inaugurated by the Honourable Jonate Mavoa, Minister of Agriculture and Fisheries of Fiji. In his address, he stressed the importance of water resources, the misuse or ignorance of which had caused the fall of ancient civilizations. While island countries were surrounded by inexhaustible sea water resources, the high cost of desalination did not render the utilization of those resources as a viable alternative. It was therefore, necessary to plan properly for the development and management of the available freshwater resources for optimum benefits. That called for, among other things, effective legislation and appropriate water-quality management policies and practices as well as appropriate technology. He also called attention to the need for measures to cope with natural disasters, particularly cyclones, which could have a damaging effect on water supplies. He expressed the hope that by sharing their expertise and exchanging experience, the participants could learn from and help each other as well as find solutions to their problems in the "Pacific way."

5. In his message, the Executive Secretary of ESCAP thanked the Governments of Australia and Fiji and the various United Nations organizations for their support of the Meeting. He pointed out that the most serious and common problem confronting Pacific countries was the provision of adequate drinking water. After outlining the main factors which contributed to that problem, he stressed the need for an integrated and co-ordinated programme for water resource development with a view to catering for immediate and long-term needs and optimizing the allocation and use of that finite and scarce resource.

6. Noting that the Meeting was the first of its kind sponsored by ESCAP in the Pacific region, he exhorted all participants to take an active interest and join in the discussions so that the common problems which emerged could be thoroughly analysed and corresponding solutions proposed. In conclusion, he expressed the hope that a rational and comprehensive action programme for water resource development would be formulated and adopted, which would serve as a guide for national regional and international action.

Election of officers

7. The Meeting elected Mr. A.T. Simpson (Fiji) as Chairman, Mr. T. Tongatule (Niue) as Vice-Chairman and Mr. F.F. Koloi (Tonga) as Rapporteur.

Adoption of the agenda

8. The Meeting adopted the following agenda:

1. Opening of the Meeting
2. Election of officers
3. Adoption of the agenda
4. Review of water resource development in the South Pacific
5. Major problems in water resource development
6. Recommended programme
7. Workshop sessions
8. Adoption of the report

II. DISCUSSION

Review of water resource development in the South Pacific

(agenda item 4)

9. The Meeting had before it document NR/MWRD/1 entitled "Water resources in the South Pacific island countries and the Trust Territory of the Pacific Islands" and eight country papers. In addition, five other papers on various aspects of water resource development in Fiji were presented to the meeting.

10. The meeting reviewed the physiography, population, climate and water resources of the sub-region, existing and proposed plans and programmes for water resource development, existing systems for collection of data on quantity and quality of water resources, national policy, legislation and institutional arrangements and manpower development, education and training in water resource development.

11. With a few exceptions, the countries in the sub-region comprised many small islands and/or atolls which were usually separated by great distances. With the exception of Nauru and Tuvalu which had a population density of over 300 per sq km and Tonga which had over 100 per sq km, the population density in the other countries was light ranging from 7 to 80 per sq km with fast growing concentrations of population on certain islands and coastal fringes.

12. The long-term average annual rainfall varied widely in the region from 200 to 8000 mm with most areas exceeding 2000 mm. As well as being seasonal, the variability of annual rainfall in one area could range from 10 per cent to 400 per cent of the long-term average rainfall.

13. Countries with larger hilly islands like Fiji, Samoa, Solomon Islands and Vanuatu and streams as sources of surface water. Most of the smaller islands had no important streams and had to depend on roof catchments and/or ground water for their supplies. Ground water was generally obtained from coastal fringes or from lenses of fresh water floating on sea water.

14. Data on area, population, annual rainfall and water sources in 10 South Pacific island countries and the Trust Territory of the Pacific Islands were as shown in table 1.

15. The major use of water in the countries was for domestic purposes. Water for irrigation was limited mainly to larger islands. There was a growing demand for commercial use, hydroelectric power generation, tourism and industry.

Major problems in water resource development

(agenda item 5)

16. The Meeting considered document NR/MWRD/2 entitled "Water resources development problems in South Pacific Island countries and the Trust Territory of the Pacific Islands" as well as the relevant sections of the country papers prepared by the participants.

17. Discussions revealed that water supplies for domestic purposes in many of the Pacific island countries were inadequate. A large part of the population on the atoll islands depended solely on rain water. During the dry season, the water stored in containers was used only for drinking and cooking. A large part of the communal reticulated water systems provided only for the basic minimum requirements and did not allow for waterborne sanitation.

18. The Meeting identified and classified the major problems faced by the countries in the development of their water resources under two broad categories.

19. The first category comprised problem/project-oriented issues which were urgent and amenable to immediate solutions and short-term measures. The problems in the second category comprised broad and long-term perspective issues which required long-term measures for their solution.

(a) *Problem/project-oriented issues:*

(i) There was a need for information on water resource assessment techniques in small islands/atolls as difficulties were being faced in carrying out the assessment of the surface- and groundwater resources of those areas;

(ii) The limited resources of the countries made it necessary that low-cost water supply and sanitation systems be utilized in the sub-region;

(iii) Information was required on the design of efficient roof catchments on which a large number of the small islands depended for their water supply;

(iv) Guidance material was required on strong and long-lasting construction materials for water tanks such as ferrocement, galvanized iron, reinforced concrete;

(v) Water losses which ranged from 30 to 50 per cent and wasteful use of water by consumers were among the causes of water shortage and high cost of water and required serious and immediate attention by all concerned;

(vi) For number of reasons, among them inadequate funds and lack of trained manpower, improper and/or inadequate operation, maintenance and repair of existing water supply systems, plant, equipment and instruments were growing and serious problems requiring urgent attention;

(vii) Information and advice on water pricing practices would be very useful in assisting the countries to formulate appropriate water-pricing policies to reflect the cost of water supplied to the consumers;

(viii) Advice was required on ways to reduce high operation and maintenance costs of those facilities resulting from various causes such as heavy sediment loads and high concentrations of minerals such as iron and maganese;

(ix) Overpumping of aquifers and groundwater lenses floating on sea water were endangering freshwater supplies with salt-water pollution;

(x) Increasing economic activities had started to raise the spectre of pollution of both surface and groundwater resources. Without appropriate measures, the problem could become a serious one in the immediate future. The health hazard arising from the use of asbestos pipes and oil leakage due to faulty pumps needed to be investigated;

(xi) The high cost of plant and equipment, including the cost of shipping over great distances, constituted a large drain on the resources of the countries;

(xii) Many of the countries did not have the resources in either the governmental or private sector to mobilize savings for capital investment required for water resources projects and were dependent on external assistance for this purpose;

(b) *Broad and long-term perspective issues:*

(i) Most of the countries did not have sufficient data on rainfall, streamflow, topography and geology to carry out a proper assessment of their surface and groundwater resources;

(ii) In most countries, there was a need for the formulation of a national water policy within the framework of and consistent with the overall economic and development plans of the country concerned;

(iii) Generally there was an absence of adequate institutional arrangements to ensure that the development and management of water resources took place in the context of national planning. There was generally insufficient co-ordination among all bodies responsible for the investigation, development and mangement of water resources;

(iv) There was no comprehensive water legislation which would provide guidance on the comprehensive and co-ordinated approach to water resources development and management;

(v) There was a need to build up technological capability of the countries giving close attention to low-cost technology and the use of local raw materials and resources;

(vi) There was a very limited supply of qualified and trained manpower required for various aspects of water resource development;

(vii) There was a need to educate the members of the public on the proper utilization, protection and conservation of water by making them aware of the fundamental and crucial issues relating to water;

(viii) Measures were required to be taken to mitigate the damage to the countries in general and to water facilities in particular caused by cyclones and associated floods.

III. RECOMMENDED PROGRAMME

(agenda item 6)

20. The Meeting discussed and considered measures to solve the problems identified in the discussion under the previous agenda item. It recognized that both short- and long-term measures would be required for the solution of those problems.

21. In general, the problem/project-oriented issues would require urgent and short-term measures for their resolution. Even some issues in that category, however, had certain aspects requiring long-term measures to ensure complete and satisfactory treatment.

22. The broad and long-term perspective issues required long-term measures by all concerned. In general those issues were concerned with the comprehensive and integrated appraoch to the development of water resources.

23. The Meeting adopted the long-term action plan shown in the annex.

24. It recommended however, that the following selected items in the comprehensive programme should be given urgent attention as they addressed the specific problems identified by the Meeting:

(a) *Assessment of water resources:*

(i) For each country in the Pacific region:

a. Establish an inventory of currently available water resource data;

b. Establish the minimal additional data collection system needed to meet development objectives, taking into account water quality, including sea-water intrusion of groundwater and sediment in streams, and small scale hydropower requirements;

c. Determine the areas which required the immediate assessment of water resources to satisfy their current and future needs;

(ii) At the sub-regional level:

a. Establish a project in the Pacific to determine optimum water resource availability and management on atolls (for water supply and agriculture), including water balance studies, techniques of assessment and evapotranspiration from coconuts, taro pits and natural vegetation, and develop guidelines on the above;

b. Develop guidelines for the assessment of water resources on volcanic islands or islands with surface-water potential.

(b) *Conservation on water and efficiency of water use:*

(i) Establish the best ways and means of educating the consumers to conserve water;

(ii) Establish a training programme for detection and repair of leakage in water supply systems and the subsequent repairs;

(iii) Establish a programme of modifications to systems to improve water supply distribution;

(iv) Establish a programme for the siting of groundwater extraction points to and the determination of withdrawal rates to avoid salt water intrusion and overpumping;

(v) Determine the priority water demands for different purposes with specific reference to the smaller atolls and communities;

(vi) Produce guidelines for the provision of water supply systems adapted for local conditions including:

a. The design of roof catchment and storage systems using appropriate materials and design methods;

b. Gravity distribution systems;

c. Hand pumps;

d. Wells.

(vii) Survey and monitoring of sources of water pollution, including microbiological, chemical, and pesticides, and the feasibility of removal thereof;

(viii) Establish guidelines for the design of waste disposal systems especially in small islands.

(ix) Establish guidelines for the security of water supplies and waste disposal systems during floods and cyclones;

(x) Coordinate activities in water pollution with the South Pacific Regional Environment Programme;

(xi) Investigate and encourage irrigated agricultural production within the constraints of other water demands;

(xii) Consider the water requirements of industries in the planning of water development projects taking into account water quality problems and the specific requirements of tourist development in the regon;

(xiii) A multi-purpose approach is recommended for the development of hydroelectric power, irrigation, gravity water supplies and recreational uses when there is a perceived need;

(c) *Policy, institution, legislation and technology:*

(i) Establish a realistic national water policy within the framework of the economic, social and environmental conditions existing in the country;

(ii) Develop a water plan within the context of national water policy taking account of the economic, social and environmental conditions existing in the country;

(iii) Undertake evaluation of recent and/or existing water projects and base future development on those findings;

(iv) Study local communities and promote their involvement in the design, construction, financing and operation of the local water supply;

(v) Establish appropriate institutional arrangements, where possible within one organization, for the promotion and co-ordination of the assessment, development and management of water resources within each country, and wherever appropriate in outer islands, appoint trained locals to control individual island water systems;

(vi) Establish simple and enforceable legislation, using local existing legislation and relevant examples from similar island countries and territories elsewhere, e.g. the Caribbean, to cover all aspects of water resource management and, in particular, groundwater extraction, pollution and the protection of surface water sources;

(vii) Identify and promote the use of appropriate technology for water resource assessment, water-quality monitoring and water-supply system construction and operation, including appropriate use of low cost energy development (e.g. solar and wind power);

(d) *Public information, education and training*

(i) Develop public awareness through suitable means, including audio-visual media programmes, so as to promote the protection of water quality and the conservation of water;

(ii) Recognising the general lack of trained manpower in the field of water resource assessment, development, management, operation and maintenance, it is essential that training programmes be organized at the subregional level, taking into account the activities of the agencies in the subregional and the continuing need for participation in both basic and specialist training courses and conferences overseas. The most urgent needs are for the centralized and field training of:

a. Water managers;

b. Water supply technicians in leakage detection, pipe repairs, instruments repairs etc.;

c. Professionals in water resource assessment and water supply design;

d. Hydrological technicians in water resources data collection and processing;

e. Villagers in the operation of water supply and waste water treatment systems;

(iii) Establish a unit in an existing university or technical agency for the collection and dissemination of water resource information/publications from within and outside the Pacific region including relevant water resource publications from United Nations agencies;

(iv) Encourage countries to produce reports on water resource problems and their solutions relevant to other countries in the region;

(v) Establish a quarterly newsletter for transmission to all relevant water agencies and departments of information on developments and incoming publications pertinent to the region;

(vi) Promote the establishment of a subregional association of water specialists to provide a direct medium for the interchange of ideas.

(e) *Mitigation of damage caused by cyclones and associated floods*

(i) Carry out, where appropriate, flood loss prevention and management measures, comprising both structural and non-structural measures, to prevent or minimize flood losses;

(ii) In the national disaster preparedness plan/activities include measures for the security of water supplies and water resources structures and where applicable their restoration/repairs.

25. The Meeting recommended that an interdisciplinary mission be organized and co-ordinated by ESCAP to visit the island countries of the South Pacific subregion including Micronesia to examine in depth their water problems and recommend appropriate measures for their solutions. The mission would give particular emphasis to the identification of problems shared by several countries and would formulate subregional action proposals.

26. The Mission would comprise between three and five water specialists in water resource assessment, development and management, from or appointed by member organizations of the United Nations family such as ESCAP, UNDTCD, UNICEF, ILO, FAO, UNESCO, WHO and WMO, subject to availability of resources.

27. The terms of the mission would be:

(a) To review ongoing and planned activities in water resources development and especially those related to the International Drinking Water and Sanitation Decade with governmental agencies involved in water resource assessment, development and management, such as those concerned with public work, water supply, health, agriculture, hydrometeorological services and geology.

(b) To examine in depth problems encountered, such as:

(i) Lack of water resource data and of suitable data collecting system;

(ii) Lack of adequate water supplies, especially in outer areas/islands;

(iii) Environmental problems related to water resources (sea water intrusion, organic and chemical pollution of water);

(iv) Water deficiencies in agriculture;

(v) Deficiencies in technologies (pumps, wells, roof catchments and others);

(vi) Lack of adequate legislation for the conservation and management of water resources;

(vii) Lack of technical personnel and resources especially for operation and maintenance of installations;

(viii) Lack of proper institutional arrangements;

(c) To recommend solutions and measures to maximize the use of manpower and other resources in the development and management of water resources including, *inter alia*

(i) Collection and utilization of water data;

(ii) Water planning, legislation and management;

(iii) Water conservation measures (both as to quantity and quality);

(iv) Training;

(v) Institutional aspects;

(vi) Water costs and financing of water projects.

28. The mission should direct special attention to low-lying limestone islands and small islands, especially atolls.

29. The mission's findings and recommendations should be drafted in co-operation and in consultation with government officials at the decision level and professional technical personnel engaged in activities related to water resources. It should take into account water resources availability; priority needs; a country's resources and the technological level and cultural background of the population concerned.

30. In order to facilitate the task of the mission, it was desirable that the relevant documentation be compiled so as to be made available upon the arrival of the mission. In addition, it was expected that a questionnaire would be circulated to the countries for completion before the arrival of the mission.

31. In this connection, the representative of ESCAP informed the Meeting that pursuant to Economic and Social Council resolution 1981/80 the UNDP resident representatives of all developing countries had been directed by the UNDP Administrator in 1982 to inform the governments that the United Nations was prepared to send on request interdisciplinary missions on water resource development to interested countries. The regional commissions were entrusted with the responsibility of playing leading roles in the organizaton and co-ordination of missions within their respective regions.

32. In the light of the foregoing information, the Meeting agreed that, provided the costs involved would not be charged against country IPFs taking into account General Assembly resolution 3338(XXIX) on developing island countries, the mission should be organized within the framework of the Economic and Social Council's resolution.

33. Accordingly, ESCAP was requested, as soon as possible, to

(a) Inform the countries of the South Pacific subregion of the recommendation of the Meeting to organize a mission in accordance with the terms of reference adopted by the meeting and that such a mission could be organized within the framework of Economic and Social Council resolution 1981/80 concerning interdisciplinary missions;

(b) Request countries to inform ESCAP whether they would require the services of such a mission;

(c) Consult with members of the United Nations system engaged in water resources to ascertain their readiness to participate in the mission, discuss financial arrangement etc.;

(d) Co-ordinate all arrangements for the organization of the mission.

IV. WORKSHOP SESSIONS

(agenda item 7)

34. Workshop sessions addressing some of the problems identified by the meeting were conducted by representatives of the United Nations and specialized agencies and other experts. The subjects of the Workshops were as follows:

(a) Surface water information network design for tropical islands by A.J. Hall (WMO);

(b) Surface water resources assessment – its problems and resolutions by H.M. Ernest (FAO);

(c) Assessment of surface water resources in catchments with limited hydrological data – a case study by D. Kammer (FAO);

(d) Investigations employed for determining yield of the groundwater resources of Tarawa atoll, Kiribati, by T.M. Daniell (UNESCO);

(e) Information and investigations required for assessing water resources for water supply on islands by T.M. Daniell and A. Falkland (UNESCO);

(f) Some espects of water resources planning and management in small islands by R. Dijon (UNDTCD);

(g) Training of water supply personnel in the South Pacific by O.V. Natarajan (WHO);

(h) Technology interchange and training, WMO Hydrological Operational Multipurpose Subsystem (HOMS) by A.J. Hall (WHO).

CLOSING SESSION

35. The report of the Meeting was adopted at the closing session on 19 March 1983 during which the participants thanked the Government of Fiji for its hospitality and generosity in hosting the Meeting and in particular the Ministry of Agriculture and Fisheries for making all the necessary arrangements. The Meeting also thanked Australia for its financial support, ESCAP for organizing the Meeting and the various United Nations bodies and specialized agencies for their co-operation.

Table 1. Summary of area, population, annual rainfall and water sources in 10 South Pacific island countries and Trust Territory of the Pacific Islands

	Cook Islands	*Fiji*	*Kiribati*	*Nauru*	*Niue*	*Samoa*	*Solomon Islands*	*Tonga*	*Tuvalu*	*Vanuatu*	*Trust Territory of the Pacific Islands*						
											Palau Islands	*Federated States of Micronesia*				*Marshall Islands*	*Northern Mariana*
												Yap Islands	*Truk Islands*	*Ponape Islands*	*Kosrae*		
Independence year	1965	1970	1978	1968	1974	1962	1978	1875	1978	1980	United Nations Trust Territory administered by the United States of America						
Capital	Rarotonga	Suva (Viti Levu)	Bairiki (Tarawa)	Nauru	Alofi	Apia (Upolu)	Honiara (Guadalcanal)	Nuku'alofa (Tongatapu)	Funafuti	Vila (Efate)	Koror	Kolonia	Moen	Kolonia		Majure	Saipan
Area of main islands (km^2)	67.08 (Rarotonga) 51.80 (Mangaia) 26.94 (Atiu) 22.27 (Mitiaro)	10,388 (Viti Levu) 5,535 (Vanua Levu)	38 (Tabiteuea) 360 (Kiritimati)	22	258	1,820 (Savai'i) 1,100 (Upolu)	5,565 (Guadalcanal) 4,165 (Malaita) 5,063 (New Georgia Group) 4,068 (Santa Isabel) 3,704 (Choiseul & Shortlands) 3,087 (San Cristobal)	260 (Tongatapu)	5.6 (Vaitupu) 2.5 (Malekula)	3,947 (Santo) 2,024 (Malekula) 915 (Efate)	334 (Babelthup)	56 (Yap)	34 (Tol) 19 (Moen)	334(Ponape)	42.8 (Kosrae)	16 (Kwajalein)	Saipan Tisizan Rota
Number of total inhabited islands and atolls	15	150	. . .	1	1	4	. . .	45	8	80	8	20	14		1	34	4
Total land area (km^2)	236	18,274	719	22	258	2,934	27,750	694	25.9	12,189	460	121	120	440	42.8	180	. . .
Population on main islands	9,802 (Rarotonga, 1976) 1,530 (Mangaia) 2,423 (Aitutaki) 1,312 (Atiu)	435,000 (Viti Levu, 1977) 101,000 (Vanua Levu)	50,400 (Gilbert Islands) 17,129 (Tarawa, 1973)			109,509 (Upolu, 1976) 42,000 (Savai'i)	60,000 (Malaita, 1976) 46,619 (Guadalcanal)	54,437 (Tongatapu) 15,065 (Vava'u) 10,812 (Ha'apia)	2,000 (Funafuti)	16,604 (Port Vila)		3,300 (Yap)			5,522	11,750 (Majuro) 8,000 (Ebeya)	. . .
Total Population	18,128 (1976) 21,323 (1971)	596,000 (1977)	54,400 (1975)	7,500 (1977)	3,843 (1976)	151,515 (1976)	196,823 (1976)	90,072 (1976)	9,000 (1977)	96,532 (1975) 112,596 (1979)	13,519 1977)	8,482	35,220	20,000	5,522	31,000	. . .
Average annual rainfall on main islands (mm)	2,134 (Rarotonga) 1,515-2,000 (other southern islands)	1,900– 6,000+	1,970 (Tarawa) 700-4,000+	203	2,000	2,200– 6,000+	3,000- 5,000 2,250 (Honiara)	1,801 (Nuku'alofa) 2,236 (Vava'u) 1,500 (Tongatapu)	3,562 (Funafuti)	2,500– 4,500	3,810 (Koror)	3,025 (Kolonia)	4,065 (Moen)	4,900 (Airport)	5,000	3,500	. . .
Dry months		July- August			June	May to August	April to November	May to November	September	May- Nov.	Jan.- March	Jan.- March	Jan.- March	Jan.- March	Jan.- March	Jan.- March	Jan.- July
Surface water supply	Streams and springs in southern group; roof water in northern group	Inadequate during drought years	No streams	No streams; shipping water during dry season	No streams	Perennial streams in old rock formation areas	Streams short and steep, adequate supply	Mainly roof catchment	No streams depend on rain catchment	Perennial streams on main islands	Perennial streams on large islands	Very small drainage areas	Very small drainage areas	Plentiful supply	Plentiful	Rain catchment	Three springs
Ground water supply	*Recently developed*	Developed *only to a* small extent	Reticulated *supply on* larger islands and dug wells		One deep well and 50 boreholes producing 400,000 m^3/year	Up to 1977 46 wells drilled. More drilling undertaken	Investigations *in Honiara* and New Georgia Group	70 and 13 *wells on* Tongatapu and Vava'u respectively	One well on *Funafuti,* eight wells on Vaitupu	Developed *at Port* Vila, Santo town and a number of villages	40 and 9 well *on* Peleliu and Angaur	Investiga- *tions and* studies made	8 wells *on Moen*	Dug wells *on atolls*	No need	On larger *islands* only	About 40 *deep wells*
Island type*	(R)(A)	(R)(A)	(A)	(A) (raised)	(A) (raised)	(R)	(R)(A)	(A)(R)	(A)	(R)	(R)(A)	(A)(R)	(R)(A)	(A)(R)	(R)	(A)	(A)(R)

* (A) – Atolls; (R) – High-raised islands.

Annex

LONG-TERM PLAN FOR WATER RESOURCES DEVELOPMENT IN THE PACIFIC REGION

INTRODUCTION

1. A large part of the population in the Pacific region lives on small islands or atolls with only limited available water resources. At present the water supply in towns and villages in many countries of the subregion is provided either by reticulation systems or by roof catchment and is far from adequate. Many of the reticulation systems are operated at low efficiency and high cost. The limited available surface and ground water should be more fully and rationally developed to meet the requirements for domestic and other uses.

2. This comprehensive programme is intended to provide a technically and economically sound framework for the planning, development and management of water resources, suited to the needs and conditions of the countries and peoples of the region, and to enhance their management capabilities. The more specific objectives of the programme are:

(a) Better assessment of the rainfall, runoff and groundwater resources which can be developed and utilized for domestic and other uses;

(b) Improvement of existing water supply systems and facilities for more efficient and economic operation and maintenance;

(c) Promotion of the accelerated development of water resources to improve water supply and water quality in towns and villages;

(d) The strengthening of national capabilities, institutional arrangements and financial support which will enable the programme of improvement and development to be put into effect efficiently;

(e) The strengthening of technical and financial assistance from the international community in training of technical personnel and in water resource development programmes in the region.

I. ASSESSMENT OF WATER RESOURCES

3. Regular and systematic collection of hydrometeorological, hydrological and hydrogeological data needs to be promoted and accompanied by a system for processing quantitative and qualitative information for various types of water bodies. The data should be used to estimate available precipitation, surface-water and groundwater resources and the potentials for augmenting these resources.

4. To this end it is recommended that countries should:

(a) Establish a national body with comprehensive responsibilities for the collection of water resources data;

(b) Expand and extend, as necessary, the network of hydrological and meteorological stations taking a long-term view of future needs;

(c) Establish observation networks and strengthen existing systems and facilities for measuring and recording fluctuations in groundwater quality and level.

(d) Make periodic assessments of surface- and groundwater resources, including rainfall, evaporation, runoff, lakes, and lagoons both for individual basins and at the national level, in order to determine a programme of investigation for the future in relation to development needs;

(e) Establish or strengthen training programmes and facilities for meteorologists, hydrologists and hydrogeologists at professional and subprofessional levels;

(f) Take specific national characteristics and conditions into account in different countries in assessing water quality and establishing water-quality criteria.

5. International organizations and other supporting bodies should, on request, take the following action:

(a) Provide technical assistance to strengthen hydrologic data collection;

(b) Provide assistance for the establishment of groundwater exploration programmes and their proper management.

II. CONSERVATION OF WATER AND EFFICIENCY OF WATER USE

6. On many islands in the region the water supply provided by reticulation systems is usually neither equitably nor efficiently distributed due to high losses and poor operation and maintenance. At the same time a large portion of the region's population does not have reasonable access to a safe water supply. The supply of water from roof catchments is minimal during the dry season on many islands due to the inadequate storage capacity of tanks.

Where water in the region is a limited and valuable resource and its development requires high investment, its use must be efficient and must serve the highest possible level of national welfare.

A. Improvement of the efficiency of water use

7. It is recommended that countries should:

(a) Establish deliberate administrative policies, such as measuring supplies, licensing diversions, charging for water and penalizing wasteful and polluting acts;

(b) Establish appropriate scales of charges that reflect the real economic cost of water or that rationalize subsidies within the framework of a sound water policy;

(c) Use school programmes and all public media to disseminate information concerning proper water use practices.

B. Efficiency in regulation and distribution of water resources

8. It is recommended that:

(a) Studies be conducted to explore the potential of groundwater basins, the use of aquifers as storage and the conjunctive use of surface and ground water to maximize efficiency;

(b) Measures be taken to avoid such withdrawal of groundwater that contamination by sea water intrusion results;

(c) Studies should explore further the possiblity of effecting interbasin transfers of water;

(d) Measures should be taken to ensure systematic planning of the distribution of water among the various uses as a prerequisite for full and rational utilization of the available water for exploitation.

C. Measurement and projections of water demand

9. In order to project future water needs it is desirable to have data on use and consumption and quality by type of user and also the information necessary to estimate the effect of the application of different policy instruments (tariffs, taxes etc.) on the various areas of demand. The demand for water for different purposes should be estimated at different periods of time in conformity with national development goals to provide the basis and the perspective for the planned development of available water resources.

10. It is recommended that countries should:

(a) Initiate action to estimate the demand for water for different purposes, e.g., roof catchment water supply, community water supply, agriculture, industry etc.;

(b) Ensure that statistics on the use and consumption of water should be organized, improved and amplified on the basis of those prepared by the existing services, supplemented by censuses, surveys etc. Censuses on productive activities should include information on volumes of water used, sources of supply, coefficients of reuse and quality data;

(c) Identify the targets to be achieved over different periods of time, taking into consideration anticipated population growths, and the priority to be given in such matters as the number of people to be served with reasonable access to a safe water supply; areas to be irrigated under different crops, and specific production per unit of water;

(d) Consider conservation as an explicit policy, bearing in mind changes in demand, water-use practices, life styles and settlement patterns;

(e) Evolve an appropriate methodology for the management of demand.

D. Community water supply and waste disposal

11. The decade 1980-1990 has been designated the International Drinking Water Supply and Sanitation Decade by the United Nations. The Decade is intended to encourage countries and the international community to make concerted efforts to ensure a reliable drinking-water supply and provide basic sanitary facilities to all urban and rural communities on the basis of specific targets to be set up by each country, taking into account sanitary, social and economic conditions.

12. To this end it is recommended that countries should:

(a) Set targets for community water supply and waste disposal and formulate specific action programmes to attain them, while evaluating the progress made at regular intervals;

(b) Establish standards of quality and quantity that are consistent with the public health, economic and social policies of Governments, ensuring by appropriate measures, duly applied, that those standards are observed;

(c) Ensure the co-ordination of community water-supply and waste-disposal planning with overall water planning and policy as well as with overall economic development;

(d) Adopt policies for the mobilization of users and local labour in the planning, financing, construction, operation and maintenance of projects for the supply of drinking water and the disposal of waste water;

(e) Consider carefully inequalities in the standard of drinking water and sewerage services among the various sectors of the population. As far as possible, design programmes so as to provide basic requirements for all communities as quickly as possible. Priority should be given to the provision of drinking water and sewerage services in areas where the quantity of water supplied is inadequate;

(f) Ensure that the allocation of funds, of other resources and of all forms of economic incentives to community water-supply and sanitation programmes reflects the urgency of the needs and the proportion of the population affected;

(g) Promote the construction of facilities by granting low-interest loans or subsidies to communities and to other entities concerned with water supply and sanitation;

(h) Provide mutual, assistance in the transfer and application of technologies associated with these programmes;

(i) Carry out special water-supply and waste-treatment programmes as national or regional undertakings or as activities of non-profit organizations, such as users' associations, where local resources do not make it possible to achieve the desired goals;

(j) Adopt pricing policies and other incentives to promote the efficient use of water and the reduction of waste water, while taking due account of social objectives;

(k) Seek to promote in rural areas with low population density, where it seems appropriate, individual water-supply and waste-water disposal systems, taking account of sanitary requirements;

(l) Carry out a programme of health education, parallel with the development of community water supply and sanitation, in order to heighten the people's awareness with respect to health;

(m) Establish, at the national level, training programmes to meet immediate and future needs for supervisory staff;

(n) Provide inventory and protection of water-supply sources.

13. International organizations and other supporting bodies should, as appropriate, and on request, take the following action:

(a) Provide technical assistance to countries in the preparation of long-term plans and specific projects;

(b) Consider adapting their criteria for financial assistance in accordance with the economic and social conditions prevailing in the recipient countries;

(c) Promote research, development and demonstration projects for reducing the costs of urban and rural water-supply and waste-disposal facilities;

(d) Promote public health education;

(e) Support research, development and demonstration in relation to predominant needs, particularly for:

(i) Low-cost ground-water pumping equipment;

(ii) Low-cost water and waste-water treatment processess and equipment, with emphasis on the use of materials and skills likely to be available to rural communities for installation, operation and maintenance;

(f) Strengthen the exchange of information, *inter alia,* by arranging expert meetings, and development of a clearing-house mechanism.

E. Agricultural water use

14. Particular attention should be given to land and water management both under irrigated and rainfed cultivation, with due regard to long-term as well as short-term productivity. National policies should provide for the properly integrated management of land and water resources.

15. In this context, countries should:

(a) Bear in mind principles of integrated land and water management when reviewing national policies, administrative arrangements and legislation, and pay heed to the need to augment present levels of agricultural production;

(b) Consider appropriate incentives such as safeguarding water rights for farmers and encouraging holders of irrigated land to adopt management practices compatible with long-term resource management requirements;

(c) Plan and carry out irrigation programmes in such a way as to ensure that surface and subsurface drainage is treated as an integral component and that provision of all requirements is co-ordinated with a view to optimizing the use of water and associated land resources;

(d) Give attention to problems of soil and water conservation through good management of watershed areas which includes a rational crop distribution, improvement of pastures, reforestation and torrent control and the introduction of appropriate agricultural soil conservation practices, taking into account the economic and social conditions existing in the respective watershed areas;

(e) Adopt appropriate pricing policies with a view to encouraging efficient use of waters by water users in animal or farm husbandry and farm management. Particular attention should be paid to groups not reached by formal education;

(f) Take steps to complete irrigation and drainage projects currently under construction as expeditiously as possible, so that benefits on past investment accrue without delay.

F. Industrial water use

16. It is recommended that countries should:

(a) Take into account the water requirements of industries in the planning and formulation of water-development projects, paying due attention to the necessary safeguards against adverse health and environmental impacts arising from industrial activities and to the needs of small-scale and rural industries;

(b) Include waste treatment or other appropriate measures to eliminate or reduce pollution as an integral part of municipal and industrial water supply systems;

(c) Provide stimulating investments and other economic incentives and regulations to use water efficiently, to treat wastes at their source and, where advantageous, jointly with domestic waste.

G. Hydroelectric power generation

17. It is recommended that countries should:

(a) Undertake studies on the multiple and integrated development of the water resources in watersheds with hydroelectric potential;

(b) Integrate plans for the development of hydropower generation with the overall development plans for both the energy and water sectors, taking into account the potential savings in foreign exchange which can accrue therefrom;

(c) Encourage small-scale hydroelectric installation to meet local energy needs, wherever economically, environmentally and socially acceptable.

III. POLICY, INSTITUTION, LEGISLATION AND TECHNOLOGY

18. Integrated policies and legislative and administrative guidelines are needed so as to ensure a good adaptation of resources to needs and reduce, if necessary, the risk of serious supply shortages and ecological damage, to ensure public acceptance of planned water schemes and to ensure their financing. Particular consideration should be given not only to the cost-effectiveness of planned water schemes, but also to ensuring optimum social benefits of water resource use, and to the protection of human health and the environment as a whole.

A. National water policy

19. In most countries, there is a need for the formulation of a national water policy within the framework of and consistent with the overall economic and social policies of the country concerned, with a view to helping raise the standard of living of the whole population.

20. To this end it is recommended that countries should:

(a) Ensure that national water policy is conceived and carried out within the framework of an interdisciplinary national economic, social and environmental development policy;

(b) Recognize water development as an essential infrastructural facility in the country's development plans;

(c) Ensure that land and water are managed in an integrated manner;

(d) Improve the availability and quality of necessary basic information, e.g. cartographic services, hydrometry, data on water-linked natural resources and ecosystems, inventories of possible works, water demand projections and social costs;

(e) Define goals and targets for different sectors of water use, including provision of safe water-supply and waste-disposal facilities, provision for agriculture, stock-raising, industrial needs and development of hydropower in such a way as to be compatible with the resources and characteristics of the area concerned. In estimating available water resources, account should be taken of water re-use and water transfer across basins;

(f) Develop and apply techniques for identifying, measuring and presenting the economic, environmental and social benefits and costs of development projects and proposals. Decisions can then be based on these factors, appropriate distribution of costs can be determined, and the construction and operation of projects can be carried out in such a way that these matters receive continuous consideration at all stages;

(g) Undertake the systematic evaluation of projects already carried out, with a view to learning lessons for the future, particularly in relation to social benefits and ecological changes, which evolve slowly;

(h) Formulate master plans for countries and river basins to provide a long-term perspective for planning, including resource conservation. Projects arising out of the national plans should be well investigated and appropriate priorities should be assigned to them;

(i) Maintain the planning and management of national water resources as a fundamental aim and as a high priority for the satisfaction of the basic needs of all groups of society;

(j) Periodically review and adjust targets in order to keep pace with changing conditions. Long-term guidelines for water management might be prepared for periods of 10 to 15 years and should be compatible with master plans. Planning should be considered a continuous activity and long-term plans should be revised and completed periodically – a five-year period seems advisable in this respect;

(k) Evaluate water-tariff policies in accordance with general development policies and direct any readjustment and restructuring that may be found necessary, so that they may be effectively used as policy instruments to promote better management of demand while encouraging better use of available resources without causing undue hardship to poorer sections and regions of the community. Water charges should as far as possible cover the costs incurred unless governments as a policy choose to subsidize them.

21. International organizations and other supporting bodies should, as appropriate, and on request, assist countries to:

(a) Evolve and formulate national water policies;

(b) Prepare national master plans and, where necessary, river-basin plans and identify projects;

(c) Prepare feasibility reports for projects identified in such general planning studies, which have some prior assurance of financing by interested donor countries or agencies;

(d) Actively promote planning techniques and procedures by arranging information exchange, convening working groups and roving or country seminars, as appropriate, and by disseminating the results of relevant case studies and research studies;

(e) Give urgent attention at the national, regional and international level to developing national expertise in the application of planning techniques by all appropriate means;

(f) Promote various available measures and techniques in public participation and pay particular attention to ways of adapting appropriate techniques to the particular circumstances of countries.

B. Institutional arrangements

22. Institutional arrangements adopted by each country should ensure that the development and management of water resources take place in the context of national planning and that there is real co-ordination among all bodies responsible for the investigation, development and mangement of water resources. The problem of creating an adequate institutional infrastructure should be kept constantly under review and consideration should be given to the establishing of efficient water authorities to provide for proper co-ordination. To this end, it is recommended that countries should:

(a) Adapt the institutional framework for efficient planning and use of water resources and the use of advanced technologies where appropriate. Institutional organization for water management should be reformed whenever appropriate so as to secure adequate co-ordination of central and local administrative authorities. Co-ordination should include the allocation of resources with complementary programmes;

(b) Promote interest in water management among users of water; users should be given adequate representation and participation in management;

(c) Consider, where necessary, the desirability of establishing suitable organizations to deal with rural water supply, as distinct from urban water supply, in view of the differences between the two in technologies, priorities etc.;

(d) Consider the establishment and strengthening of river basin authorities, with a view to achieving a more efficient, integrated planning and development of the river basins concerned for all water uses when warranted by administrative and financial advantages;

(e) Secure proper linkage between the administrative co-ordinating agency and the decision-makers.

C. Legislation

23. Each country should examine and keep under review existing legislative and administrative structures concerning water management and, in the light of shared experience, should enact, where appropriate, comprehensive legislation for a co-ordinated approach to water planning. It may be desirable that provisions concerning water resource management, conservation and protection against pollution be combined in a unitary legal instrument, if the constitutional framework of the country permits. Legislation should define the rules of public ownership of water and of large water engineering works, as well as the provisions covering

land ownership problems and any litigation that may result therefrom. It should be flexible enough to accommodate future changes in priorities and perspective. To this end, it is recommended that:

(a) An inventory and a critical examination of rules (whether written or unwritten), regulations, decrees, ordinances and legal and legislative measures on water resources and development should systematically be carried out;

(b) A review of existing legislation be prepared in order to improve and streamline its scope to cover all aspects pertaining to water resource management; protection of quality, prevention of pollution, penalties for undesirable effluent discharge, licensing, abstraction, ownership etc.;

(c) Although legislation should generally be comprehensive, it ought to be framed in the simplest way possible, and be consistent with the need to spell out the respective responsibilities and powers of governmental agencies and the means for conferring rights to use water on individuals;

(d) Legislation should allow for the easy implementation of policy decisions which should be made in the public interest, while protecting the reasonable interests of individuals;

(e) Legislation should define the rules of public ownership of water projects as well as the rights, obligations and responsibilities and emphasize the role of public bodies at the proper administrative level in controlling both the quantity and quality of water. It should appoint and empower appropriate administrative agencies to carry out this controlling function and to plan and implement water-development programmes. It should also spell out, either in primary or subordinate legislation, administrative procedures necessary for the co-ordinated, equitable and efficient control and administration of all aspects of water resources and land-use problems as well as the conflicts which may arise from them;

(f) Legislation should take into account the administrative capacity to implement it;

(g) Countries should document and share their experience so as to have a basis for possible improvement of their legislation;

(h) Priority should be accorded to the effective enforcement of the provisions of existing legislation, and where necessary, administrative and other arrangements should be strengthened and rendered more effective to achieve this objective.

24. International organizations and other supporting bodies should, as appropriate, and on request, assist countries to:

(a) Improve and streamline existing legislation and prepare new draft legislation;

(b) Arrange the exchange of information and disseminate the results and experience of selected countries for the benefit of others.

D. Development of appropriate technology

25. Developing countries need to build up technological capability at the national and regional levels. Priority should be given to technologies of low capital cost, and the use of local raw materials and resources taking environmental factors into account. Developed countries should accelerate the process of transfer of experience and know-how, technical assistance and training to developing countries.

26. To this end it is recommended that countries should:

(a) Review the adequacy of existing institutional arrangements for the development of appropriate technologies in water resource management, and provide support for their development;

(b) Provide every possible encouragement and support to national institutions concerned with the development of appropriate technologies in water resource development;

(c) Encourage the widest possible diffusion of acquired knowledge on the development of appropriate technology; establish and expand enterprises and productively apply the appropriate technologies that have been developed;

(d) Review the extent of public participation in the planning, construction, operation and maintenance of water projects and take steps to ensure a greater level of participation, through consultations and the transfer of knowledge starting at the village level;

(e) Develop facilities for the servicing and maintenance of installed hydraulic equipment, including the manufacture of spare parts;

(f) Promote the standardization of equipment to help solve operational problems resulting from shortages of spare parts;

(g) Promote subregional and regional arrangements for the exchange of information and experience in the planning design and construction of water projects with other regions where similar conditions prevail.

27. International organizations and other supporting

bodies should, as appropriate, and on request, assist countries to:

(a) Make a review of the adequacy of existing constitutional arrangements for the development of appropriate technology in the water resources field;

(b) Support national efforts to manufacture construction materials, to service imported equipment, to manufacture spare parts and to manufacture the equipment itself;

(c) Evolve standard designs and plans, wherever possible;

(d) Raise funds to enhance the transfer of technologies and to adapt these technologies to local needs.

IV. PUBLIC INFORMATION, EDUCATION AND TRAINING

A. Public information and extension service

28. In order to ensure maximum attention to the proper utilization, protection and conservation of water, it is of decisive importance that all citizens be made aware of fundamental matters relating to water. For that reason education and research have to be efficiently supplemented by the provision of broad information to the public. Effective public information aims at the creating of general as well as personal responsibility for the crucial water issues. It is considered an essential task for governments to motivate their citizens to adopt a sound view on matters concerning their daily handling of water. Given a general feeling of responsibility for the local resources, people will be aware of the importance of the protection and conservation of water.

29. In this context it is recommended that countries should:

(a) Direct information to all citizens, first of all through the normal channels offered by primary and adult education and in connection with regular health programmes and information schemes for parents;

(b) Initiate special information campaigns conducted by the use of brochures, newspapers, radio and television, and other forms of popularization;

(c) Prepare people for the consequences of changed life patterns which could be the effect of improved water availability in areas where water shortage formerly restricted various activities;

(d) Inform people of the negative ecological, hydrological and sanitary consequences of misuse of water.

B. Education and training

30. In the past many countries in the region have relied on foreign countries to supply technical assistance in the design and construction of water projects. Countries should accord priority to conducting surveys to determine national needs for administrative, scientific and technical manpower in the water resources area.

31. In this context it is recommended that countries should:

(a) Conceive manpower surveys for water development as integral components of overall surveys of the need for trained manpower in all sectors of economic development in the nation, so as to provide really effective instruments for policy planning and project implementation;

(b) Take steps to encourage national professional experts to work in their own countries;

(c) Take steps to strengthen and expand the facilities and existing institutions, universities, colleges, polytechnics and training centres by providing more teachers, teaching materials etc., so that the quantity and quality of their output can be increased;

(d) Review the curricula of the existing institutions and training centres and expand them to include subjects pertaining to water resource development, the conservation of land and water resources, the teaching of basic anti-pollution measures for lessening pollution and other water-borne diseases in rural communities;

(e) Take steps to establish training programmes, on-site training and training centres for water plant operators and water distribution operators as well as training in other areas where a special need exists;

(f) Publish technical manuals and other guidance material in water project design and construction, with particular relevance to local conditions;

(g) Take steps to encourage operational managers and supervisors to play their part, both individually and collectively, as non-professional and part-time trainers and instructors of their own subordinate staff.

32. International organizations and other supporting bodies should, as appropriate, and on request, assist countries to:

(a) Conduct surveys on available manpower and needs in the field of water resources management and utilization;

(b) Establish new training centres, as and when requested by countries;

(c) Provide scholarships for undergraduate courses.

V. MITIGATION OF DAMAGE CAUSED BY CYCLONES AND ASSOCIATED FLOODS

33. In order to mitigate damage caused by cyclones and associated floods there is need for programmes to:

(a) Upgrade meteorological observing and telecommunication facilities to improve the capability for forecasting, detecting and tracking cyclone and for issuing timely and accurate cyclone warnings to their populations;

(b) Carry out, where appropriate, flood loss prevention and management measures comprising both structural and non-structural measures to prevent or minimize flood losses;

(c) Prepare and/or improve national disaster prevention and preparedness plans which must be disseminated as widely as possible to the people;

(d) Determine the extent of vulnerability to storm surges on the basis of historical records so that adequate protection measures could be devised and installed;

(e) Establish institutional arrangements for the compilation of cyclone and flood damage which would be useful for planning purposes.

Part Two

WORKING PAPERS PRESENTED BY THE SECRETARIAT

I. WATER RESOURCES IN SOUTH PACIFIC ISLAND COUNTRIES AND THE TRUST TERRITORY OF THE PACIFIC ISLANDS

(NR/MWRD/1)

INTRODUCTION

The Pacific island countries share characteristics common to a large number of islands and atolls. Each of them is make-up of islands and atolls and have a small geographic area, while great distances separate them from any continent or large island. Water supply is difficult for domestic and other uses, particularly in densely populated areas, due to the small land area, a lack or perennial streams and uneven distribution of rainfall.

This paper describes the physiography, population and its distribution, climate and natural conditions of surface water and ground-water in the South Pacific island countries and the Trust Territory of the Pacific Islands in the North Pacific.

I. SOUTH PACIFIC ISLAND COUNTRIES

A. Cook Islands

1. Physiography and population

There are 15 islands in the Cook group, with a total area of 236 km^2, scattered over an area of some 2.2 million km^2 and situated between 8° and 23° S latitude and 156° and 167° W longitude. They have a population of about 18,000.

In the Southern group, Rarotonga (67.08 km^2), the capital and largest island, Mangaia (51.80 km^2), Aitutaki (28.25 km^2), Atiu (26.94 km^2), Mitiaro (22.27 km^2) and Mauke (18.39 km^2) are elevated and volcanic in origin, and they support 88 per cent of the total Cook Islands population.

Manuae (6.22 km^2) and Takutea (0.29 km^2) in the Southern group and the islands of the Northern group, comprising Penrhyn (9.84 km^2), Manihiki (5.44 km^2), Rakahanga (4.14 km^2), Palmerston (2.07 km^2), Pukapuka (1.29 km^2) and Suwarrow (1.52 km^2) are low lying atolls, while Nassau (1.29 km^2), in the Northern group, is a sand key on a coral reef foundation. A total population of some 2,000 on the northern islands live mainly on a diet of fish and coconuts.

2. Climate

The wet season, when the climate is warm to hot and humid, extends from December to March. On Rarotonga, the mean annual temperature and rainfall over the past 40 years were 23.6° C and 2,134 mm. The other islands in the Southern group receive an annual average of between 1,515 and 2,000 mm of rainfall.

3. Water resources

(a) *Surface and rain water*

Water supplies on the volcanic islands were originally obtained from permanent inland streams or fresh water springs near the coast. Subsequently, rain water tanks, initially constructed of sand and cement and later of galvanized iron and steel, were installed for community purposes. These community facilities, usually of 45 m^3 capacity, are still found in many villages, but the installation of individual household tanks in houses that increasingly reflect European design has resulted in many families having their own supplies.

In the Northern group, roof water stored in tanks is the main source of domestic supply. Additional supplies could be obtained from the fresh water lens, but the pumping facility and abstraction rates need careful design and management to maintain acceptable quality.

(b) *Ground water*

In recent years the gallery system of water supply has been introduced on Rarotonga and on Aitutaki. The installations, consisting essentially of a porous pipeline buried below the water table along an intake area, are maintenance free once commissioned. On Rarotonga, water from each of the galleries is gravitated via storage reservoirs to a ring main which services virtually every domestic, industrial and commercial facility on the island.

On the islands of Aitutaki, Atiu and Mauke, drillholes in the volcanics supplement community water supplies. Their yield is less than 800 litres per hour. Depth of hole is determined by the height of the drill collar above sea level.

A drilling project sponsored jointly by the New Zealand and Cook Islands Governments was undertaken in 1979 on the outer islands of the Southern group. It entails drilling eight holes in the volcanics on Mangaia, Atiu, Mauke and Aitutaki, and one hole in the Makatea (a broad uplifted coral reef) on Mauke. In the volcanics the water is probably perched, with some leakage penetrating to underlying rocks. In the Makatea the hole will penetrate to the dome shaped fresh water lens known to "float" on salt water.

Although in the Southern group the quality of water is variable, it generally receives little or no treatment.

B. Fiji

1. Physiography and population

Fiji is composed of more than 300 islands, most of which are situated between 15° and 22° S latitude and 177° W and 175° E longitude. The total land mass is 18,274 km^2. The two largest islands, Viti Levu and Vanua Levu, have areas of 10,388 and 5,535 km^2 respectively. The next two largest islands are Kandavu and Taveuni. Situated adjacent to these four islands are three main groups of small islands, the Lomaiviti-Moala group, the Mamanutha-Yasawa group and the Lau group. Isolated from all these islands is Rotoma, which is situated 420 km north of Viti Levu.

Viti Levu has a central plateau with elevations greater than 1,000 m. The lowlands are found below 150 m and are generally flatter land forming the coastal fringe and several large deltas, where the majority of the population has settled. The total population of Fiji was estimated at 596,000 in 1977. About 73 per cent of the population lives on Viti Levu, while 17 per cent lives on Vanua Levu.

2. Climate

Fiji has a tropical oceanic climate. The temperature varies from 16° C to 32° C. The dominant winds are the south-east trades which control the pattern of rainfall. The high land which lies on the windward side receives more rainfall. The south-eastern halves of Viti Levu and Vanua Levu receive a great deal of rainfall. The average annual rainfall varies from 1,900 mm to 3,600 mm. The wettest month is usually March and the driest month is July.

The only parts of Fiji where the mean annual rainfall is less than 1,800 mm are in the extreme west of Vanua Levu, around the coastal fringes of western Viti Levu and in parts of the Yasawa and Lau Islands. The annual rainfall between 1965 and 1969 was very low, causing drought conditions and considerable hardship over a large part of Fiji.

3. Water resources

(a) *Surface water*

Surface water is used to supply all the large communities and most of the villages. Nearly all villages have been settled on the tributaries of main rivers, which usually remain clean after rains. The surface water can be readily polluted by village and cattle effluent.

During the drought years of the late 1960s, the Government had to truck water to isolated communities or to ship water to distant islands at great expense. In recent years, owing to the increase of tourists in the drier and sunnier parts of Fiji, greater demands have been placed on surface and ground water.

(b) *Ground water*

To date ground-water supplies have been developed only to a small extent. The main areas where ground water has been investigated are in western Viti Levu and Venua Levu. No aquifer has yet been found that will provide large urban supplies of suitable quality. The main use of ground water will therefore be for rural water supply where surface supplies are inadequate or not available. There is need for investigation of ground water on smaller islands which are either limestone or volcanic.

C. Kiribati

1. Physiography and population

Kiribati consists of four main groups – the Gilberts, the Phoenix Islands, the Northern and Southern Line Islands and Ocean Island. They are situated between 4° N and 3° S latitude and 172° E to 157° W longitude. The Gilberts group has a total land area of 272 km^2, among which the largest island is Tabiteuea (38 km^2) and the smallest is Tamara (4.8 km^2). Ocean Island is 6.3 km^2; the Line Islands total 412 km^2; and the Phoenix group total 28.2 km^2. The total land area is 719 km^2. The islands are all low-lying atolls, except for Ocean Island which rises to 87 m about sea level.

The estimated population at the end of 1975 was 54,400 of whom 50,400 lived on the Gilbert Islands, 2,430 on Ocean Island and 1,570 on the Line Islands. At the December 1973 census, Tarawa was the most populous island, with a total of 17,129. The administrative centre, Bairiki, is on Tarawa.

2. Climate

The climate of the area is dominated by the dry equatorial zone, which extends as a narrow belt over the Central Pacific, and by an intertropical front in the zone of convergence of north-easterly and south-easterly trade winds which remain fairly constant between 5° and 8° N.

Rainfall varies considerably, not only between the islands, but also from year to year. In an average year, annual rainfall in the Gilberts ranges from 1,000 mm in the vicinity of the equator, to over 1,500 mm on Tarawa, and 3,000 mm in those islands farthest to the north. In the Phoenix Islands, annual rainfall ranges between 1,000 and 1,500 mm, and the Line Islands' average varies from about 700 mm at Christmas Island to more than 4,000 mm at Washington Island 400 km away. Ocean Island, the central and southern Gilberts, the Phoenix Islands and Christmas Island are subject to severe droughts lasting many months. At such times, as little as 200 mm of rain may fall in a year.

3. Water sources

(a) *Surface water*

No streams exist on any of the atolls. The surface water bodies of the lagoons contain saline water. Fresh water ponds occur on the northernmost atolls, Butaritari and Makin, which receive high annual rainfall.

(b) *Ground water*

Fresh ground-water occurrence of a significant extent is, in general, limited to the larger islands, where lenses of fresh water, floating on salt water, have developed. Generally, fresh water lenses extend on those parts of the islands where coral sands form a sufficiently wide central ridge. The thickness of the fresh water lens below sea level is controlled by the head of fresh water above sea level. Observations on some of the islands indicate a thickness of fresh water lenses ranging between 2 and 40 m.

Butaritari Island appears to be almost entirely underlain by a fresh water lens. Fresh water is found in shallow wells as close as 15 m from the lagoon and 45 m from the ocean.

Sources of water supply in Kiribati include shallow wells, waterholes, galleries and roof catchments collecting rainfall. A centrally organized water supply exists so far only on the southern islands of the Tarawa atoll.

For the water supply of Tarawa, presently about 210 m^3 per day of ground water are pumped from galleries at three different areas. Additionally, rain water from roof catchment is supplied to the system. The present population of southern Tarawa, numbering about 15,000, can be supplied at a rate of from 9.6 litres per person per day in dry periods to 36.6 litres per person per day in periods with sufficient rainfall. Additionally, a sea-water sewerage system has been installed in the densely populated island of Betio. Urban Tarawa water supply is potable and is chlorinated. Elsewhere, water supplies are relatively contaminated and polluted and have high total coliform counts. No water treatment is undertaken.

D. Nauru

1. Physiography and population

Nauru, a single raised atoll of 22 km^2 with a circumference of 19 km, is located about 42 km south of the equator at 166° 56'E longitude. The ground rises from a sandy beach to form a fairly fertile belt, 150 to 300 m wide, encircling the island. Further inland the coral cliffs rise to a central plateau about 30 m above sea level. The plateau is composed largely of phosphate-bearing rock, which covers about three-fifths of the entire area. The highest point is 70 m above sea level.

In March 1977 the estimated total population was 7,500. The population is widely scattered along the coastal fringe, but the migrant workers are concentrated in dormitory apartment blocks in the Nauruan Phosphate Corporation area on the waterfront near its loading cantilevers.

2. Climate

The climate is tropical and tempered by sea breezes. The average annual rainfall is only 203 mm. The annual rainfall is extremely variable. It has been as low as 104 mm and as high as 4,572 mm. The wettest period is during the westerly monsoon season from November to February.

3. Water resources

There are no rivers on the island. Water supplies are mainly from roof catchments. During prolonged dry periods, water is imported as ballast in the ships which regularly call at the island, pumped ashore into cement storage tanks and delivered by truck to households. This operation is handled by the Nauruan Phosphate Corporation.

There are some shallow wells in the areas which were populated prior to the start of the phosphate mining industry and where palm trees, pandanus fruit trees and vegetables are grown.

E. Niue

1. Physiography and population

Niue, an uplifted coral island (the largest in the world) with an area of 258 km^2, is located at 19° S latitude and 169° W longitude. Originally it was an atoll; a ring of reefs and islets surrounding a lagoon. Orogenic movements pushed up the lagoon. The island takes the shape of two terraces, the lower being 27 m above sea level and the upper saucer-shaped plateau rising to 65 m.The island extends 19 km from north to south and has a circumference of over 60 km by road.

The most recent census in September 1976 gave a total population of 3,843. The population is entirely settled in the coastal area. The central plateau is covered by a thick bush and is underdeveloped. The administrative centre, Alofi, recorded a population of 970.

2. Climate

Situated just inside the tropics, Niue has a pleasant climate and is fanned by the south-east trade winds. The island is on the edge of the hurricane belt. The average annual rainfall is 2,177 mm. The wettest month is January with average rainfall of 272 mm, while the driest month is June with an average rainfall of 84 mm.

3. Water resources

There are 13 villages along the coast. There is no surface water. Traditionally, drinking and domestic water is obtained from natural cavities and roof catchments. In recent years, one "deep well" was dug and about 50 boreholes were drilled. They are all equipped with reciprocating pumps which yield a maximum of 200 gallons per hour. Total ground-water extraction may amount to approximately 400,000 m^3 per year. The boreholes are located 1.5 to 2.0 km from the coast. Some boreholes drilled near the coast have yielded brackish water. As yet no drilling has been done in the interior.

F. Samoa

1. Physiography and population

Samoa consists of two large islands and several small ones and has an area of 2,934 km^2. It is located between 13^{o} and 15^{o} S latitude and 168^{o} and 173^{o} W longitude. The two main islands are Upolu (1,100 km^2) and Savai'i (1,820 km^2). The island of Upolu extends about 72 km from east to west and 24 km from north to south. Savai'i is also about 72 km across but is 35 km wide.

The islands have numerous volcanic peaks, the highest being Mr. Mata'aga of 1,850 m on Savai'i and Mt. Fito of 1,100 m on Upolu. Savai'i has a central core of volcanic peaks surrounded by a ring of lava-based plateau, then lower hills and coastal plains. Upolu has a chain of volcanic peaks running from one end of the island to the other with hills and coastal plains on either side.

The islands' volcanic origins have produced a terrain with abundant streams and waterfalls. At sea, the coral reef is broken in many places, thus exposing the lagoon.

The estimated population at the end of 1976 was 151,515, which included 109,509 on Upolu and 42,006 on Savai'i. The Samoan population in New Zealand at the same date was 27,400, about half being New Zealand born.

2. Climate

The south and south-east windward areas receive from 5,000 to 7,000 mm of rain annually. On the leeward side, the islands receive from 2,500 to 3,000 mm of rain. There is, however, a marked dry season from May to August. At the capital, Apia, the average annual rainfall for the past 75 years of record is 2,929 mm, while the maximum and minimum annual rainfalls are 4,387 mm and 1,765 mm respectively.

3. Water resources

(a) *Surface water*

The depth of weathering of the volcanic rocks increases with age and reduces their infiltration capacity. The eastern part of Upolu is composed of the oldest rocks, the Fagaloa Volcanics, and these are largely overlain by the generally more permeable Salani Volcanics in the south-eastern and central parts of the island. On Savai'i, Fagaloa and Salani formations are mainly restricted to the central northern and southern portions of the island. The relatively low permeability of the Fagaloa rocks and of certain areas of the Salani Volcanics results generally in high water tables and their perennial streamflows. On the younger parts of the islands, western Upolu and the western half of Savai'i, the high permeability results in rapid infilatration and dispersion of direct recharge through ground water to the sea. Streamflows in these areas are rare to non-existent. The complex rainfall-runoff relationship in these volcanic areas is controlled very largely by this variability and by temporal variations in the elevation and configuration of the ground water table.

Though extremely diverse, most Samoan water supply schemes are reticulated by gravity and fed from inland streams and springs. The capacity of the reticulation system, as well as the dry-weather flows at the source, is frequently inadequate. Water quality is often poor, in particular during the wet season when streams carry a large amount of debris from upstream. Other populated areas in the western parts of Upolu and Savai'i have no water supply.

The extension of the urban areas and the development of rural areas, coupled with a rapid population growth, consequently require considerable additional quantities of water. Schemes for tapping additional surface water and upgrading existing reticulation systems are being undertaken. Construction of large-scale artificial catchment areas for rain water harvesting in the higher island areas is planned.

(b) *Ground water*

Up to 1977, a total of 46 wells had been drilled or dug in Samoa. The majority of these wells are located in coastal and near coastal areas (500 to 3,000 m inland) with a maximum site altitude of 80 m above mean sea level. Saline water intrusion is a general problem where wells are located too close to the coastline, particularly in the youngest volcanic formations.

After the completion of the 1976-1977 programme, a truck-mounted rotary drill (maximum drilling depth 200 m at 22.5 cm bore diameter) was being used by the Geological Services Section. It was envisaged to drill 16 to 18 additional wells; six in the Apia town area, which have been completed and are producing 100 litres per second, seven on Savai'i and three or four wells in the higher inland areas of Upolu.

Because of its isolated location, Samoa has very poor access to services of overseas manufacturers of pumps, pipes, engines and spare parts. Only 35 per cent of the existing wells on both Upolu and Savai'i were in operation in 1978. Once the problems of supplying equipment and providing service for repair and maintenance have been overcome, ground water will form a reliable water source of increasing importance for industrial, agricultural and domestic purposes.

G. Solomon Islands

1. Physiography and population

Solomon Islands consists of a double chain of six large islands and many smaller ones located between 5° and 12° S latitude and 155° and 170° E longitude. The total land area is 29,785 km^2.

The largest island is Guadalcanal (5,650 km^2). The other major islands are Choiseul, New Georgia, Santa Isabel, Mataita and San Cristobal. They vary in length from 145 to 200 km, and in width from 30 to 50 km. The major islands are rugged and mountainous, the highest named peak is Mt. Makarakombou (2,447 m) on Guadalcanal. The only extensive coastal plains are on the north-east coast of Guadalcanal. Many outer smaller islands are coral atolls and raised coral reefs.

The most heavily populated island is Malaita, with about one third of the group's population (60,000 in 1976). The next most populated island is Guadalcanal (including the capital, Honiara) with 46,619 in 1976. Honiara had a population of about 15,000.

2. Climate

Solomon Islands experiences a tropical climate, hot and humid with an oceanic modification. The wet season begins in late October and ends in April. The dry season begins in April and may extend to November. Cyclones are sometimes experienced during the wet season. The average annual precipitation in most land areas is between 3,000 and 5,000 mm. The average annual precipitation at Honiara is 2,250 mm.

Temperatures vary between 22° C and 29° C. Inland areas sometimes experience temperatures as low as 16° C at night.

3. Water sources

(a) *Surface water*

All the larger islands are well watered by rivers which are short and steep over most of their length. The longest river, Mbokakimbo, on Guadalcanal, is 92 km in length and drains an area of 365 km^2. Flash flooding is common in the larger rivers.

Good drinking water is generally abundant throughout the country except in some outlying areas during extreme drought conditions. A reticulated water supply is provided in Honiara, Gizo, Auki, Malu'u, Mundo, Dodo Creck, Kira Kira, Sauta Cruz and Tulagi.

(b) *Ground water*

Three ministries are involved in ground-water development. They are the Ministry of Works and Public Utilities, the Ministry of Health and Medical Services and the Ministry of Natural Resources. Their activities are co-ordinated by the Water Resources Committee. The Committee formulates policies on surface and ground water development.

Investigations for ground water have been mostly confined to Honiara and the areas east and west of it. Most of these have been aimed at locating water for domestic and industrial consumption. A smaller area that has been under investigation is Noro in the New Georgia group, where urban and industrial development were under consideration. With a growing population, increased economic activities and the uneven distribution of surface water, ground water will become more significant as a natural resource.

Most wells produce potable water. During drilling, water samples are collected and tested by the geochemical laboratory of the Ministry of Natural Resources.

H. Tonga

1. Physiography and population

Tonga consists of three main island groups with a fourth smaller group (Niuas) to the north. The three main groups from north of south are Vava'u (seven islands), Ha'apai (16) and Tongatapu (four). They are located between 15° and 23° 30' S latitude and 173° and 177° W longitude. Total land area is 694 km^2. The largest island is Tongatapu (30 km long and 14 km at its widest part) with an area of 260 km^2. From north to south the kingdom extends 560 km.

There are about 150 islands, but only 45 are permanently inhabited. The census held in December 1976 revealed a total population of 90,072, compared with 77,421 in 1966. Tongatapu had a population of 54,437, Vava'u 15,065, Ha'apai 10,812, Eua 4,486 and Niuas 2,328. The population of the capital, Nuku'alofa, was 18,396 in 1976.

2. Climate

The climate is semi-tropical with moderate rainfall and high humidity during the west season which extends from December to April. Meteorological records from Nuku'alofa show temperatures ranging from 10.6° C to 30.5° C. Average annual rainfall between 1949 to 1970 amounted to 1,801 mm at Nuku'alofa and 2,236 mm at Vava'u.

3. Water sources

There are no large surface water supplies in Tonga, and the source of domestic, agricultural and industrial water is from either roof catchment or from hand dug or drilled wells tapping a lens of fresh water floating on denser sea water.

The piped water supply in major islands is shown in table 2.

A large part of the rural population gets water directly from rain. The roof catchment area and volume capacity of storage tanks of 35 villages as of 1976 are shown in table 3.

Table 2. Piped water supply in major islands of Tonga

Group / Island	Area (km^2)	Population	Number of wells	Piped water supply: Coverage of island	Piped water supply: Availability
Niuas	43.5	2 328	1	Nil	½
Vava'u	114.0	15 065	13	¼	Full time
Ha'apai					
Lifuka		2 947	2	¼	Full
'Uiha		1 647	2	¼	Full
Tongatapu	260	57 437	70	¾	Full
'Eua	30	4 486	–	¾	Full

Table 3. Rural water supply in Tonga

Island	Village	Area (km^2)	Population	Roof area catchment (m^2)	Tanks	Volume (litres)
Vava'u Group						
Vava'u	Tefisi	100	600	300	1	34 095
	Vailamo		135	67	1	29 549
	Longomapu		600	483	4	109 104
	Toula		185	195	1	54 552
Koloa	Holeva		209		1	31 822
	Koloa	2	106	237	1	63 644
Okoa	Okoa	0.5	183	207	1	45 460
Olo'ua	Olo'ua	0.4	114	181	2	43 414
Pangaimotu	'Utulei	8	162	297	1	40 914
'Utungake	'Utungake	1.9	240	209	1	27 276
	Nga'unolo	1	215	272	1	63 644
Ofu	Ofu	1	280	358	1	45 460

Table 3. *(Continued)*

Island	*Village*	*Area (km^2)*	*Population*	*Roof area catchment (m^2)*	*Tanks*	*Volume (litres)*
Ha'apai Group						
Mo'unga'one	Mo'unga'one	1.5	321	294	5	123 992
Ha'ano	Muitoa		150	50	2	102 285
	Ha'ano	6.5	362	622	4	200 024
	Pukotala		262	212	1	90 920
	Fakakakai		404	520	3	186 841
Foa	Fotua	14	262	427	6	195 478
Lifuka	Koulo	13	285	485	8	200 933
	Holopeka		196	260	6	145 472
Tofua	Hokula)	)		77	2	40 459
	Hamatu'a)	42)	107	32		
	Manaka)	)		48	1	5 455
Fotuha'a	Fotuha'a	2	203	290	4	94 330
Lofanga	Lofanga	1.5	428	720	3	90 693
Ha'afeva	Ha'afeva	1.5	551	929	2	90 920
Kotu	Kotu	0.5	180	302	1	45 460
Matuku	Matuku	0.3	115	104	1	93 193
Tungua	Tungua	1.2	439	585	3	172 293
'O'ua	'O'ua	1	257	477	4	202 524
Nomuka	Nomuka	3.8	971	1 550	7	319 129
Fonoifua	Fonoifua	1	158	165	2	86 374
Mango	Mango	0.8	116	93	2	63 644
Tongatapu Group						
'Atata	'Atata	1	126	291	4	144 563
'Euaiki	'Euaiki	0.8	131	409	6	112 173
Tongatapu	(total)	260	57 437			
'Eua	(total)	30	4 486			

I. Tuvalu

1. Physiography and population

Tuvalu is a group of nine coralline atolls and islands (raised atolls) of which eight are inhabited. It is located between 5° and 10°S latitude and 176° and 179°E longitude. The total land area of the islands is 25.9 km^2. The largest island is Vaitupu, 5.6 km^2. The main island, the seat of the Government, is Funafuti, with an area of 2.5 km^2. The smallest atoll, Niulakita, is only 0.4 km^2. The atolls extend over 560 km in a winding line from Nanumea in the north to Niulakita in the south. They are no more than 5 m above sea level.

According to the census of 8 December 1973, the total population was 5,887. By the end of 1977, the estimated population was 9,000. There were about 2,000 residents in Funafuti; Nuitao, Nanumea and Vaitupu each had a population ranging from 800 to 1,200.

2. Climate

The climate is not unduly trying, particularly during the season of the north-easterly trade winds (March to October), but it becomes enervating during the season of rains and westerly gales (November to February). Rainfall varies considerably, not only between the islands but also from year to year. At Funafuti the average annual rainfall of the 34 years of record is 3,562 mm. The wettest month is January, with average rainfall of 412 mm, while the driest month is September, with an average rainfall of 203 mm.

Table 4. Number of wells and tanks in Tuvalu

Islands	*Area (km^2)*	*Population*	*Annual rainfall (mm)*	*Bailed wells*	*Tanks*	*Remarks*
Nukulaelae	1.66	347	2 643	1	5	Yield brackish water
Funafuti	2.54	2 120	3 083	1	7	Little prospects for ground water due to narrowness
Nukufetau	3.07	626	2 311	3	7	Three shallow wells on small islet of Fale yield fresh water
Vaitupu	5.09	1 273	3 057	8	8	Good prospects for ground water
Nui	3.37	603	3 489	13	6	Most of larger islets may hold a fresh water lens
Niutao	2.26	866	2 135	3	9	May have substantial ground water in the centre
Nanumanga	3.10	605	3 050	–	14	
Nanumea	3.61	844	3 257	1	10	Brackish water on the main island. Fresh water wells on Motofoliki islet
Niulakita	0.41	65	3 354	–	2	Good prospects for ground water

3. Water sources

Because of the atoll terrain, there are no rivers. Water supplies come from roof catchments and bailed wells. The pumped water from ground water is held in tanks with a capacity of 50,000 gal or more. The number of wells and tanks in each island is shown in table 4.

J. Vanuatu

1. Physiography and population

Vanuatu is an archipelago comprising 80 islands scattered over 800 km from north to south. They are located between 12° and 21° S latitude and 166° and 171° E longitude.

The total land area is 12,189 km^2, with the main islands of Santo (3,947 km^2), Malekula (2,024 km^2) and Efate (915 km^2). The largest island, Santo, is 145 km from north to south and 65 km from east to west. Efate, where the capital Vila is situated, extends about 45 km from east to west and 30 km from north to south. Other large islands of the group are Aoba, Maewo, Pentecost, Ambrym, Erromanga, Tanna and Aneityum.

The highest peak in the group is Mt. Tabwemasana of 1,877 m on the island of Santo. While half the islands are simply islets and rocky volcanic outcrops, the other half are punctuated by numerous peaks in a terrain dominated by mountains and plateaux with only limited coastal plains.

The 1967 census revealed a total population of 77,988, including about 4,000 French subjects and 1,600 British subjects. The estimated population in December 1975 was 96,532, of which 16,604 lived in Vila and 4,954 in the Santo urban area. The rest lived in rural areas.

2. Climate

By and large the climate is of the hot, humid and rainy type. Average monthly temperatures recorded in in Port Vila and Santo vary from 20° C in August to 30° C in January. Average annual rainfall ranges from 2,500 to 4,500 mm, with 200 to 225 rainy days. Rainfall and temperatures decrease from the south to the north. In the summer from December to April, tropical cyclones sweep across the archipelago.

3. Water sources

(a) *Surface water*

In spite of the abundance of rainfall, most islands do not have perennial streams as a result of their small dimensions and rugged topography. They have only short river courses and gullies with short-lived flows. The only exceptions are some perennial streams on the main islands, i.e. the Jourdain, Sarakata and Navaka rivers in Santo, the flows of which have not been studied yet. There are some lakes in the craters of extinct volcanos. The water in these lakes is not utilized as they are too far away from human settlements.

Owing to the lack of perennial streams, a large part of the population relies on ground water or rain water for domestic use. As a result of the scattering of inhabitants, only 20 per cent of the rural population uses ground water, while 80 per cent collects rain water in barrels, tanks or cisterns.

(b) *Ground water*

The first hydrogeological missions were initiated in 1965, focusing upon a preliminary reconnaissance of Vate Island, of the south-eastern parts of Santo Island and of two volcanic islands of the Shepherd group, Tongariki and Tongoa. A full-time hydrogeologist started working in 1972. Since then, local water resource studies have developed as a support to rural water supply projects. By the end of 1980, the Department of Mineral Resources and Rural Hydraulics, under the "Land Ministry", was in charge of water resource studies and of the execution of water development and distribution projects. In villages the community groups were responsible for the management of water supply systems, while in cities a water service took the responsibility.

In Port Vila daily consumption is 2,000 m^3. Water is pumped from two tubewells located in the coastal plain. Santo town, with a population of about 5,000, is supplied by means of a well dug in coral limestone at an elevation of 10 m, yielding some 150 m^3 per hr. In rural areas there are two kinds of distribution systems: one provides a standpipe with a tap in the centre of the village at a rate of 50 litres per capita per day, and the other provides a tap for each family at a rate of 100 litres per capita per day.

II. TRUST TERRITORY OF THE PACIFIC ISLANDS

A. Physiography and population

The Trust Territory of the Pacific Islands consists of 2,141 islands and atolls spread over 7.8 million km^2 in the west central Pacific Ocean between the equator and latitude 22° N and from longitude 130° to 172° E. The Turst Territory has been administered by the United States of America for the United Nations, but this political arrangement is in the process of dissolution as the various districts of the Territory assume a greater measure of self-government. These islands and atolls have a total land area of 1,779 km^2, and about 130 are inhabited. The largest island, Babelthuap, in the Palau group, has an area of 334 km^2.

The names given by Europeans to the islands of Micronesia are the Western Caroline Islands in the west, which includes the Palau and Yap groups; the Eastern Caroline Islands in the middle, consisting of the Truk and Ponape groups; the Marianas Islands in the north; and the Marshall Islands in the east. Guam is the largest island of the Marianas Islands, but has been a territory of the United States since 1898 and was not included in the Trust Territory.

As the Trust Territory, the islands were divided into administrative districts named the Palau, Yap, Truk, Ponape, Marshall, Marianas and Kosrae districts. The first group to negotiate its political status was the Marianas District, which became the Commonwealth of the Northern Marianas in 1976. Upon satisfactory cessation of the Trust arrangement, but in some sort of association with the United States, the Marshall and Palau districts will form separate self-governing entities, and the Yap, Ponape, Kosrae and Truk districts belong to the Federated States of Micronesia.

In 1977, the estimated population of Micronesia (excluding inhabitants of the Northern Marianas) was 109,975 and was divided among the districts as follows:

District	*Area (km^2)*		*Population*
Truk	72	(14 islands)	35 220
Marshalls	180	(29 atolls and 5 islands)	27 096
Ponape	377		21 187
Palau	460	(200 islands)	13 519
Yap	121		8 482
Kosrae	106		4 471

About 20,000 Micronesians, or 18 per cent of the population, were residing in outer islands, accessible only by vessels. The rest of the population was generally within a day's journey of district centres.

B. Climate

Throughout the Micronesian sector, temperatures generally range from about 23° to 30° C and are relatively uniform. Annual rainfall varies greatly, ranging from 2,160 mm in the Marianas to 4,900 mm on Ponape. The highest annual rainfall of about 10,000 mm occurs in the mountainous interior of Ponape. In some of the northernmost Marshalls, annual rainfall is only 250 to 400 mm.

Throughout the entire region the wettest months are July to November and the driest January to April. During the drier season the trade winds are dominant. In summer and autumn the doldrums often oppress the islands and typhoons may afflict the Caroline and Marianas groups.

C. Water sources

An extensive literature covers the hydrology and geology of much of Micronesia. This literature is most readily available at the Micronesian Area Research Center at the University of Guam, the Pacific Collection at the University of Hawaii, the United States Geological Survey offices in Honolulu and Guam, and the United States Geological Survey Library at Reston, Virginia.

1. Palau Islands

(a) *Surface water*

On most major islands annual rainfall exceeds 3,200 mm. Perennial streams occur on the volcanic terrain of Babelthuap, but not in the limestone caps of other islands where runoff is transient. During the drier months, even the largest streams yield less than 0.01 m^3 per second. A small lake, about 50,000 m^2 in area, is found in the upper area of Babelthuap's Ngardok River, the largest stream in the Palau group.

The people have relied on rain catchment, stream flow, seepage and dug wells for water supply. At present, surface water is the chief supply for the major population areas of Koror (administration centre) and Babelthuap. The small population of the atoll islands and of Angaur and Peleliu must depend on dug wells to supplement rain catch.

(b) *Ground water*

Immediately following the American occupation, about 40 wells were dug in limestone on Peleliu and nine on Angaur, many of them yielding brackish water. The investigations by the United States Geological Survey have concluded that the ground water resources of the volcanic rocks are not capable of extensive exploitation, while the limestones of Peleliu and Angaur are moderately good aquifers.

2. Yap Islands

The Yap Islands consist of four major islands – Yap, Tomil, Rumung and Map – and more than 20 atolls and has a total land area of 120 km^2, of which the largest island, Yap, has an area of 56 km^2. Total population is about 8,000, of whom 40 per cent live on Yap.

(a) *Surface water*

At Kolonia, the administration centre, the average annual rainfall is 3,025 mm. About 57 per cent of the total rain is discharged by streams, none of which drains an area larger than 3 km^2. A limited central water system serves Kolonia and some villages with a pipeline route from the stream diversion (Gitam Dam) to the town. Of approximately 91 villages on the four main islands, seven have village-wide systems.

(b) *Ground water*

The United States Geological Survey made fundamental geological and hydrological studies of the major islands 20 years ago, and since then numerous engineering consulting reports on water supply have been prepared. Without raised limestone formations the prospect of producing large supplies of good water are slim. On Yap a weathered zone aquifer of about 100 hectares has been identified. The weathered zone is as much as 30 m deep.

3. Truk Islands

The Truk District includes the large Truk lagoon complex and many atolls. The six major islands, all of them volcanic, are part of the lagoon and account for 70 per cent of the total district land area of 120 km^2. The largest island, Tol, has an area of 34 km^2, and Moen, the second largest and district centre, has an area of 19 km^2. Total population of the district is about 35,000 in 1977, of which more than two thirds live on the islands of the lagoon.

(a) *Surface water*

On Moen the average annual rainfall is 4,065 mm. The volcanic islands are dissected by numerous small streams with drainage areas of less than 5 km^2. Some of the streams are perennial but are little more than seeps during the dry season.

(b) *Ground water*

The United States Geological Survey conducted the original geological and hydrological investigations and since then has continued a programme of subsidiary studies and data collection. There are no limestones, except on the atolls, so that the only known exploitable aquifers are in the weathered zone on the volcanics. Prior to 1975, several successful wells were drilled, and since then 23 test holes (diameter 200 mm) have been drilled on Moen, eight of which have become producing wells. Sustained pump rates of up to 14.4 m^3 per hr. have been obtained. Ground water is being considered as the primary supply to meet future population demands on Moen, where the population is expected to increase to 15,000 by 1990.

4. Ponape Islands (including Kosrae)

The Ponape group in the Eastern Carolines includes the principal volcanic island of Ponape (334 km^2), with several satellite islands just off its coast, Kosrae, formerly

Table 5. Rainfall statistics of 12 stations in the South Pacific region

Station	Years of data	Annual totals: Mean (mm)	Annual totals: Standard deviation (S.D.)	Mean monthly totals: Mean (mm)	Mean monthly totals: S.D. (mm)	Mean monthly totals: Coefficient of variation (percentage)	Wettest month: Mean/month (mm)	Wettest month: S.D.	Driest month: Mean/month (mm)	Driest month: S.D.
Tarawa (Kiribati)	28	1912	843	159	68	43	325/1	216	95/10	118
Funafuti (Tuvalu)	34	3562	667	297	67	22	412/1	186	203/9	96
Rotuma (Fiji)	31	3533	420	294	66	22	408/3	192	196/8	93
Nandi (Fiji)	34	1889	454	157	103	66	291/1	160	49/7	50
Lauthala Bay (Fiji)	32	3018	563	251	82	33	377/3	167	132/8	106
Malden (Line)	36	690	–	57	26	46	114/3, 4	–	18/11, 12	–
Pukapuka (Northern Cooks)	49	2806	518	234	79	34	378/1	172	160/7	92
Aitutaki (Southern Cooks)	49	1894	477	158	64	40	245/2	120	83/6	66
Rarotonga Airport (Southern Cooks)	49	2038	390	170	61	36	273/3	132	93/7	62
Apia (Samoa)	89	2900	592	242	118	49	438/1	217	99/7	62
Alofi (Niue)	66	2041	457	170	76	45	272/1	167	84/6	63
Pitcairn	34	1663	482	138	12	9	157/7	105	122/11	87

Sources: W.R. Dale, ed., *Pacific Island Water Resources* (Wellington, Department of Scientific and Technical Research, 1981), p. 38.

called Kusaie, (10 km^2) also a relatively large volcanic island 450 km to the southeast of Ponape, and several atolls within 720 km of the main island. The largest atoll, Pingelap, has a land area of 1.7 km^2. Nearly two thirds of the total population lives on Ponape and one sixth on Kosrae.

Ponape and Kosrae are ruggedly mountainous with deep, narrow valleys and steep slopes. No sedimentary coastal plain of significance has formed, but mangrove swamps ring much of their inner coasts. The maximum elevation of 791 m is found in central Ponape. On Kosrae the maximum elevation is 628 m.

(a) *Surface water*

Rainfall is plentiful even along the sea coast (annual average of 4,900 mm at the airport) and extremely high (in excess of 10,000 mm) in the mountainous interiors of the main islands. Ponape has the largest rivers in Micronesia, and most are perennial streams which have provided an adequate water supply for traditional living.

The water supply for the district centre at Kolonia on Ponape is obtained from the Nanepil River at a run-of-river diversion where flow has never fallen below 0.045 m^3/sec. The reliable flow is about 0.175 m^3/sec, considerably in excess of present demand. The villages are satisfactorily supplied by streams and catchments. Most inhabitants live along the coasts, thus minimizing pollution of streams.

(b) *Ground water*

The Ponape Islands were not included in the extensive geological investigations done by the United States Geological Survey in Micronesia. Aquifers have not been identified. There has been no compelling need to seek ground water sources as a water supply, although dug wells are used on atolls.

5. Marshall Islands

The Marshall Islands comprise about 1,150 islands in the eastern-most of the Trust Territory's districts in an area of 466,000 km^2 of the central Pacific. Total land area is only 181 km^2. The largest islands rarely exceed a few square kilometres, and the largest combined land mass within an atoll is the 16.3 km^2 Kwajalein Atoll. Most of the population of 27,000 lives on four major atolls: Majuro, Kwajalein, Jaluit and Arno. Majuro, the district centre, has the largest population, about 10,000, followed by Kwajalein.

Average annual rainfall is about 3,500 mm. The wettest months are October and November.

(a) *Surface water*

Every island is composed of a fossil reef association lying below 10 m elevation. Traditionally the population has depended on rain catchment, shallow dug wells and coconuts for water supply. The construction of the missile tracking centre on Kwajalein and the urbanization of Majuro created a need for central water systems in these two areas. Now the major source of water there is catchment from airfields and other urban complexes. The rain catchment as a supply source may be adequate for the traditional life style, but is deficient where urbanization takes place.

(b) *Ground water*

The ground-water resources of the larger islands consist of fresh water floating as a thin lens on sea water in accordance with the Ghyben-Herzberg principle. Frequently only brackish water is obtained. At best, small wells yielding less than 0.001 m^3/sec could successfully exploit the fragile lenses for fresh water. Dug wells that avoid draining water from deep in the lens are the most reliable. Ground water is difficult to develop safely in even moderate quantities because the islands tend to be narrow; therefore the lenses are thin and unstable.

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II. WATER RESOURCE DEVELOPMENT PROBLEMS IN SOUTH PACIFIC ISLAND COUNTRIES AND THE TRUST TERRITORY OF THE PACIFIC ISLANDS

(NR/MWRD/2)

INTRODUCTION

The South Pacific island countries and the Trust Territory of the Pacific Islands comprise thousands of islands and atolls. The size of these islands varies greatly. Viti Levu of Fiji has a land area of 10,388 km^2, and the main islands of Samoa, Solomon Islands and Vanuatu range from 1,100 to 5,600 km^2. However, Nauru has a land area of only 22 km^2, and the area of the largest island of Tuvalu is only 5.6 km^2. Most of these islands and atolls are small, with an area of only a few square kilometres.

The annual rainfall also varies greatly among these islands. Ponape Islands of the Trust Territory has an average annual rainfall of about 5,000 mm, while Nauru and some islands of Kiribati within the equatorial dry zone have an average rainfall of only 400 to 700 mm a year.

Although in most capitals and some townships and villages there are centralized systems of water supply, a large number of people in these island countries rely on coconuts as the prime source of drinking water and on rain water collected by roof catchments for their cooking and washing. During the dry season the available water is reduced to a minimum. To seek more supplies of fresh water the possibility of exploiting ground water has been extensively explored.

As the size of island area and the climate vary greatly, the availability of surface and ground water differs among these countries as well as among the islands and atolls within a country. This paper discusses the important factors of water resource management in these island countries. First, it reviews the existing institutional arrangements for water resource management in these countries and the main considerations for efficient institutional establishment. Secondly, it describes the various types of water resources and problems encountered in their assessment and exploitation. Thirdly, it reviews the current development of water resources for various uses and associated problems. The main purpose is to throw light on the situation and the problems to be tackled in water management. Based on the discussion of the first three sections, the last section of the paper sums up the major problems in the development and management of water resources in the island countries.

I. INSTITUTIONAL ARRANGEMENTS

For the proper management of water resources needed to meet various demands of the economic and social development of a country, the existence of efficient institutional arrangements is a prerequisite. Generally, the activities related to water resource management are undertaken by more than one governmental agency.

In most countries the ministry or department of public works has the main responsibility for water supply works. The mineral resources department is responsible for ground-water exploration. In some countries there are ministries of urban development and health which are also involved in water supply development. In Solomon Islands, three ministries are involved in ground-water development – the Ministry of Works and Public Utilities, the Ministry of Health and Medical Services and the Ministry of Natural Resources. Their activities are co-ordinated by a Water Resources Committee. In Tonga, the Tonga Water Board directly manages the operation of the water supply schemes in Tongatapu, Vava'u and Ha'apai. The village water schemes are administered by individual village water committees and supervised directly by the Public Health Division of the Ministry of Health.

In the South Pacific island countries the greatest demand for water is for domestic use, and the most widely used water sources are rainfall collected by roof catchments and freshwater lenses on small atoll islands or ground-water aquifers on small islands. However, there are a number of perennial rivers on the main islands of Fiji, Samoa, Solomon Islands and Vanautu. Ponape Island of the Trust Territory with a land area of only 334 km^2 has perennial rivers. These large and small river basins can be developed to supply cheap and abundant water for domestic, agricultural, commercial and industrial uses. Some of these rivers have hydroelectric potential for development. In Samoa the first hydroelectric set was installed in 1928 and is still in service. Three hydro projects were under construction in 1980. There are also possibilities for trans-basin diversion of water. Therefore, the integrated development and management of these river basins could be multi-purpose undertakings, which might be dealt with by a number of governmental departments and would require proper and effective coordination.

At present many water supply reticulation systems are operated by local public utilities or public water service bodies in the case of townships and municipalities or by community groups in the case of villages. The available information indicates that future extension or improvement of these waterworks will mainly rely on the exploitation of ground water. The investigation and exploitation of ground water requires expertise and equipment which the local governmental agencies do not possess. The construction cost per capita served is usually high and is normally beyond the financial capability of the local communities. Therefore, technical and financial support from the central government is needed. In many cases technical and financial assistance from external sources is necessary to accelerate the development programme. In this respect the central government can play an important role in determining the priority of water resource development in the overall national development programme and in seeking foreign assistance.

Another important consideration is the lack of appropriate institutional arrangements for water quality management. The exploitable surface and ground waters on these small islands are extremely scarce, while the demand for fresh water will increase with the improvement of living standards and with urbanization. These limited resources should be highly valued and protected from contamination. On many Pacific islands there is a lack of adequate facilities for the disposal of excreta, solid wastes and waste water. The small creeks and aquifers are vulnerable to contamination. The current practices in animal husbandry may cause damage to the environment, including the water sources. Along the coast line and on atoll islands the aquifer and freshwater lenses will be easily contaminated by sea-water intrusion if they are not properly managed, particularly during the dry season.

II. ASSESSMENT OF WATER RESOURCES

The surface and ground water resources in individual countries are described in the secretariat paper entitled "Water resources in South Pacific Island countries and the Trust Territory of the Pacific Islands" (NR/MWRD/1). In order to avoid duplication this section places emphasis on the deficiencies and problems encountered in the investigation and utilization of water resources.

A. Surface water – stream flow

Perennial streams exist only on large islands in Pacific island countries, i.e. Viti Levu (10,388 km^2) and Vanua Levu (5,535 km^2) of Fiji; Guadalcanal (5,650 km^2), Choiseul, New Georgia, Santa Isabel, Malaita and San Cristobal of Solomon Islands; Santo (3,947 km^2), Malekula (2,024 km^2) and Efate (915 km^2) of Vanuatu; Savai'i (1,820 km^2) and Upolu (1,100 km^2) of Samoa; and Babelthup (334 km^2) and Ponape (334 km^2) of the Trust Territory. On some islands, such as Rarotonga (67 km^2) of the Cook Islands and Tongatapu (260 km^2) of Tonga streams flow during the rainy season but there are none during the dry period. Most of these volcanic islands have high peaks, such as Mt. Makarakombou (2,447 m) on Guadalcanal, Mt. Victoria (1,424 m) in Fiji and Mt. Mata'aga (1,850 m) on Savai'i. Almost all these islands are rugged and mountainous. The islands' volcanic origins have produced terrain with many streams of small drainage areas. Most of these streams are short with steep courses over most of their length resulting in swift flows with a wide variation between the wet and dry seasons. The small size of the drainage areas and thin covering soil of young geologic formations further reduce the volume of base flow. Owing to this wide variation, the dependable flow which can be utilized for various uses is only a small portion of the total annual flow.

For example, the eastern part of Upolu is composed of the oldest rocks, the Fagaloa Volcanics. The relatively low permeability of the Fagaloa rocks results generally in high water tables and perennial streamflows. The highly variable spatial permeability of the rocks forming the catchments of perennial streams and rivers makes runoff regimes difficult to predict. Streamflow records of various streams on Upolu indicate that runoff coefficients of the corresponding catchment areas range from less than 0.3 to more than 0.6, despite certain similarities in geology and topography. Mean annual discharges from these areas are generally in the order of 0.04 to 0.08 cms per km^2, but can be considerably higher or lower depending on the geology and the annual rainfall. The only reliable data from which the dependable surface flows can be estimated are the long-term flow measurement records.

The runoff regime varies with the forest cover of the catchment. In many island countries farmers traditionally adopt the practice of shifting cultivation. It is estimated that 45 per cent of Samoa's forests have been cleared. The removal of forest cover has reduced the capacity of the land to absorb and retain precipitation. In general, the removal of forest cover results in higher peak flows during the flood season and lower base flows in the dry season. Furthermore, the higher flows accelerate the erosion process and degrade water quality. On those islands with steep slopes, soil conservation measures are important from the viewpoint of water conservation.

According to the available references, streamflow records are scarce and no information on potential reservoir sites on these islands is available.

B. Ground water on islands

1. Niue

The lens supplying ground water appears to have the potential for considerably increased withdrawal. The immediate problem is the lack of means of extraction and distribution. Although windmills have the significant advantage of reducing the energy cost of extracting water, the Public Water Department is experiencing difficulties with the present windmills which are expensive to maintain. Moreover, parts are difficult to obtain and the mills are not very efficient.

2. Samoa

The past well-drilling programme has confirmed the existence of plentiful ground-water resources in many parts of the islands of Samoa. As compared with surface water supplies, the use of ground water supplies is expensive. Because of its isolated location, very poor access to services of overseas manufacturers of pumps, pipes, engines and spare parts and limited local repair and maintenance facilities, the country's ground-water development schemes run behind schedule and have a record of low utilization.

The 1979 diesel fuel costs for water supply pumping were estimated at $ 100,000 per year, and power costs for water supply pumping accounted for another $ 65,000 per year. In 1979 the pumped water supply systems served an estimated 40,000 persons (about 25 per cent of the population). On this basis fuel costs alone averaged some $ 40 per family per year and $ 50 if other operating costs were to be included. This cost level is much higher than the rate of $ 4 charged per family per year, and than the operating costs of gravity-reticulated surface supply systems which are only $ 6 per family per year. The importance of the development of surface water is well demonstrated as is the degree of subsidy involved in the present tariff structure.

3. Solom Islands

Investigations have been confined to the capital, Honiara, and the areas east and west of it. The aquifers can be divided into two types, alluvial and limestone. Ground-water resources have not been fully explored or assessed owing to a lack of expertise and high costs.

4. Tonga

In view of the high cost of fuel, the Government has embarked upon a pilot-windmill scheme for water pumps. The performance of the four windmills will be observed and evaluated to determine technical and economic feasibility.

5. Vanuatu

In the course of the last 10 years a fair amount of knowledge of ground-water resources has been acquired. The quantity of ground water is generally adequate to serve current needs. The main problems are the lack of retention of water on volcanic islands where large quantities are lost as runoff to the sea and the excessive depth of the aquifer under the plateaus.

6. Ponape Islands of the Trust Territory

The Ponape Islands were not included in the extensive geological investigations carried out by the United States Geological Survey in Micronesia. There has been no compelling need to seek ground-water resources as a water supply, although dug wells are used.

C. Ground water on atolls

Fresh ground-water occurrences of any significant extent are, in general, limited to large atoll islands where lenses of fresh water, floating on salt water, have developed. Generally, freshwater lenses extend to those parts of the islands where coral sands form a sufficiently wide central ridge. The thickness of the freshwater lens below sea level is controlled by the head of fresh water above sea level. According to the Ghyben-Herzberg theory, an elevation of 1 m above sea level corresponds to 40 m of depth of the lens below sea level. Actual depths of the interface on many atoll islands seem, however, to deviate considerably from the theoretical values. These deviations are considered to be caused by inhomogeneities in the aquiferous sediments and disturbances of the equilibrium through the influence of ocean tides.

The exclusive source of recharge of the freshwater lenses is local rainfall. The rate of infiltration is generally high on the very permeable coral sands and gravels. The recharge is counterbalanced by a movement of fresh water towards the sea and the lagoon where it is dispersed into salt water.

In coral reef limestones the permeability is usually very high and ground water movement is rapid along open hollows. Generally, only thin freshwater lenses can form where coral limestones occur near the water table. Where thicker sand deposits extend on an island, a thicker freshwater lens is likely to develop. Observations on some of the atoll islands indicate thicknesses of freshwater lenses ranging between 2 and 40 m.

The water lens is highly vulnerable to sea-water intrusion owing to the low elevation (3 to 5 m) and small size of atoll islands. It is important to take all related factor – rainfall inputs, withdrawal and other out-flows and storage – into consideration in determining its safe yields.

D. Roof catchment of rain

Rain water from roof catchments is commonly used by the people of the Pacific islands. The water is stored in a large number of tanks for community water supply or in individual household tanks. The amount of useable water is determined by the area of the roof catchment, the storage capacity of tanks and the intensity and distribution of rainfall in a year. During the dry season supplementary supplies of water from dug wells or drilled holes are desirable if ground water is available.

The wooden shakes used as roofing material were found to be a source of offending material affecting water quality. Other materials, such as galvanized iron coated with bituminous film, have been used on some islands.

The three main islands of Tokelau are atolls lying close to sea level and little ground water is available. Residents rely on roof catchments, small tanks and galleries for water supply. It is calculated that the average per capita area of roof catchment among the three atolls of Tokelau varies from 17 to 51 m^2, which is much larger than that of 0.93 to 2.7 m^2 on the atolls of Tonga.

Owing to the limited capacity of storage tanks not all rainfall can be caught and stored in tanks during the wet season. Assuming a catchment efficiency of 50 per cent, it is estimated that the total utilizeable rain water would be 3.75 m^3 per capita per year with a catchment area of 3 m^2 per capita and annual rainfall of 2,500 mm. That is equivalent to an average of about 10 litres per capita per day.

III. WATER RESOURCES DEVELOPMENT

A. Domestic use

The present status and the adequacy of domestic water supply are reviewed under two categories: the reticulated community water supply systems and the individual household water supply.

1. Reticulated supply systems

(a) *Cook Islands*

About 50 per cent of the population resided on the main island of Rarotonga in 1976, while another 30 per cent lived on other three main islands. A World Health Organization sanitary engineer prepared a master plan for a reticulated water supply system in 1973-1975 which included a water main circling the island of Rarotonga and connected to water intakes tapping surface streams at suitable elevations in the central volcanic core. Several of these intakes were to be replaced by infiltration galleries, which would collect higher yields at a lower altitude. Investment funds exceeding \$ 1,000,000 have been made available by New Zealand for the financing of the water supply scheme. Water will be delivered free of charge for the entire system with a production capacity of 14,000 m^3 per day.

On the islands of Aitutaki, Atiu and Mauke, drill holes in the volcanics supplement community water supplies.

(b) *Fiji*

About 90 per cent of the population lives on the two main islands of Viti Levu and Vanua Levu. It was estimated in 1980 that 84 per cent of urban households had piped water and 74 per cent of the rural population had reasonable access to a clean water supply. Surface water is used to supply all the large communities and most of the Fijian villages. Nearly all the latter have been settled on the tributaries of main rivers. The only areas in Fiji where the mean annual rainfall is less than 1,800 mm are the extreme west of Vanua Levu, around the coastal fringes of western Viti Levu and in parts of the Yasawa and Lau Islands. In these dry zones there is a shortage of water supply during the dry season.

(c) *Kiribati*

Kiribati comprises numerous small atolls. About 93 per cent of the population lives on the 16 Gilbert Islands. About 17,000 people (30 per cent) live on Tarawa atoll where the capital Bairiki is located. A centrally organized water supply exists so far only on the southern islands of the Tarawa atoll. Sources of water supply are shallow wells, water holes, galleries and roof catchment collecting rain water. Currently, about 210 m^3 per day of ground water are pumped from galleries at three different areas. The present population of southern Tarawa, about 15,000, can be supplied at a rate of 9.6 litres per capita per day (lcd) in dry periods and 36.6 lcd in periods with sufficient rainfall. The recurrent costs of south Tarawa water supply are about \$ 300,000 per year. It represents about \$ 66 per family per year. A full charge for water supplies would place heavy burdens on urban family budgets.

(d) *Nauru*

On Nauru island there is no reticulated water supply system. Water supplies are mainly from roof storage tanks, and in prolonged dry periods water is imported in the regular shipping and is pumped ashore into cement storage tanks and distributed to houses by tanker.

(e) *Niue*

The present reticulated supply is piped from boreholes to central village tanks which supply communal taps. The catchment tanks serve as a backup but are inadequate in drought periods. Some villages are almost totally dependent on these catchment tanks, as their communal taps are supplied from a neighbouring village system, and when the supplying villages have a high withdrawal there is little or no supply to the end-of-line villages.

The communal tap system provides for the basic minimum acceptable daily usage and does not allow for water-borne sanitation and individual house connections. According to the National Development Plan 1980-1984, following completion of water projects now underway, the government supply should be adequate to meet the needs of the hospital, the hotel and government houses in parts of Alofi South. There is, however, little available for new development projects, particularly those sited outside a restricted area in Alofi South.

(f) *Samoa*

Samoa consists of two main islands and several small ones. In 1980 the population of Upolu was about 120,000 and that of Savai'i was 45,000. Though extremely diverse, most Samoan water supply schemes are reticulated by gravity and fed from inland streams and springs. Some water is supplied from pumped wells. The capacity of the reticulation systems and the dry-weather flows at the source are frequently inadequate. Other populated areas in the western part of Upolu and Savai'i have no water supply. About three fourths of both islands have piped water supply. Water is available for about half the time of each island.

The extension of the urban areas and the development of rural areas, coupled with a rapid population growth, consequently require considerable additional quantities of water. Schemes for additional surface water and upgrading existing reticulation systems are being undertaken. Construction of large-scale artificial catchment areas for rain-water harvesting in the higher island areas is planned.

(g) *Solomon Islands*

The most heavily populated island is Malaita, which has one third of the population. The next most heavily populated island is Guadalcanal, with 46,619 people in 1976, where the capital, Honiara, is located. A reticulated water supply is provided in Honiara, Gizo, Auki, Mahu'u, Mundo, Dodo Creck, Kira Kira, Santa Cruz and Tulagi. At present, surface water is the main source. Generally abundant water is available throughout the country except in some outlying areas during extreme drought conditions.

(h) *Tonga*

Of the total population of 90,128 (1976), 57,437 (64 per cent) live on Tongatapu Group and 15,065 (17 per cent) on Vava'u Group. The existing reticulated supply systems cover about one fourth of the area on Vava'u Group islands and on Lifuka and the 'Uiha islands of Ha'apai Group. On Tongatapu and 'Eua islands the reticulated supply covers about three fourths of the area. The source of water is from either roof catchment or from hand dug or drilled wells tapping a lens of fresh water. There is a programme for upgrading the quantity of water storage capacity in rainwater catchments as well as by drilling for ground water. The objective is to provide a minimum of 23 litres for each person daily for 30 days with the catchment area providing enough rain water to fill that storage four times a year. The programme was scheduled to be completed in 1983. Capital investment provided for in the Third Development Plan is beyond the financial resources of the Kingdom. Foreign aid will be necessary to meet a substantial part of the programme.

(i) *Tuvalu*

The nine coral islands have an area ranging from 0.41 km^2 to 5.09 km^2. The most populated island of Funafuti had a population of 2,100 in 1977. The two main water sources are rain water stored in public cisterns and pumped water from bailed wells. However, the storage capacities of cisterns and catchment area on these islands are inadequate. Most of the inhabitants use rain water for drinking and cooking and well water for washing and bathing. Well water is often saline at least to a limited extent.

(j) *Vanuatu*

In December 1975 the estimated population was 96,532, of whom 16,604 (17 per cent) were living in Vila the capital, and 4,954 (5 per cent) in Santo urban area. In Vila daily consumption is 2,000 m^3 per day. Water is pumped from two tubewells located in the coastal plain. Santo is supplied by means of a well dug into coral limestone at an elevation of 10 m, some 8 m deep, and yields some 150 m^3 per hour. About 78 per cent of the population lives in rural areas and only 20 per cent of them are served by water supply systems. Two categories of distribution systems are offered to them: one provides a standpipe with a tap in the centre of the village at a rate of 50 lcd; the other provides a tap for each family (there are several dwellings for each family) and a consumption of 100 lcd.

(k) *Trust Territory of the Pacific Islands*

In 1980 the six districts of the Trust Territory had a total population of 115,000, of whom approximately 30,000 were served by some type of communal or community water systems. Some of these systems offer a degree of protection or treatment, but most have deficiencies which render the system inadequate or unacceptable from a public health standpoint. One example is the common occurrence of low pressure and negative head conditions in most of the major governmental centre systems. Another example is the loss of as much as 50 per cent of the water by leakage in the distribution system and/or household services. This large-scale leakage is causing a water shortage crisis. In most of the government centres water hours are enforced at the rate of 4 hours of water per day.

2. Individual household water supply

It is estimated that about one half of the population in Tonga, 70 per cent of the population in Kiribati and in the six districts of the Trust Territory are not served by community water supply. For these people the provision of water for domestic household usage is the responsibility of the individual family. Most individual home water supplies consist of some type of roof catchment system with storage in partially closed or open containers outside the house.

There is no statistical data on the adequacy of water supply of these self-supplying households. Apparently the capacity of storage containers limits the quantity of water supply during the dry season. The distribution of rainfall during a year directly affects the available supplies of water in various seasons.

The people on small islands without a ground-water supplement and with a long dry season are confronted with a serious problem in water supply. For example, on eight small islands of Tuvalu water supplies mainly come from roof catchments that run into household tanks. There is a plan to keep at all times a reserve of drinking water in storage corresponding to an emergency supply of 10 lcd for a period of 100 days. Even this low-level target is far from being achieved due to the inadequate catchment roof area and storage capacity. On many South Pacific islands the dry season extends for three months or longer every year. It is essential to provide enough water storage capacity for each family.

Besides the inadequacy of water quantity, the quality of water supplies is also a problem. In almost all instances, no provision is made to discard the initial runoff with its contaminants from the roof or to provide any type of filtration or disinfection. Without cover the water in containers can be easily contaminated. Most homes do not have interior plumbing. When water is carried from container to the place of use, there are chances of contamination with unsanitary vessels.

B. Agricultural use

In most Pacific island countries agriculture is the largest sector in the national economy and employs the largest part of the economically active population. However, most of agricultural and livestock production is for subsistence and yields are uniformly low. Irrigation is practised only for rice production of limited extent in Fiji, Solomon Islands and the Ponape District of the Trust Territory.

1. Fiji

Rice is the staple food for more than half of Fiji's population. In 1981 the total rice field area was 10,352 ha, of which only about 1,300 ha were irrigated. In 1981 the yield of irrigated fields was 3.0 to 3.5 tons per ha, while the yield of rainfed fields was only 1.8 tons per ha. By the end of the Eighth Development Plan in 1985, the total irrigated area will increase to 2,000 ha. The Government is investigating small-scale appropriate technology which will lead to farmers undertaking irrigated rice production on their own with little direct assistance from the Government. In the foreseeable future, Fiji will continue to reply on rice imports.

2. Solomon Islands

Brewers Solomon Associates, Ltd. (BSA), the sole producer of rice in the country, expanded the irrigated area from 378 ha in 1974 to about 845 in 1978. Using modern methods and improved inputs, the production of this crop is heavily mechanized and involves large-scale operations. With increasing yields and cropping intensity, production of paddy rose from 1,237 tons in 1974 to 7,106 tons in 1978. The rice equivalent output of about 4,600 tons is sufficient to meet domestic consumption requirements, although some rice continues to be imported to meet domestic consumption preferences. The BSA plans to increase the irrigated area to 2,000 ha in a few years.

3. Trust Territory

In 1972 an irrigation project for rice covering 81 ha was planned, and a specialist and equipment have been obtained to initiate the scheme at Ponape.

4. Other countries

In Pacific island countries the irrigated area is not expected to expand substantially owning to the lack of experience of farmers, high capital cost and shortage of large plain areas.

In some countries raising of cattle and other livestock has been increasing significantly as a result of government efforts to achieve self-sufficiency in meat supply as well as to promote meat exports. In Vanuatu there are 120,000 head of cattle – more than the human population. In Solomon Islands, the Government is implementing a beef cattle development project to increase the national herd to 50,000 head with a sufficient number of animals available for slaughter to meet domestic consumption requirements. In estimating the total water requirement, the quantity of water for livestock should be taken into account.

C. Industrial and commercial uses

In Fiji there is a wide range of local industries for the production of agricultural equipment, building materials, containers, plastics, furniture, foodstuffs and clothing. Products are made for domestic consumption and export. In other island countries most manufacturers are confined to the processing of agricultural products, such as fruit canning, meat canning, fish freezing and salting and copra crushing. These industries are important to their national economies as sources of main export items. They are mostly located in the capital or major towns where there is piped water service. Other industries like handicrafts, boat building and furniture-making do not consume much water.

In order to create more employment opportunities and enhance national income some island countries have made great efforts in promoting industrial development in recent years. In Samoa, under the New Zealand Pacific Islands Industrial Development Scheme, a new leather goods industry has been established. In December 1977 the Asian Development Bank approved a $ 2.25 million loan for a coconut oil mill. In Tonga the Asian Development Bank approved a $ 370,000 loans in 1977 to provide the infrastructure for the Small Industries Centre. About 24 industrial lots will be available. In Palau District the Micronesian Industrial Corporation opened a $ 3.7 million copra crushing mill in 1976 and planned to buy all the copra produced in the Trust Territory.

In the Cook Islands there were 10,857 tourists in 1976; Fiji had 161,707 in 1975; Samoa 33,776 in 1976; Tonga 9,312 in 1976; Trust Territory 20,579 in 1977; and Vanuatu 17,929 in 1976. In other countries, Kiribati, Nauru, Niue, Solomon Islands and Tuvalu, tourism has not made significant progress. For small island countries tourism could become a major earner of foreign currency. In Fiji there were 3,313 rooms in hotels with more than 30 beds at the end of 1976. It was estimated that about $ 70 million was earned from tourism in 1977, which exceeded the earnings for sugar, the most important export commodity. However, since the energy crisis in 1973, the increasing rate of tourists has slumped. To promote tourism, an adequate supply of clean water and the availability of sanitation facilities are pre-requisites.

IV. MAJOR PROBLEMS

The above sections clearly indicate that water supplies for domestic use in the Pacific island countries are inadequate, particularly in Kiribati, Tonga and Tuvalu. A large part of the population on atoll islands depends solely on rain water. During the dry season the water stored in containers is used only for drinking and cooking. A large part of the communal reticulation water systems provides only for the basic minimum requirement and does not allow for water-borne sanitation.

To increase the water supply for domestic and other uses, the development of the water resources in the Pacific islands needs to be accelerated and the limited available resources should be properly managed. In this regard, the countries are facing a number of difficult problems.

A. Water resources assessment

1. Surface water

In order to assess the water resources potential and the resources which can be economically developed on small islands data on the availability of long-term rainfall and streamflow are essential. To determine the feasibility of reservoir projects, topographic maps and geological information are required. According to the available information these data are lacking for most of these island countries.

2. Ground water

Ground-water aquifers and freshwater lenses exist on many volcanic islands and coral atolls. Few of them have been investigated in detail to determine their safe yields, mainly due to the lack of professional manpower and equipment.

B. Supply of equipment and spare parts

For most of these island countries well-drilling, pump, pipes and auxiliary equipment and fuel have to be imported from a long distance away. The supply of equipment and spare parts is difficult and expensive. The lack of skilled labour for operation and maintenance of the machinery and equipment is another difficult problem. For these reasons some completed development projects have been operated only with partial success or at partial capacity.

C. Conservation of water

Owing to the small size of the islands and atolls and the wide variation of rainfall, the water available during the dry season is inadequate. The cost of water from either underground or surface storage is very high, but many existing community water systems supply water to consumers free of charge and do not have any meters or any other control. The loss of water from leakage in the commual water systems in the six districts of the Trust Territory was estimated at as high as 50 per cent.

D. Water pollution

A large part of the reticulation water systems in the Pacific island countries does not have water treatment and filtration facilities. There is no control of water quality. The surface water sources as well as ground water aquifers can easily be polluted by men's activities including land reclamation, mining and waste and excreta disposal.

E. Development funds and technical capability

Among the 10 South Pacific island countries and the Trust Territory of the Pacific Islands six countries became independent or semi-independent only within the last ten years. Many of these 11 countries have been receiving technical and financial assistance from external sources for their development programmes for many years. For example, in Tuvalu all development projects listed in the Second Development Plan, 1980-1983, will be financed by external aid. Tuvalu does not have the resources either in the government or the private sector to mobilize savings for capital investment on any of these proposed projects. Similarly, the low technical capability of these countries does not allow them to undertake major engineering works independently. The pace of water resources development in these island countries will therefore be determined to a large extent by the availability of technical and financial assistance from external sources.

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III. DRAFT COMPREHENSIVE PROGRAMME FOR WATER RESOURCES DEVELOPMENT IN THE PACIFIC REGION

(NR/MWRD/3)

INTRODUCTION

A large part of the population in the Pacific region lives on small islands or atolls with limited available water resources. At present the water supply in towns and villages in many countries of the region provided either by reticulation systems or by roof catchment is far from adequate. Many of the reticulation systems are operated at low efficiency and high cost. The limited available surface and ground water should be more fully and rationally developed to meet the requirements for domestic and other uses.

This comprehensive programme is intended to provide a technically and economically sound framework for the planning, development and management of water resources, suited to the needs and conditions of the countries and peoples of the region, and to enhance their management capabilities. The more specific objectives of the programme are:

(a) Better assessment of the rainfall, runoff and groundwater resources which can be developed and utilized for domestic and other uses;

(b) Improvement of existing water supply systems and facilities for more efficient and economic operation and maintenance;

(c) Promotion of accelerated development of water resources to improve water supply and water quality in towns and villages;

(d) The strengthening of national capabilities, institutional arrangements and financial support which will enable the programme of improvement and development to be put into effect efficiently;

(e) The strengthening of technical and financial assistance from the international community in training of technical personnel and in water resource development programmes in the region.

I. ASSESSMENT OF WATER RESOURCES

Regular and systematic collection of hydrometeorological, hydrological and hydrogeological data needs to be promoted and accompanied by a system for processing quantitative and qualitative information for various types of water bodies. The data should be used to estimate available precipitation, surface-water and groundwater resources and the potentials for augmenting these resources.

To this end it is recommended that countries should:

(a) Establish a national body with comprehensive responsibilities for the collection of water resource data;

(b) Expand and extend, as necessary, the network of hydrological and meteorological stations taking a long-term view of future needs;

(c) Establish observation networks and strengthen existing systems and facilities for measuring and recording fluctuations in groundwater quality and level;

(d) Make periodic assessments of surface- and groundwater resources, including rainfall, evaporation, runoff, lakes, and lagoons both for individual basins and at the national level, in order to determine a programme of investigation for the future in relation to development needs;

(e) Establish or strengthen training programmes and facilities for meteorologists, hydrologists, and hydrogeologists at professional and subprofessional levels;

(f) Take specific national characteristics and conditions into account in different countries in assessing water quality and establishing water-quality criteria.

International organizations and other supporting bodies should, on request, take the following action:

(a) Provide technical assistance to strengthen hydrologic data collection;

(b) Provide assistance for the establishment of groundwater exploration programmes and their proper management.

II. CONSERVATION OF WATER AND EFFICIENCY OF WATER USE

On many islands in the region the water supply provided by reticulation system is usually neither equitably nor efficiently distributed due to high losses and poor operation and maintenance. At the same time a large portion of the region's population does not have reasonable access to a safe water supply. The supply of water from roof catchments is minimal during the dry season on many islands due to the inadequate storage capacity of tanks. Since water in the region is a limited and valuable resource and its development requires high investment, its use must be efficient and must serve the highest possible level of national welfare.

A. Improvement of the efficiency of water use

It is recommended that countries should:

(a) Establish deliberate administrative policies, such as measuring supplies, licensing diversions, charging for water and penalizing wasteful and polluting acts;

(b) Establish appropriate scales of charges that reflect the real economic cost of water or that rationalize subsidies within the framework of a sound water policy;

(c) Use school programmes and all public media to disseminate information concerning proper water use practices.

B. Efficiency in regulation and distribution of water resources

It is recommended that:

(a) Studies be conducted to explore the potential of groundwater basins, the use of aquifers as storage and the conjunctive use of surface and ground water to maximize efficiency;

(b) Measures be taken to avoid such withdrawal of groundwater that contamination by sea water intrusion results;

(c) Studies should explore further the possibility of effecting interbasin transfers of water;

(d) Measures should be taken to ensure systematic planning of the distribution of water among the various uses as a prerequisite for full and rational utilization of the available water for exploitation.

C. Measurement and projections of water demand

In order to project future water needs it is desirable to have data on use and consumption and quality by type of user and also the information necessary to estimate the effect of the application of different policy instruments (tariffs, taxes etc.) on the various areas of demand. The demand for water for different purposes should be estimated at different periods of time in conformity with national development goals to provide the basis and the perspective for the planned development of available water resources.

It is recommended that countries should:

(a) Initiate action to estimate the demand for water for different purposes, e.g., roof catchment water supply, community water supply, agriculture, industry etc.

(b) Ensure that statistics on the use and consumption of water should be organized, improved and amplified on the basis of those prepared by the existing services, supplemented by censuses, surveys etc. Censuses on productive activities should include information on volumes of water used, sources of supply, coefficients of reuse and quality data;

(c) Identify the targets to be achieved over different periods of time, taking into consideration anticipated population growths, and the priority to be given in such matters as the number of people to be served with reasonable access to a safe water supply; areas to be irrigated under different crops, and specific production per unit of water;

(d) Consider conservation as an explicit policy, bearing in mind changes in demand, water-use practices, life styles and settlement patterns;

(e) Evolve an appropriate methodology for the management of demand.

D. Community water supply and waste disposal

The decade 1980-1990 has been designated the International Drinking Water Supply and Sanitation Decade by the United Nations. The Decade is intended to encourage countries and the international community to make concerted efforts to ensure a reliable drinking-water supply and provide basic sanitary facilities to all urban and rural communities on the basis of specific targets to be set up by each country, taking into account sanitary, social and economic conditions.

To this end it is recommended that countries should:

(a) Set targets for community water supply and waste disposal and formulate specific action programmes to attain them, while evaluating the progress made at regular intervals;

(b) Establish standards of quality and quantity that are consistent with the public health, economic and social policies of Governments, ensuring by appropriate measures, duly applied, that those standards are observed;

(c) Ensure the co-ordination of community water-supply and waste-disposal planning with overall water planning and policy as well as with overall economic development;

(d) Adopt policies for the mobilization of users and local labour in the planning, financing, construction, operation and maintenance of projects for the supply of drinking water and the disposal of waste water;

(e) Consider carefully inequalities in the standard of drinking water and sewerage services among the various sectors of the population. As far as possible, design programmes so as to provide basic requirements for all communities as quickly as possible. Priority should be given to the provision of drinking water and sewerage services in areas where the quantity of water supplied is inadequate;

(f) Ensure that the allocation of funds, of other resources and of all forms of economic incentives to community water-supply and sanitation programmes reflects the urgency of the needs and the proportion of the population affected;

(g) Promote the construction of facilities by granting low-interest loans or subsidies to communities and to other entities concerned with water supply and sanitation;

(h) Provide mutual assistance in the transfer and application of technologies associated with these programmes;

(i) Carry out special water-supply and waste-treatment programmes as national or regional undertakings or as activities of non-profit organizations, such as users' associations, where local resources do not make it possible to achieve the desired goals;

(j) Adopt pricing policies and other incentives to promote the efficient use of water and the reduction of waste water, while taking due account of social objectives;

(k) Seek to promote in rural areas with low population density, where it seems appropriate, individual water-supply and waste-water disposal systems; taking account of sanitary requirements;

(l) Carry out a programme of health education, parallel with the development of community water supply and sanitation, in order to heighten the people's awareness with respect to health;

(m) Establish, at the national level, training programmes to meet immediate and future needs for supervisory staff;

(n) Provide inventory and protection of water-supply sources.

International organizations and other supporting bodies should, as appropriate, and on request, take the following action:

(a) Provide technical assistance to countries in the preparation of long-term plans and specific projects;

(b) Consider adapting their criteria for financial assistance in accordance with the economic and social conditions prevailing in the recipient countries;

(c) Promote research, development and demonstration projects for reducing the costs of urban and rural water-supply and waste-disposal facilities;

(d) Promote public health education;

(e) Support research, development and demonstration in relation to predominant needs, particularly for:

(i) Low-cost ground-water pumping equipment;

(ii) Low-cost water and waste-water treatment processes and equipment, with emphasis on the use of materials and skills likely to be available to rural communities for installation, operation and maintenance;

(f) Strengthen the exchange of information, *inter alia,* by arranging expert meetings, and development of a clearing-house mechanism.

E. Agricultural water use

Particular attention should be given to land and water management both under irrigated and rainfed cultivation, with due regard to long-term as well as short-term productivity. National policies should provide for the properly integrated management of land and water resources.

In this context, countries should:

(a) Bear in mind principles of integrated land and water management when reviewing national policies, administrative arrangements and legislation, and pay heed to the need to augment present levels of agricultural production;

(b) Consider appropriate incentives such as safeguarding water rights for farmers and encouraging holders of irrigated land to adopt management practices compatible with long-term resource management requirements;

(c) Plan and carry out irrigation programmes in such a way as to ensure that surface and subsurface drainage is treated as an integral component and that provision of all requirements is co-ordinated with a view to optimizing the use of water and associated land resources;

(d) Give attention to problems of soil and water conservation through good management of watershed areas which includes a rational crop distribution, improvement of pastures, reforestation, avalanche and torrent control and the introduction of appropriate agricultural soil conservation practices, taking into account the economic and social conditions existing in the respective watershed areas;

(e) Adopt appropriate pricing policies with a view to encouraging water users in efficient animal or farm husbandry and farm management. Particular attention should be paid to groups not reached by formal education;

(f) Take steps to complete irrigation and drainage projects currently under construction as expeditiously as possible, so that benefits on past investment accrue without delay.

F. Industrial water use

It is recommended that countries should:

(a) Take into account the water requirements of industries in the planning and formulation of water-development projects, paying due attention to the necessary safeguards against adverse health and environmental impacts arising from industrial activities and to the needs of small-scale and rural industries;

(b) Include waste treatment or other appropriate measures to eliminate or reduce pollution as an integral part of municipal and industrial water supply systems;

(c) Provide stimulating investments and other economic incentives and regulations to use water efficiently, to treat wastes at their source and, where advantageous, jointly with domestic waste.

G. Hydroelectric power generation

It is recommended that countries should:

(a) Undertake studies on the multiple and integrated development of the water resources in watersheds with hydroelectric potential;

(b) Integrate plans for the development of hydropower generation with the overall development plans for both the energy and water sectors, taking into account the potential savings in foreign exchange which can accrue therefrom;

(c) Encourage small-scale hydroelectric installation to meet local energy needs, wherever economically, environmentally and socially acceptable.

III. POLICY, INSTITUTION, LEGISLATION AND TECHNOLOGY

Integrated policies and legislative and administrative guidelines are needed so as to ensure a good adaptation of resources to needs and reduce, if necessary, the risk of serious supply shortages and ecological damage, to ensure public acceptance of planned water schemes and to ensure their financing. Particular consideration should be given not only to the cost-effectiveness of planned water schemes, but also to ensuring optimum social benefits of water resource use, and to the protection of human health and the environment as a whole.

A. National water policy

In most countries, there is a need for the formulation of a national water policy within the framework of and consistent with the overall economic and social policies of the country concerned, with a view to helping raise the standard of living of the whole population.

To this end it is recommended that countries should:

(a) Ensure that national water policy is conceived and carried out within the framework of an interdisciplinary national economic, social and environmental development policy;

(b) Recognize water development as an essential infrastructural facility in the country's development plans;

(c) Ensure that land and water are managed in an integrated manner;

(d) Improve the availability and quality of necessary basic information, e.g. cartographic services, hydrometry, data on water-linked natural resources and ecosystems, inventories of possible works, water demand projections and social cost;

(e) Define goals and targets for different sectors of water use, including provision of safe water-supply and waste-disposal facilities, provision for agriculture, stock-raising, industrial needs and development of hydropower in such a way as to be compatible with the resources and characteristics of the area concerned. In estimating available water resources, account should be taken of water re-use and water transfer across basins;

(f) Develop and apply techniques for identifying, measuring and presenting the economic, environmental and social benefits and costs of development projects and proposals. Decisions can then be based on these factors, appropriate distribution of costs can be determined, and the construction and operation of projects can be carried out in such a way that these matters receive continuous consideration at all stages;

(g) Undertake the systematic evaluation of projects already carried out, with a view to learning lessons for the future, particularly in relation to social benefits and ecological changes, which evolve slowly;

(h) Formulate master plans for countries and river basins to provide a long-term perspective for planning, including resource conservation. Projects arising out of the national plans should be well investigated and appropriate priorities should be assigned to them;

(i) Maintain the planning and management of national water resources as a fundamental aim and as a high priority the satisfaction of the basic needs of all groups of society.

(j) Periodically review and adjust targets in order to keep pace with changing conditions. Long-term guidelines for water management might be prepared for periods of 10 to 15 years and should be compatible with master plans. Planning should be considered a continuous activity and long-term plans should be revised and completed periodically – a five-year period seems advisable in this respect;

(k) Evaluate water-tariff policies in accordance with general development policies and direct any readjustment and restructuring that may be found necessary, so that they may be effectively used as policy instruments to promote better management of demand while encouraging better use of available resources without causing undue hardship to poorer sections and regions of the community. Water charges should as far as possible to cover the costs incurred unless Governments as a policy choose to subsidize them.

International organizations and other supporting bodies should, as appropriate, and on request, assist countries to:

(a) Evolve and formulate national water policies;

(b) Prepare national master plans and, where necessary, river-basin plans and identify projects;

(c) Prepare feasibility reports for projects identified in such general planning studies, which have some prior assurance of financing by interested donor countries or agencies;

(d) Actively promote planning techniques and procedures by arranging information exchange, convening working groups and roving or country seminars, as appropriate, and by disseminating the results of relevent case studies and research studies;

(e) Give urgent attention at the national, regional and international level to developing national expertise in the application of planning techniques by all appropriate means;

(f) Promote various available measures and techniques in public participation and pay particular attention to ways of adapting appropriate techniques to the particular circumstances of countries.

B. Institutional arrangements

Institutional arrangements adopted by each country should ensure that the development and management of water resources take place in the context of national planning and that there is real co-ordination among all bodies responsible for the investigation, development and management of water resources. The problem of creating an adequate institutional infrastructure should be kept constantly under review and consideration should be given to the establishing of efficient water authorities to provide for proper co-ordination. To this end, it is recommended that countries should:

(a) Adapt the institutional framework for efficient planning and use of water resources and the use of advanced technologies where appropriate. Institutional organization for water management should be reformed whenever appropriate so as to secure adequate co-ordination of central and local administrative authorities. Co-ordination should include the allocation of resources with complementary programmes;

(b) Promote interest in water management among users of water; users should be given adequate representation and participation in management;

(c) Consider, where necessary, the desirability of establishing suitable organizations to deal with rural water supply, as distinct from urban water supply, in view of the differences between the two in technologies, priorities, etc.;

(d) Consider as a matter of urgency and importance the establishment and strengthening of river basin authorities, with a view to achieving a more efficient, integrated planning and development of the river basins concerned for all water uses when warranted by administrative and financial advantages;

(e) Secure proper linkage between the administrative co-ordinating agency and the decision-makers.

C. Legislation

Each country should examine and keep under review existing legislative and administrative structures concerning water management and, in the light of shared experience, should enact, where appropriate, comprehensive legislation for a co-ordinated approach to water planning. It may be desirable that provisions concerning water resource management, conservation and protection against pollution be combined in a unitary legal instrument, if the constitutional framework of the country permits. Legislation should define the rules of public ownership of water and of large water engineering works, as well as the provisions covering land ownership problems and any litigation that may result therefrom. It should be flexible enough to accommodate future changes in priorities and perspective. To this end, it is recommended that:

(a) An inventory and a critical examination of rules (whether written or unwritten), regulations, decrees, ordinances and legal and legislative measures on water resources and development should systematically be carried out;

(b) A review of existing legislation be prepared in order to improve and streamline its scope to cover all aspects pertaining to water resource management; protection of quality, prevention of pollution, penalties for undesirable effluent discharge, licensing, abstraction, ownership etc.;

(c) Although legislation should generally be comprehensive, it ought to be framed in the simplest way possible, and be consistent with the need to spell out the respective responsibilities and powers of governmental agencies and the means for conferring rights to use water on individuals;

(d) Legislation should allow for the easy implementation of policy decisions which should be made in the public interest, while protecting the reasonable interests of individuals;

(e) Legislation should define the rules of public ownership of water projects as well as the rights, obligations and responsibilities and emphasize the role of public bodies at the proper administrative level in controlling both the quantity and quality of water. It should appoint and empower appropriate administrative agencies to carry out this controlling function and to plan and implement water-development programmes. It should also spell out, either in primary or subordinate legislation, administrative procedures necessary for the co-ordinated, equitable and efficient control and administration of all aspects of water resources, and land-use problems as well as the conflicts which may arise from them;

(f) Legislation should take into account the administrative capacity to implement it;

(g) Countries should document and share their experience so as to have a basis for possible improvement of their legislation;

(h) Priority should be accorded to the effective enforcement of the provisions of existing legislation, and where necessary, administrative and other arrangements should be strengthened and rendered more effective to achieve this objective.

International organizations and other supporting bodies should, as appropriate, and on request, assist countries to:

(a) Improve and streamline existing legislation and prepare new draft legislation;

(b) Arrange the exchange of information and disseminate the results and experience of selected countries for the benefit of others.

D. Development of appropriate technology

Developing countries need to build up technological capability at the national and regional levels. Priority should be given to technologies of low capital cost, and the use of local raw materials and resources taking environmental factors into account. Developed countries should accelerate the process of transfer of experience and know-how, technical assistance and training to developing countries.

To this end it is recommended that countries should:

(a) Review the adequacy of existing institutional arrangements for the development of appropriate technologies in water resource management, and provide support for their development;

(b) Provide every possible encouragement and support to national institutions concerned with the development of appropriate technologies in water resource development;

(c) Encourage the widest possible diffusion of acquired knowledge on the development of appropriate technology; establish and expand enterprises and productively apply the appropriate technologies that have been developed;

(d) Review the extent of public participation in the planning, construction, operation and maintenance of water projects and take steps to ensure a greater level of participation, through consultations and the transfer of knowledge starting at the village level;

(e) Develop facilities for the servicing and maintenance of installed hydraulic equipment, including the manufacture of spare parts;

(f) Promote the standardization of equipment to help solve operational problems resulting from shortages of spare parts;

(g) Promote subregional and regional arrangements for the planning, design and construction of water projects and the exchange of information with other regions where similar conditions prevail.

International organizations and other supporting bodies should, as appropriate, and on request, assist countries to:

(a) Make a review of the adequacy of existing constitutional arrangements for the development of appropriate technology in the water resources field;

(b) Support national efforts to manufacture construction materials, to service imported equipment, to manufacture spare parts and to manufacture the equipment itself;

(c) Evolve standard designs and plans, wherever possible;

(d) Raise funds to enhance the transfer of technologies and to adapt these technologies to local needs.

IV. PUBLIC INFORMATION, EDUCATION AND TRAINING

A. Public information and extension service

In order to ensure maximum attention to the proper utilization, protection and conservation of water, it is of decisive importance that all citizens be made aware of fundamental matters relating to water. For that reason education and research have to be efficiently supplemented by the provision of broad information to the public. Effective public information aims at the creating of a general as well as personal responsibility for the crucial water issues. It is considered an essential task for Governments to motivate their citizens to adopt a sound view on matters concerning their daily handling of water. Given a general feeling of responsibility for the local resources, people will be aware of the importance of the protection and conservation of water.

In this context it is recommended that countries should:

(a) Direct information to all citizens, first of all through the normal channels offered by primary and adult education and in connection with regular health programmes and information schemes for parents;

(b) Initiate special information campaigns conducted by the use of brochures, newspapers, radio and television, and other forms of popularization;

(c) Prepare people for the consequences of changed life patterns which could be the effect of improved water availability in areas where water shortage formerly restricted various activities;

(d) Inform people of the negative ecological, hydrological and sanitary consequences of misuse of water.

B. Education and training

In the past many countries in the region have relied on foreign countries to supply technical assistance in the design and construction of water projects. Countries should accord priority to conducting surveys to determine national needs for administrative, scientific and technical manpower in the water resources area.

In this context it is recommended that countries should:

(a) Conceive manpower surveys for water development as integral components of overall surveys of the need for trained manpower in all sectors of economic development in the nation, so as to provide really effective instruments for policy planning and project implementation;

(b) Improve the working and living conditions for national professional experts to facilitate and encourage them to work in their own countries;

(c) Take steps to strengthen and expand the facilities and existing institutions, universities, colleges, polytechnics and training centres by providing more teachers, teaching materials etc., so that the quantity and quality of their output can be increased;

(d) Review the curricula of the existing institutions and training centres and expand them to include subjects pertaining to water resource development, the conservation of land and water resources, the teaching of basic anti-pollution measures for lessening pollution and other water-borne diseases in rural communities;

(e) Take steps to establish training programmes, on-site training and training centres for water plant operators and water distribution operators as well as training in other areas where a special need exists;

(f) Public technical manuals and other guidance material in water project design and construction, with particular relevance to local conditions;

(g) Take steps to encourage operational managers and supervisors to play their part, both individually and collectively, as non-professional and part-time trainers and instructors of their own subordinate staff.

International organizations and other supporting bodies should, as appropriate, and on request, assist countries to:

(a) Conduct surveys on available manpower and needs in the field of water resources management and utilization;

(b) Establish new training centres, as and when requested by countries;

(c) Provide scholarships for undergraduate courses.

Part Three

COUNTRY PAPERS SUBMITTED BY GOVERNMENTS

I. FEDERATED STATES OF MICRONESIA

INTRODUCTION

The Federated States of Micronesia (FSM) is a new nation now concluding a Compact of Free Association with the United States. It is composed of four island groups of the Trust Territory of Pacific Islands. The four island groups, as formed under the Constitution of the Federated States of Micronesia, are Kosrae, Truk, Ponape, and Yap.

FSM covers some 1 million square miles of the western Pacific Ocean between 1° S and 13.5° N and between 130° and 172° E. It includes more than 600 islands and atolls.

The land areas of the four island groups of FSM are: Kosrae, 42.8 square miles; Ponape, 133.4 square miles; Truk, 49.18 square miles; and Yap, 45.92 square miles. The total land area of FSM is 271.30 square miles.

Temperature in FSM ranges from mid-70° to the mid-80° F. Rainfall is heavy in Ponape and Kosrae which have over 200 inches per year whereas Truk and Yap have long dry spells during the year.

A. EXISTING WATER RESOURCES DEVELOPMENT

There are three main water systems in Truk, Ponape and Yap, and Kosrae has a series of community type systems. All of the three main systems are provided with collection, storage and treatment facilities. The systems differ from one another as described below.

1. *Kosrae* – Population 5,522 (census of 15 September 1980). There are five main communities on the island. Each community has its own system. Water is collected from surface water that is dammed in the upper streams and distributed to individual homes. No treatment of water supplies is made in these systems. However, one of the systems which serves the seat of the State government is being renovated to include water treatment. Very few houses are located in this area.

Because of limited funds, the trend now is to assist families to install rain catchments. The State legislature provides 50 per cent of the cost and the families provides 50 per cent and the remaining labour. This programme was recently started and about 10 per cent of the families have been provided with rain catchments. The Division of Environmental Health provided technical assistance and supervision for this programme.

2. *Ponape* – Population 22,367 (census of 15 September 1980). There is a central system with a daily storage capacity of about 4 million gallons including the sedimentation tank. Water is dammed at the upper stream and flows by gravity to the treatment plant, more than a mile away, and to the consumers. It serves about 35 per cent of Ponape's total population. The treatment includes sedimentation, filtration and chlorination. At the present time the system is beset with problems, since as insufficient water to supply the demand, faulty construction, leaks, and inadequate size of intake line which can only deliver 1.7 mgd which is much less than the demand. Thus, the system is turned off for about 8 hours each night (8 p.m. to 5 a.m.) in order to refill the tank.

In addition to the main system, there are a number of small community type systems serving from 10 families to over 100 families, depending on the size of the systems. With the exception of the ones which serve over 100 families all of these community type systems are without treatment. Experience has shown that community systems in the villages are not properly maintained due to lack of funds and the technical inability of the villagers to maintain the systems.

The third type of system that is being encouraged in the State are the individual rain catchments. A variety of types of rain catchment has been introduced, including square and circular plaster type, slab, fiber glass and ferro cement. The outer islands or atolls are taking full advantage of rain catchment.

Wells are available in most of the outer islands but they were constructed in such a manner that they are always contaminated. Methods of obtaining water from these shallow well (rope tied to a bucket) are constantly introducing contamination into the system. Placement of hand pump is impractical because of maintenance problems.

3. *Truk* – Population 37,383 (census of 15 September 1980). There are two main water systems in the State of Truk. One is located on the island of Moen which is the seat of the government, the other is in the nearby island of Dublon. Both systems are treated. The Moen system is larger serving over half of the 1,168 households of Moen, while the Dublon system serves half of the 350 households. The Moen system is a combination of several deep wells and surface runoff collection. Well drilling is still continuing and more than 5 wells have been completed. A total of 14 wells are planned; each of these wells is expected to produce over 40 gallons per minute. The Dublon system is a sub-surface seepage or a shallow spring and the water is chlorinated before distribution.

Throughout the lagoon of Truk State there are several types of systems used by the people. Some are small community type systems where surface run-off, spring and stream water are piped and distributed. There are also individual rain catchments that are either concrete or fiber glass. In the outer islands on the low atolls, rain water catchments are the main source of obtaining potable and safe drinking water. There are also wells, but as discussed earlier, they are always contaminated.

Since September there has been an epidemic of cholera in Truk. The continued incidence of cholera is especially noticeable in the lagoon where the sanitary quality of water is very poor.

4. *Yap* – Population 7,870 (census of 15 September 1980). There is one central system in Yap serving the main town of Colonia. All water for Colonia are obtained from two open impoundments which are fed by a stream and runoff. Both reservoirs have a capacity of 29 million gallons and are not protected from public access.

Raw water obtained from the reservoir are treated at a nearby small treatment plant. The treatment provides flocculation, clarification, and filtration. Chlorine is added with aluminum sulfate and lime. Chlorine residual has a mean of 0.1 mg/l. All parameters monitored are within the acceptable limit, except for turbidity which exceeds the allowable 1.0 unit monthly limit but within the 5.0 average over two-day period.

While the system serves a very limited number of households with a population base of 1,750, it actually serves more as people from the village continuously commute to the State center.

An estimate of over 2,000 people use the system daily.

B. EXISTING PROBLEMS

Problems which exist in all the central systems throughout FSM are:

1. Insufficient production.
2. Insufficient chlorination or lack of disinfection.
3. Leakage and wastage.
4. Inadequately trained plant operators.

The government has identified funds for correcting some of the problems. It has also established a training programme to train operators at the local community college with the assistance of engineers from the University of Guam.

C. IRRIGATION, FLOOD CONTROL AND HYDROPOWER

Very little has been done in the area of irrigation and flood control. The reason may be due to the natural topographs of the islands which create easy runoff which avoids serious flooding. With the exception of Kosrae and Ponape States which are currently developing limited hydropower systems, other States do not have such systems.

Future plans for water development are directed towards improving and providing safe water in the villages. Individual type of systems is being encouraged by the government. Some States even provide support to individual family to build such catchments. At the present time no agency is conducting any assessment, or collecting data for both ground and surface water. The Department of Public Health is the only government agency which is responsible for monitoring and surveillance of the existing systems.

D. NATIONAL POLICY

The present national policy that is enforced for water quality and safe drinking water are those established for the whole Trust Territory of the Pacific Islands. The policies are as follows:

1. Water Quality Policy

The marine and fresh water quality standard defined the goals to which policies concerning water quality should be directed. These regulations state:

- Water quality will be maintained to provide for the propagation of aquatic life and recreational purpose.
- Achievement of water quality goals should not represent an unreasonable barrier economic and social development.
- There shall be no direct or indirect discharge of sewage or other waste into any planned or intended ground or surface sources of drinking water.
- All sewage shall receive a degree of treatment necessary to protect the beneficial uses of the water.
- To the extent practical, all new point sources of pollution shall not be discharged to near-shore or fresh waters.

2. Drinking Water Policy

The "Public Water Supply Systems Regulations" express concern that "public water supply systems are protected against contamination and pollution . . ." This concern is also reflected in the "National Interim Primary Drinking Water Regulations" that became effective June 24, 1977. Under the "Safe Drinking Water Act," which the Trust Territory regulations has implemented, a public water system may be granted variances and exemptions that allow noncompliance with some of the "Interim Primary Regulations" if no "unreasonable" health risk is involved. Under these regulations, though, systems with exemptions must be in compliance within a specified time.

The policy as stated in the Trust Territory "Public Water Supply Systems Regulations" is to insure that "sufficient safe drinking water will be available for all." In order to fulfill the above commitment, in the past most efforts were directed to increasing water supply with little attention given to increasing water quality. Only recently has concern been expressed that little or nothing was being done to improve water quality.

E. PROBLEMS/PROJECT ORIGINATED ISSUE

The problems faced by all FSM States are not only related to design or construction of water systems, but also with the operation and maintenance of these systems.The latter problem is compounded by lack of funds, lack of properly trained manpower and difficulties in obtaining necessary supplies and materials.

Although funds have been made available for improvement of the four major systems, funds for maintenance are not always available. Maintenance of small community water systems is even more difficult. It is for these reasons that the government is encouraging and promoting individual family type systems. Since maintenance of these systems is easier and the likelihood that families will initiate and continue to maintain the systems is probable.

F. BROAD AND LONG TERM PERSPECTIVE ISSUES

Trust Territory Environmental Protection Board Regulation Title 63, Chapter 13, Subchapter VII sets forth requirements governing protection, usage, classification of water in the TTPI. The established policy in this regulation is bending in all FSM States. These policies are listed in above paragraphs. All planning that either directly or indirectly affect fresh water must meet the requirements of this regulation.

I I. FIJI

INTRODUCTION

Fiji comprises two large islands, Viti Levu and Vanua Levu, each approximately 50 miles across, and many small islands. The main large island has received most attention and has several regional schemes in operation or under design. The first major water supply dam, Vaturu Dam, will be opened on 26th November. Village water supply schemes have been developed for over a decade. The other large island has received less attention and on the many small islands only responses to particular requests.

A. SURFACE WATER – DATA SYSTEMS

1. Authorities Collecting and Disseminating Data

The Mineral Resources Division, Geological Section undertakes the investigation of groundwater resources. Public Works Department, Hydrology Section carries out the assessment of surface water resources and various hydrological investigations. Surface water quality is monitored by the Water and Sewerage Branch. The Meteorological Service collects meteorological and climatological data including rainfall.

2. Public Works Department – Hydrology Section

Although some river stations were installed prior to 1970 it was not until 1971 that the Section commenced operating a general network of river and rainfall stations established for long term data purposes. The Section is run by about 100 permanent and temporary local staff and 3 expatriate persons. A National Office establishes guidelines on most activities and 3 Divisional offices organize all work associated with the data gathering effort.

3. National Hydrological Station Networks

The principal networks are rainfall and stream measuring stations, however other minor associated ones obtain climatological, tidal flood warning and sediment data.

a. *Station Network – Design*

The networks are designed to achieve a minimum density compatible with hydrological variability of the regions so that a reasonable statistical sample is obtained. This may not be possible in some regions because of access and lack of habitation. Special project needs must also be satisfied which causes temporary imbalances in network density.

The stations are defined under 3 main categories:

a) Primary or basic stations

b) Secondary stations

c) Special stations

Data purposes may also be listed under 4 main headings:

1. Basic data
2. Project data
3. Research data
4. Operational data.

Basic data for long term water resources assessment comes from stations under category (a) and (b) whereas other data comes under (b) or (c).

In this way a number of stations may fulfil a multipurpose which saves on capital costs.

b. *Rainfall Network*

The present operational stations consist of 62 manually read ones and 98 equipped with an automatic recording instrument.

All instrumented stations have either a standard raingauge or a storage raingauge installed for checking purposes.

The standards followed are generally those of the New Zealand Meteorological Service.

These stations are combined with the Fiji Meteorological Service station networks which will be discussed separately by them.

c. *Stream Network*

The present fully operational stations comprise 40 manually read daily staff guage ones and 49 equipped with an automatic water level recorders. All of these stations have regular discharge measurements taken according to a set programme.

The standards adopted generally conform to those used by many major water authorities elsewhere.

In addition to full time stations there are some 30 to 35 partial record stations where discharge readings are taken on a seasonal or casual basis i.e. during flood or drought surveys.

There are 2 manually read stations and 8 automatic recorder stations installed to obtain tidal and flood levels.

4. Instrumentation

Continuous recording of stream levels in Fiji is essential for adequate data. It is also necessary for catchment rainfall to be recorded in this way to define temporal storm patterns and intensity.

Conventional float type instruments and mechnically actuated ones are preferred to battery dependent types because of environmental and servicing difficulties.

a. *Stream Stations*

Only 3 Elliott pressure type and 3 float type circular chart recorders remain in operation because of their low accuracy. Over 40 Ott. and Alpina float type strip chart recorders are the standard now used in Fiji with mechanical clockwork giving 6 to 8 weeks autonomy. Gauge height scales are generally 1:10 metric and time scales 1 cm per hour.

b. *Rainfall Stations*

Casella natural siphon recorders are gradually being phased out but 26 still remain in operation. The standard automatic recorders in use tatalling 60 units are the Dines tilting-siphon type with a daily or weekly duration, and the Siap tipping-backet type using a strip chart with monthly autonomy. Eleven (11) Hellmann siphon type strip chart recorders are also used.

c. *Current Meters*

The Ott C31 and C2 model propeller type current metres are mostly used, however some Siap ME Series metres are also in use. No facilities to check metre ratings are available in Fiji but occasional checks are made against new instruments.

d. *Cableways*

Hydrological Services Pty. Ltd. double drum type gauging winches have been installed at about 7 sites to satisfy essential project needs.

5. Field Operations

Operational priorities are generally set by the Central National Office according to project or specific needs. Gauging operations and routine servicing are organized by the 3 Divisional offices. Construction and repair work programmes are prepared by the Central Office to cater for improved networks and to co-ordinate the national needs.

a. *Transport*

Vehicles to service the networks of station are an essential requirement. At present 10 four wheel drive vehicles are needed for adequate operations, however maintenance time and breakdowns generally reduce this by about one-third.

b. *Discharge Measurements – Gaugings*

Measurements of the flow at hydrometric stations are essential to determine the stage – discharge relationship which in turn must be obtained to calculate daily discharges. The type of measurement made is either wading, cableway or float. The velocity methods used are:

a) Single point for small shallow streams

b) Two point and three point methods for larger streams

c) Full measurements and surface velocities are done occasionally to check the vertical distribution of velocity.

The discharge computation is done by the mean-section method.

The frequency of measurements needed will depend on the stream's channel or bed stability and the accuracy specified for various projects which may require intensive monitoring. All general network stations are gauged on a monthly routine basis, however priority stations may be manned continuously by a party.

Stream recorder charts are changed and checked by staff during the routine monthly gauging cycle or more often if possible. Rainfall recorders with daily charts are changed by local observers at many stations, however all long term instruments are changed by staff as a monthly routine.

6. Data Extraction, Processing and Dissemination

Present data processing is in a transition stage between manual and machine methods using computer facilities.

The extraction step from original charts to the listing of figures will continue to be manually done for sometime, however the processing and publication of data for distribution will be done by computer. There is a substantial backlog of data awaiting extraction, editing, processing and analysis.

a. *Rainfall – Depths*

These data are mostly the easiest to process. Hourly, daily and monthly amounts are listed and routine summaries giving monthly totals have been prepared for several years. Selected stations will be used for durations down to 10 minutes.

b. *Stream Flows – Discharges*

Although hourly and daily water levels are readily extracted, the conversion of these levels to daily discharges requires the availability of the flow rating. This can delay calculations for 12 months. The manual calculation of daily discharges has been limited to project stations and some primary stations, totalling about 18. Computer processing has been done on about 7 stations.

c. *Flow Rating Curves*

The stage – discharges relationship is obtained by plotting gauging measurements on natural scale graph paper and preparing a flow rating curve. The gauging are then transferred to logarithmic paper after adjusting the stage for zero flow. Satisfactory rating curves are available for about two-third of the stations where the rating deviation will range between ± 10 to 15%. Some stations may exceed ± 30%.

The log-log extrapolation together with float gaugings, slope measurements and velocity-area extensions forms the basis of determining a complete flow rating equation. Most ratings are difficult to obtain over a short period.

d. *Flood Warning and Special Reports*

A rather basic flood-warning system for the Rewa River is available to advise those authorities concerned. An increasing number of special reports and short studies by hydrologists are also availble.

e. *Hydrological Data Bank – Computer System*

A project between Public Works Department Hydrology Section and Electronic Data Processing Services is well advanced to establish a National Data Bank using computer facilities and programmes. Although it is not fully operational it is hoped to achieve a complete storage, processing and retrieval system to cope with Fiji's development. The dissemination of information to all users should then be possible. A small computer in the National Data Unit handles intermediate processing of flow data and inventories of instrument and equipment items including spare parts.

7. Training

Staff training has always had high priority in this specialized work. In-service training at two levels was conducted in 1979 and three overseas hydrologists provide constant back-up to three local counterparts. A full time Training Officer is expected to shortly, to advance training and work procedures for subordinate staff.

8. Hydrological Data – Network Evolution

Hydrological networks are never static. In Fiji the priority of major water development projects have gradually transformed the initial networks. Research and operational data demands will make further changes. Regular reviews are necessary to avoid needless station construction and ensure an equable network growth towards a satisfactory station density.

The country's economy generally sets the speed of evolution. Some project stations may be retained and incorporated into the secondary station network which will result in a capital saving because of earlier project cost contributions. Others may be discarded after acceptable correlations are established with permanent stations and thus will save an operating costs.

a. *Network Development and Planning*

The networks should undergo an expansion geared to the development potential of a region and preliminary programmes of action determined by Government priorities. The most important point of this expansion is its timing. Many years of data are necessary to adequately define the water resources of a region, so it is no good waiting until a project starts to collect specific site data. It is far better to use a long term station nearby and relate that data to the project site for a restricted period.

B. GROUND WATER

1. Investigations

Up to present very little groundwater resource evaluation has taken place. Investigations have often been limited to providing borehole supplies on a relatively ad hoc basis when all other sources of supply have been investigated and found wanting in some respect. Fortunately this philosophy is changing and the idea that groundwater resources need to be assessed and quantified has begun to be accepted.

2. Equipment

Groundwater investigations are carried out by Mineral Resources Department at the request of the Public Work Department. M.R.D. is equipped with a Drilling Section with two rotary rigs, three percussion rigs and three diamond coring rigs. Over the last two years up-to-date resistivity equipment to replace older worn out equipment and well logging instrumentation has been purchased or given to Fiji on aid projects. The hydrogeology section of M.R.D. also has the use of an HP9845 computer with floppy discs and matri printer. Rainfall data is acquired from the Metereological office and hydrological data from P.W.D. Hydrology Section.

3. Aid

Fiji government has received aid over the years usually in the form of equipment. Test pump and drilling rigs have been supplied by Australia, more recently the Japanese International Cooperation Agency provided 200 million yen (approx. F$800,000) in equipment, including a drilling rig, borehole pump, pipes etc. United Kingdom provided aid to the Fiji Government by supplementing the salaries of U.K. professional staff to fill in-line Fiji government posts. One of the two hydrogeological posts is occupied by such a person. In the late 1970's aid was provided in the form of a technical cooperation hydrogeologist seconded from the Institute of Geological Sciences, U.K., to carry out a groundwater resources study of the Nandi basin area. This was a World Bank requirement prior to loan facilities being provided to build the Vaturu Dam and associated trunk mains for the now almost extant Nandi-Lautoka scheme.

United Nations, in the early 1970's, provided aid in the person of a hydrogeologist to carry out a nation-wide project.

4. Staffing

Groundwater evaluations are carried out using the hydrogeological unit of the Mapping/Hydrogeology Section of M.R.D. The following staff work full time on groundwater or related projects.

1 – Senior Geologist (hydrogeology)
70% technical
30% administration.

2 – Technical Officer Grade II/1 No.
Acting Geologist (hydrogeology)

1 – Senior Technical Assistant

1 – Technical Assistant.

The unit has the technical assistance of the Acting Principal Geologists Mapping/Hydrogeology for about 20% of his time and about 50% of his time is spent of administrative duties associated with groundwater. This unit can also call upon the expertise of a geophysicist and the time of another two technical assistants from time to time.

The vast majority of boreholes completed by the

Drilling Section are drilled for groundwater purposes. The Section consists of the following established staff:

1 – Drilling Superintendent
1 – Drillers high grade } Drilling supervisors
1 – Technical Officer }
5 – Drillers

5. Legislation

Since no legislation exists concerning groundwater nobody has a duty to know about groundwater resources, nobody, therefore can evaluate it properly to allow conservation, control and water resource planning. At present investigation and development is regrettably somewhat haphazard.

6. Specific Schemes

A number of schemes to investigate or provide groundwater sources are being conducted at present to facilitate public supplies:

(1) *Vanua Levu Groundwater Scheme*

A total of thirteen production boreholes are in the process of construction for supply to individual villages and settlements. This project is supported by Japanese aid.

(2) *Sigatoka Regional Groundwater Scheme*

A yield of 4100 m^3/d (37600 gph) has been proved from a induced recharge scheme in the Sigatoka river gravel deposits. Stage II of the scheme to prove a further 6800 m^3/d (1.5 mgd) will commence in 1983.

Quality is proving a problem both in high manganese and iron values and salinity from residual older groundwater in the gravels. The Mn/Fe problem does not appear to improve with pumping whereas salinity does appear to be decreasing with time.

(3) *Taveuni*

An investigation to prove groundwater supplies in southern Taveuni for village/settlements is about to get underway.

(4) *Tavua/Vatukoula Regional Water Supply Scheme*

Groundwater resource investigations have begun and exploratory drilling of five – six boreholes is imminent. Demands are 11350 m^3/d (2.5 mgd) for the total scheme but much less for Tavua only. Groundwater resources are sort for part or all demands to reduce treatment costs.

C. MANAGEMENT

The Water and Sewerage Service is a section of the Public Works Department although the Government has asked for a report on the possibility of creating a separate department to cover all aspects of water and sewerage investigation, design, construction, operation and maintenance. The Hydrology Section operates under the general direction of the Water and Sewerage Section.

Investigations of basic resources such as groundwater, catchments capacities and river flows are initiated by head office of the Water & Sewerage Section and carried out by the appropriate section of PWD or by other Departments such as Mineral Resources as appropriate.

D. STAFFING AND TRAINING

Being a small country Fiji has no ready supply of labour for immediate use on technical work. We must therefore import our skills, first for doing the work and then for training our own people. In this we have been aided most generously and we feel we have made the best possible use of that aid. In the field of hydrology we have established a regime which is beginning to show possible career paths and so engenders a feeling of unity and loyalty. At the same time the development of training schedules is providing the means to follow those paths.

E. POLLUTION

With regard to pollution we in Fiji are fortunate in two ways. Firstly the scale of our operations is not such that pollution on a massive scale is a problem and secondly we have a number of organizations which become involved in most projects and, though it might not be their main intention, serve to ensure that attention is paid to environmental and health matters.

The most serious problem of pollution is that of providing a healthy environment. We have made good progress in the provision of a supply of water and we are progressing well on the monitoring and control of its quality. So far we have relied on external testing of water but we have recently introduced monitoring within the Water and Sewerage Section of the PWD.

At times the many organizations, boards, departments and committees and so on we have to deal with is frustrating but when eventually progress is made we appreciate that the checks and balances they have provided and permitted progress without pollution of our physical, and cultural environments.

Table 6. Water supply in urban centres in Fiji for 1981

Urban centres	*Number of metres*	*Estimated population served*	*Average daily demand (cu.m.)*	*Source of water*
Suva	23 908	132 000	44 500	Catchment + River
Nausori	3 862	21 200	4 300	River
Deuba	531	2 900	1 100	Catchment
Levuka	540	3 000	1 000	Catchment
Navua	804	4 400	390	Catchment
Korovou	98	550	100	River
Lautoka	7 435	41 000	12 400	Catchment
Nadi	5 384	29 600	8 300	River
Tavua	644	3 500	790	River
Vaileka	742	4 100	940	Catchment + River
Sigatoka	998	5 500	1 120	Catchment + Borehole
Ba	3 715	20 400	4 550	Catchment
Labasa	3 639	20 000	4 200	Catchment
Savusavu	460	2 500	340	Catchment
Total	52 760	290 650	84 030	

F. THE EXISTING WATER SUPPLY SITUATION

Public Works Department maintains and operates metered water supplies in the fourteen major urban centres in Fiji. Table 6 gives statistics for 1981 relating to these supplies.

The most recent census of September 1976 gave a total Fiji population of slightly over 588,000 persons, and allowing an annual growth rate of 2 per cent, the 1981 population is estimated at about 649,000. Based on the above table, approximately 44 per cent of Fiji's population is supplied with water from these urban systems.

The water used for urban supplies is with only one exception drawn from surface sources, in most cases from protected catchments under natural forest cover. Other supplies depend on a combination of upland and river abstraction sources, whilst a few, such as Sigatoka, Tavua and Nausori are drawn entirely from unprotected rivers. As in other parts of the world, it is becoming increasingly difficult to acquire land solely for use as a catchment area, and a national policy is needed which establishes the relative priorities of timber, agriculture and water.

All urban supplies receive some degree of treatment, with chlorination being provided as a minimum. The majority of centres provide chemical dosing, followed by sedimentation and filtration, whilst the more modern plants also include fluoridation.

The urban plants in general provide water of high quality, and the aim is to meet the WHO standards for portable water.

Beyond the perimeter of the urban supplies lie the rural areas, with a total population of approximately 359,000. The population density is generally low although there are small communities, particularly in the cane farming districts, and in Government's administrative centres where a piped water supply is virtually essential, even though the provision of this service is uneconomic financially. Table 7 gives the 1981 statistics for these minor supplies.

The sources tapped for these schemes range from boreholes, to intakes with afforested catchments, and run-of-the river abstraction systems. Most are chlorinated, and in a few instances small treatment plants are provided.

There are many small communities, often remote and difficult of access, where a metered water supply operated by PWD is impracticable. The majority of these are villages, having populations ranging from 50 to 500 persons, with

Table 7. Water supply in small communities in Fiji for 1981

Small communities	*Number of meters*	*Estimated population served*	*Average daily demand (cu. m.)*	*Source of water*	*Supply serves*
Tubou	235	1 300	210	Catchment	Village
Naboro	54	300	70	Catchment	Prison
RKS	89	500	175	Catchment	School
QVS	42	230	85	Catchment	School
Colo-i-Suva	49	270	20	Catchment	Forestry
Rotuma	16	90	20	Borehole	Village
Korotogo	87	480	330	Borehole	Hotels etc.
Varavu	131	720	110	Borehole	Farming areas
Koronubu	80	440	65	Borehole	
Vunisamaloa	131	720	140	Borehole	
Navoli	62	340	65	Borehole	
Veisaru	147	800	115	Borehole	
Taganikula	112	620	70	Catchment	Farming
Somosomo	215	1 180	250	Catchment	Village
Nabouwalu	117	640	70	Catchment	Govt. Sta. etc.
Seaqaqa	44	240	40	River	Farming
Naselesele	82	450	35	Borehole	Village
Total	1 693	9 320	1 870		

about 200 persons as an average number. Since 1965, Government has provided a basic water supply to such communities through a subsidised self-help programme, under which Government meets most of the cost of the installation (on average about 75-80 per cent), with the balance being raised by the community, which must also provide free unskilled labour. About 1000 such schemes have been completed to date, and the programme continues with an average of 55 new installations annually.

These schemes provide unmetered and untreated water for consumers, and strong preference is given to gravity pipelines fed from a small dam in an undisturbed catchment. Such ideals are not always possible, particularly in the smaller islands, where surface sources may be unreliable or non-existent. In these cases, communal storage tanks are provided, in capacities ranging from 3500 to 25000 gallons, fed from the roofs of all houses within convenient distance of the tank. Churches and schools often have large roof areas, and with average annual rainfalls of about 75" (1900 mm), can provide an assured supply in all but the longest drought, providing water is not wasted. The per capita consumption is impossible to estimate in these self-help schemes, but under severe conditions may be as low as 2.5 gallons (11 litres) per person per day.

Maintenance of the installation becomes the responsibility of the community after an initial 'guarantee period' of six months, when PWD will rectify any faults which may develop. It is becoming apparent that this aspect of communally owned schemes is neglected, leading to the need to renew installations after a life of 8 or 10 years.

Government also offers a subsidy (currently \$500) to individuals requiring a borehole. This scheme has had a modest success and about 100 installations have been completed since its introduction in 1974.

Many rural dwellers particularly individual households are beyond the reach of Government's reticulation systems, and are unable to benefit, for one reason or another, by self-help projects or boreholes. These persons must rely on their own ingenuity in providing water for their families. Most rely upon roof storage tanks made of corrugated galvanised iron, which are available fairly cheaply in a standard range of sizes up to 1000 gallons.

Rainforced concrete tanks are more rare, and ferro-cement tanks are just beginning to come into use. Shallow wells are often sunk, and a selective use of tank and well water is not uncommon. Solar powered pumping systems have been initiated but not yet assessed.

Tanks and wells are vulnerable to drought, and a prolonged dry season results in water shortages which can seriously affect people in rural areas, and particularly large users of water such as schools, health centres etc. In this situation, the PWD may be asked to deliver emergency supplies by road tanker or barge to the affected areas. A nominal charge is made for this water.

G. METEOROLOGICAL INFORMATION

1. Rainfall Data

Rainfall and other meteorological observations commenced about a century ago at Suva, Penang Mill and Wainunu. Eight rainfall records extend back to the 1800's and there are now about 357 places in the station register of which some 280 are currently operating.

The Meteorological Service is the custodian of the national rainfall data archive. Observations are mostly 24 hour manual raingauge totals read at 9 a.m. They have been made by a number of different agencies and individual observers, mostly equipped and coordinated by Meteorological Service as official cooperative stations. Many of the long period records were gathered by planters. Other early records were set up by the sugar industry which still maintains a large network. Others were taken by public servants as part of official duties. Frequently, cooperative stations were set up because another Government Department had a need for the data. (e.g. Department of Agriculture, Public Works Department). Many observers have been unpaid volunteers.

From the 1960's and increasingly in the 70's Public Works Department built up a separate rainfall network, sometimes duplicating and in the end replacing some of the earlier Met. Service gauges, presumably because the latter were not producing satisfactory records. Public Works Department introduced a policy of paying honoraria to unofficial observers and to employees to compensate for weekend and holiday time. This policy is now being introduced by the Met. Service in the hope that it will counteract the falling off in regularity and quality of observations which has been apparent in Fiji (as elsewhere) in the last ten or twenty years.

The Public Works Department maintains quality control and archives the data for its own stations. It issues monthly summary sheets for stations in Western and Central Division from its Lautoka and Suva offices.

The daily manual raingauges in use have (in recent years at least) mostly been 127 mm (5 inch) gauges, with rim 30 cms (1 ft) above ground. Many of the sugar industry gauges are non-standard, mounted on posts at about 1 m (3 ft) above ground.

As well as the manual gauges, recording raingauges are now in use at 9 Meteorological Service stations (most since the 50's) end at about 100 stations operated by Public Works Department (most with only short periods of record).

From the recorder charts, Met. and PWD both extract hourly rainfall totals, and these are written on manuscript sheets, each with one station-month's data, but both organisations have a back-log of data extraction to be updated. Met. also extracts maximum rainfall amounts recorded each month in selected intervals from 10 minutes to 72 hours, used as a basis for calculating depth-duration-frequency relationships of extreme falls. This work is up to date only for Nandi Airport and Suva/Lautbala Bay.

2. Other Meteorological Data

Fiji Meteorological Service organises a network of 47 "climatological" stations in Fiji, including 16 synoptic reporting stations. As well as rainfall and air temperatures, some of these observe tank evaporation or the elements required to estimate potential evapotranspiration and open water evaporation.

Data from climate stations is gathered, quality controlled, processed, archived, and has been published by Meteorological Service in a similar fashion to rainfall. Sunshine and solar radiation data are tabulated as hourly values on monthly data sheets. Nandi and Nausori airport data (including rainfall) have been captured into the New Zealand Meteorological computer data system, and some summarised data for Nandi Airport has been included in relevant New Zealand publications and summaries.

There has been a fairly satisfactory distribution of sunshine recorders. There could well be more tank evaporimeters and anemometers. About five second order solar radiation stations are planned for the near future.

3. Computer Data Archiving and Processing

In 1980 Meteorological Service and Hydrology Section of Public Works Department independently started work on establishing computer processing and archiving of rainfall data at the Government Electronic Data Processing (EDP) Services computer facilities in Suva.

A decision was made to set up jointly a single computer rainfall data system, thus providing Fiji national rainfall data archive. Up till now effort has been concentrated on creating a computer data base and improving quality control.

The following data files have been established:

(a) Station information

(b) Daily rainfall

(c) Daily climate data

and other including hourly rainfall are planned. A considerable volume of historical rainfall data has been captured and current data entry has commenced.

III. MARSHALL ISLANDS

INTRODUCTION

The Marshall Islands, located 5250 miles southwest of San Francisco, California in the central Pacific ocean, consist of two nearly parallel chains of coral atolls and islands which extend for 700 miles, from the northwest to the southwest, about 130 miles apart. The Eastern or Ratak (Sunrise) Chain encompasses 16 major atolls and islands; the Western or Ralik (Sunset) Chain includes 18 atolls and islands. (Figure 1) Together, these two chains contain 1152 islands and islets dispersed over more than 500,000 square miles of the central Pacific, but the total land area is only 70 square miles. Currently, 31,045 people live in the Marshall Islands. Geographical features of these islands are shown in table 8.

The islands are coral caps on great dome volcanoes which rise 18,000 feet from the ocean floor. The dome volcanoes have formed in two rows which correspond to lines of weakness in the ocean floor. Several drillings on Enewetak and east of Wotje Atolls indicate the balsaltic shield of the related domes at the 4200 feet and 6000 feet respectively below sea level. At no point are any of the Marshall islands higher than 30 feet above sea level.

The climate is tropical – hot, and humid with an average temperature of 81° F and daily variations of less than 12° F. The islands are cooled slightly by the prevailing seasonal trade winds. Rainfall averages 180 inches per year in the southern atolls, with the wettest time in October and November; it is lighter in the northern group of islands, averaging 70 inches per year. Average monthly temperatures and rainfall in the Marshall islands are shown in table 9.

The Marshall islands are generally not considered to be in the typhoon belt, although storms are spawned somewhat to the west of the Ralik Chain. However, because the islands are true atolls with low-lying reefs and land mass, they are easily flooded during storms and tidal surges. As recently as late 1979, a series of tidal surges struck the most densely-populated areas of Majuro Atoll over a two-week period, destroying hundreds of homes and causing millions of dollars of damage.

At the present time, over 60 per cent of the total population of the Marshall Islands reside on only two atolls: Majuro and Kwajalein. Employment is centered on Majuro Atoll where there are 3,500 workers, most of them Marshallese employees, and Kwajalein Atoll where 600 Marshallese receive U.S. wage scales at the Kwajalein Missile Range. Approximately one-third of the total population of the people live in a subsistence economy on the outer islands.

Unemployment is a major problem because unskilled workers from the outer islands flock to the urban areas seeking to enter the cash economy through jobs in copra production, handicraft manufacture, or short term construction projects.

Numerous studies by various agencies of the U.S. Government and the United Nations have identified and isolated the most apparent problems of this newly emerging nation. A Five-Year U.S. Capital Improvement Programme initiated in 1976 attempted to provide the minimal infrastructure necessary for economic development. Although much progress has been made under this programme, these objectives have not been met. Economic development throughout the Marshalls must proceed under constraints of limited land, energy and water.

The present development programme now being implemented calls for a significant improvement in infrastructure, particularly in the outer islands, to lay the base for developing agricultural and marine resources. The intention is to reverse the flow of people to the urban cultures of Majuro and Ebeye (Kwajalein) by developing the resources of the outer islands and improving services there.

A. HYDROGEOLOGY

Atolls are generally circular to elongated coral reefs that encircle a central lagoon. They usually contain numerous small islands consisting of recent reef atoll sediments which have accumulated on top of the outer portions of the atoll platform. On the ocean sides the islands descend very steeply, but on the lagoon sides the slopes are very slight, a factor which may be of significance in the propagation of tidal signals through the island groundwater bodies. Deep Drilling into atolls shows that the present reefs overlie a thick succession of carbonates ranging from unconsolidated lagoonal sediments to well-lithified coralline limestones and reef plate. Indications are that these carbonates from 4500 to 6000 feet thick limestone which in turn overlies olivine basalt. This basalt basement has also been reached beneath other atolls and suggests and ultimate volcanic origin.

Reef formation on these atolls has been significantly affected by quarternary glacial-induced sea level changes. Typically, periods of emergence have resulted in solution and erosion of the reef platform, and period of resubmergence have resulted in renewed limestone deposition on the embedded surface. Consequently, the upper-most deposits of the atolls are characterized by numerous geologic (and usually hydrologic) uncomformities.

The unconformity with the greatest significance for fresh ground water bodies is the uppermost one. The upper sediments generally being less than 6,000 years old and the underlying sediment approximately 120,000 years old. It is usually found at depths of 26 to 39 feet below mean sea level and generally corresponds to drilling breaks from unconsolidated sediments to hard limestone. Below this horizon the material is more permeable, contains saline water, and readily transmits the oceanic tidal signal. Above this horizon the material is generally less permeable and tends to contain fresh water; however, tidal mixing at the sediment interface creates an extensive brackish transition zone that extends well into the base of the recent island sediments.

Although the data available in the Marshall are limited, certain general assumptions can be made. The sole source of recharge to the groundwater body comes from rainfall. A portion of the rainfall is directly evaporated from the ground surface, an additional portion of the rainfall is evaporated and transpired from the soil zone, and the remaining rainfall component recharges the ground water body. It should be noted that the permeability of the surface materials is large enough so that surface runoff to the ocean is negligible and can be ignored in any water budget calculation.

The fresh groundwater beneath the typical atoll, recharged by rainfall, occurs as a lens-shaped body called a Ghyben-Herzberg Lens, which floats on and displaces sea water by virtue of the difference in densities of fresh and sea water.

The significance of the groundwater bodies to the future development of the urban areas of the Marshalls and the outer islands cannot be minimized. The increasing urban populations and the desire to reverse the trend by attracting people back to the outer islands can only be accomplished with careful planning and development of the valuable water resources.

B. EXISTING WATER RESOURCE DEVELOPMENT

Present development of water resources by this Government is concentrated on Majuro Atoll and in Ebeye, Kwajalein Atoll, where over 60 per cent of the population lives.

On Majuro, water is supplied primarily by catchment off the airport runway. A series of pumps transport the raw water to adjacent reservoirs totaling 15 million gallons (U.S.). After treatment, 2 million gallons are stored in a covered reservoir and from there delivered 11 miles to the main population area. Two 100,000 elevated storage tanks and two 0.5 million gallon reservoirs provide pressure and additional storage in the center of the most populated area.

Supplementing this system are the transmitter site lens wells consisting of 3 pumping stations which provide up to 50,000 gallons/day during the normal dry season: December to April. Total consumption is approximately 100 million gallons/year servicing approximately 8000 people. Additional water is supplied by private roof catchment and wells but are limited. On the western end of Majuro (20 miles), the population also uses roof catchment and individual wells.

The water supplies as presently developed on Majuro are barely adequate to serve the existing population during normal rainfall years. On occasions, such as the present time, periods of prolonged drought produce acute water shortages. Moreover, any further increase in water demand, such as would result from population growth or increased tourist and hotel development will require additional water supplies.

C. PROPOSED PLANS FOR GROUND WATER DEVELOPMENT

Currently under study by the Government are two basic approaches:

Short Term

1. Increase surface catchment, both on Majuro and Ebeye, by enlarging the catchment/storage capabilities and improving the efficiency of the existing system. Feasibility studies are now being conducted;

2. Leak detection monitoring – Scheduled in early June;

3. Installation of two reverse osmosis desalination units – 40,000 gallons/day portable units on order.

Table 8. Geographical features of the Marshall Islands

Name	*Type*	*Approximate no. of islets*	*Area (km²)*	
			Lagoon	*Dry Land*
Ratak Chain				
Taongi	atoll	10	78.04	3.24
Bikar	atoll	7	37.40	0.49
Utirik	atoll	10	57.73	2.43
Taka	atoll	6	93.14	0.57
Mejit	island	1	none	1.86
Ailuk	atoll	55	177.34	5.36
Jimo	island	1	none	0.16
Likiep	atoll	65	424.01	10.26
Wotje	atoll	75	624.35	8.18
Erikub	atoll	16	230.30	1.53
Maloelap	atoll	75	972.73	9.82
Aur	atoll	43	239.78	5.62
Majuro	atoll	64	295.05	9.17
Arno	atoll	103	338.69	12.95
Mili	atoll	92	763.27	15.93
Knox	atoll	18		
Ralik Chain				
Eniwetok	atoll	44	1 004.89	5.85
Ujelang	atoll	30	65.97	1.74
Bikini	atoll	36	594.15	6.01
Rongerik	atoll	14	143.43	1.68
Rongelap	atoll	61	1 004.32	7.95
Ailinginae	atoll	25	105.96	2.80
Wotho	atoll	18	94.92	4.33
Ujae	atoll	15	185.94	1.86
Lae	atoll	20	17.66	1.45
Kwajalein	atoll	93	2 173.79	16.39
Lib	island	1	none	0.93
Namu	atoll	54	397.64	6.26
Jabwot	island	1	none	0.57
Ailinglaplap	atoll	56	750.30	14.69
Jaluit	atoll	91	689.74	11.34
Kili	island	1	none	0.93
Namorik	atoll	2	8.42	2.77
Ebon	atoll	22	103.83	5.75
Marshalls Total		1 225	11 672.79	180.87

Table 9. Average monthly temperatures and rainfall in the Marshalls

Month	Temperature (°C)		Rainfall (mm)	
	Kwajalein	*Majuro*	*Kwajalein*	*Majuro*
January	27.3	27.1	95.0	227.6
February	27.4	27.3	59.7	177.3
March	27.9	27.3	157.7	235.0
April	27.8	27.3	159.0	261.9
May	27.7	27.4	246.6	359.4
June	27.7	27.2	252.2	309.1
July	27.8	27.2	246.4	346.5
August	28.0	27.5	259.1	299.2
September	27.8	27.4	276.1	365.5
October	28.0	27.4	304.0	406.4
November	27.6	27.3	291.1	390.7
December	27.6	27.3	234.4	301.8

Source: Trust Territory Quarterly Bulletin of Statistics.

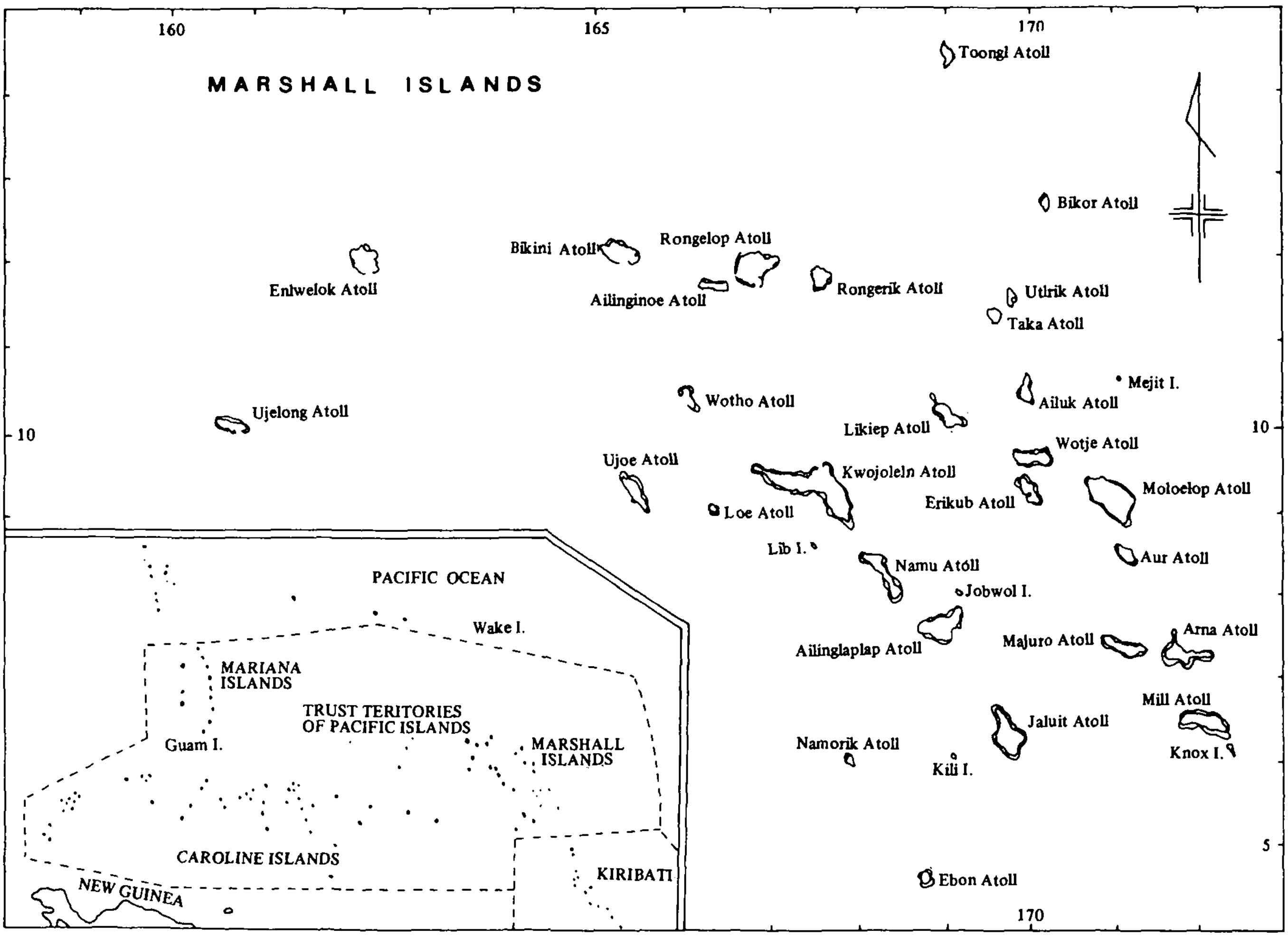

Figure 1. Map of the Marshall Islands.

Long Term

1. Development of the Laura (western end of Majuro Atoll) lens well;

2. Insallation of waste heat recovery units on the new power plant generators to distill up to 100,000 gallons/day for each unit in operation;

3. Installation of a sewer system with salt water flushing in the main population area.

Funding for Phase I (5 miles) of the sewer/salt water system has been provided by U.S. Congressional Funds. Design contracts have been let and completion of the initial construction phase should be completed with 24 months.

When the sewer system becomes functional, a considerable reduction of fresh water usage plus a cleansing of the ground water body is expected. Contamination is a major problem at present.

In the initial design of the new Majuro Power Plant, provisions were made for additions of waste heat recovery units to each 3,200 kW engine. Each unit is capable of producing up to 100,000 gallons/day. Although initial purchase costs are somewhat expensive, operation and maintenance costs are relatively small. Further studies are being conducted.

Laura has the potential for a considerable amount of groundwater development, provided it proceeds slowly and with caution. Although very little is known of the details of the groundwater occurrences on Laura, it is known that recharge is high and that substantial parts of the island contain very fresh water, at least at the ground water surface. A thorough study of this area is indicated to verify:

1. Variations in fresh water lens thickness in space and time;

2. Changes in groundwater salinity with depth and time;

3. Fluctuations in groundwater levels, both seasonally and in response to tidal fluctuations;

4. Subsurface geology, especially the location of hard low-permeability layers which exert considerable control on fresh groundwater occurrence and salinity.

Such a study should continue for at least a year prior to development/construction. Once completed, a continuous monitoring programme should be included as part of the normal day-to-day operation. It should be noted that a similar study has been completed for the Kwajalein Missile Range next to Ebeye. Kwajalein has a similar, albeit smaller, land area than Laura but has a known reservoir of over 200 million gallons within the groundwater body. If similar geologic conditions exist on Laura, there is a possibility that Laura has a groundwater source of between 300 to 400 million gallons. Feasibility studies are now being made to install a 12" pipeline from the new Majuro Airport to Laura (approximately 20 miles).

The Government of the Republic of the Marshall Islands has a policy to develop to the fullest extent the groundwater potential not only in Majuro and Ebeye but on all the outer islands. Feasibility studies, encouragement of conservation, training, alternate energy projects, are but a few of the ongoing programmes designed to provide adequate water supplies to all its people. The Government would welcome any assistance in furthering this goal.

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IV. NIUE

INTRODUCTION

A brief description of Niue can be simply given as, a raised coral atoll with an area of 259 km^2, a population of just over 3,000 and the significant fact applicable to this meeting is that Niue has no river of one form or another.

Before the groundwater lens was discovered in 1964, Niue was dependent solely on rainwater collected in communal water tanks. Very few at that time would have their own water catchment tanks.

The present system (bore water through communal taps) which met adequately the needs of the people in 1964, is now very much outdated and inadequate for present day needs. It must be appreciated however that the population at that time was about 5,500. Today, the development of Niue's living standards is such that a new and complimentary scheme must be implemented as soon as possible.

A. NATIONAL DEVELOPMENT PLAN 1980-1985

The objectives of the plan are as follows:

(a) To provide a continuous tap supply of potable water to all households;

(b) To provide adequate supplies for industrial, commercial and government enterprises;

(c) To provide adequate supplies for existing and proposed agricultural development projects;

B. REPORT ON VILLAGE WATER RETICULATION FOR NIUE

Arising from the above objectives the Public Works Department compiled a comprehensive report to cover all the villages on Niue.

The present water supply is piped from boreholes to central village tanks which supply communal taps. The communal taps serve as a back up to catchment tanks but are inadequate in drought periods as experienced lately and in 1977.

The communal tap system provides for the basic minimum acceptable daily useage and does not allow for water borne sanitation and individual house connections.

A recent health project has already led to the installation of many waterseal latrines. The new houses which are being constructed now usually have flushed toilet facilities included, as well as approximately 20-30 per cent households would have washing machines, thus the urgent need to increase village water supplies.

The present scheme is jointly sponsored by New Zealand, Australia and the South Pacific Commission to a certain extent.

One small village was completed at the end of 1982 and one large village is almost completed now.

C. GROUNDWATER RESOURCES OF NIUE

In 1979/80 this comprehensive report was undertaken by the Department of National Development Bureau of Mineral Resources, Geology and Geophysics of the Australian Government. This report perhaps gave us a better guidance for the development and upgrading of the present bore water/communal tap systems. Fears were unfounded that over pumping could affect the water lens dramatically.

Conclusions and recommendations arising from the report are as follows:

1. Niue is a raised coral atoll with about 300 m of mainly miocene limestone overlaying a volcanic seamount;
2. Groundwater on Niue is contained in a freshwater layer overlaying salt water. The thickness of the freshwater layer is 50-80 m beneath the central basin of the island, and over 100 m beneath the perepheral rim. Salt water intrusion is evident for 500 m inland from the coast, where mixing has been facilitated by fissures in the limestone;
3. The elevation of the water-table is 1.8 m above sea level in the centre of Niue, and freshwater generally flows radially outwards to the sea;
4. Water balance calculations for a model freshwater layer 50 m thick drawn up to 25 m indicate that the safe yield of the Niue aquifer is about 11,000 litre/day/ha;
5. Aquifer tests carried out on specially constructed bores in the interior of Niue indicate that safe long-term pumping rates could be up to about 8 litres/sec.

   To avoid upcoming of salt water, drawdown should be controlled to be no more than one-half the elevation of the water-table above the mean sea level datum;

6. The present Niue water supply is based on low-yielding, uncased, narrow diameter bores. The supply could be improved by the development of larger-diameter cased bores whose casing was perforated below the water-table. A drilling rig capable of constructing bores with 12.5 to 15 cm casing should be procured;
7. The use of turbine pumps yielding 1.5 to 2.5 litres/sec is recommended and bores of this capacity could be spaced one per 15 ha;
8. Groundwater in the interior of Niue has a total dissolved solids content of 136 to 261 mg/litre and is a bicarbonate water. The water is suitable for drinking, and, if bores are protected from bacteriological contamination, urban water supplies can be developed from a central source;
9. The fresh groundwater is generally suitable for irrigation, however, the high bicarbonate content might cause white carbonate deposits to form on fruit and leaves where irrigation is by overhead sprinklers;
10. There is a possibility of ground-water pollution occurring as a result of the application of pesticides and fertilisers. Groundwater quality, especially nitrate concentrations, should be monitored in irrigation areas.

D. WATER MANAGEMENT LEGISLATION FOR NIUE December 1981

This legislation is commissioned by Australian Development Assistance Bureau.

The provision of location, construction and use of bores poses a problem from a view point of the landowner who gave permission to drill the bore on his land, little realising that the 500 m radius provision will not allow him to build within that distance, as well as prohibiting livesstock enclosures.

However the document is equally important for the purpose of control and prevention of any likely contamination of the water lens.

This document is to be jointly controlled and monitored by the Public Works Department and Health Department.

E. PROBLEMS FACING THE DEVELOPMENT OF WATER RESOURCES

1. *Finance*

This will always be a problem but it must be realised that Niue is very appreciative of all financial assistance received to date from various sources and as well as all technical assistance.

2. *Plant and Equipment*

Replacement of much needed plant and equipment can be a real prohibitive factor to the present reticulation scheme if the existing plants are not replaced soon.

3. *Manpower*

Local trained technicians and tradesmen are capable of carrying out the scheme. Sometimes they are faced with community commitments which could affect even the most well prepared programmes.

4. *Hurricanes & Cyclones*

These can be damaging to windmills, polluting water tank supplies with salt water sprays, as well as to houses and buildings supplying these water tanks.

V. NORTHERN MARIANA ISLANDS

The Commonwealth of the Northern Mariana Islands is comprised of fourteen (14) islands, most of which is of coral atoll and some volcanic in nature. The villages are mostly centered in the low land areas of the coast and is where most of the development is found. Among the 14 islands only there are with significant development. The water resources of the three inhabited islands are found in coralline limestone acquifer. Deep well construction and development is the predominant water sources.

The three major islands are Saipan, Tinian and Rota. Saipan is the most heavily populated area. Its water resources are found in high level basin and in most parts in low level basin.

Water supply is of major concern of our Administration at this time, so high emphasis in increasing and developing for more good quality water is being undertaken. Major sources of water such as springs flow during the rainy season have been carefully planned for modifying its present system and is being considered for expansion due to great losses during peak rainy seasons.

In the Commonwealth, the major water supply is by drilled wells and some springs. The wells vary in depths and in elevation. In some areas, high basal water with good quality could be found. Other areas in the low lying areas has a lot milder quality due to high salinity or chloride content.

The quality of water at the high level basin is much superior than that of the low level basin. Chloride levels range from 30-50 mg/l in the high level acquifer, whereas, the southern low land acquifer is from 150-1,000 mg/l. Tinian, a neighboring island has an infiltration gallery, constructed during the Navy Administration and it is the primary source of water. Rota has a high level water, a spring, which is also the primary water source for that island.

Water resource in the Commonwealth of the Northern Marianas varies in different development. Among the different resources development the government administers includes irrigation system, basically for farming purposes. Surface water resource has not played a major role as yet in irrigating due to high cost and its complicated design due to the islands topography. Therefore, much of the Commonwealth's irrigation system is from drilled wells and springs location at nearby sources.

Hydropower system has not yet being given priority at this time but has been looked and considered upon. While Saipan water coast seems encouraging to generate electricity by "Hydro Energy", cost plays a major stumbling block in its becoming a reality. It will, though, perhaps lessen the dependence of petroleum fuel, which is a costly operation.

Flood control measures have been undertaken and special projects in locating and determining area of where flooding is a threat have been completed, although, actual construction for protective measures have not been initiated at this time. Major flood areas are within the city development and any construction will be very aesthetically unpleasant. Mapping have been prepared by the U.S. Corps of Engineers.

The present system on data collection is being done more by government agencies and also from the help of the water resources and the U.S.G.S. The U.S.G.S. plays a major role in overseeing the development of streams, rivers, and springs in the Commonwealth.

The implementation of national Policy, and legislative arrangement are determined by the congressional leaders and executive authorities. Little has been done on national policy, but the Commonwealth do in fact has established guidelines to meet Environmental Protection Agency (EPA) standards, the Safe Drinking Water Act and Water Pollution Control Act. Much of the institutional arrangement is geared toward meeting the U.S. EPA requirements and the Commonwealth's own standard. An adoption of the Commonwealth Drinking Water Regulation have been promulgated and effectuated on August 15, 1982. The adoption of the regulation came about thru an act in the establishment of a Division of Environmental Quality within the Department of Public Health and Environmental Services.

During the past few years, not much have been done in terms of manpower development. Education and training facilities is being done at institutional levels. The Commonwealth do feel the need for manpower development and does this year made it possible to have a training programme for individuals in the Water Supply Operations and Maintenance. Public information programme is minimal but is being done thru public radios, newspapers when a need arises.

The major problems in water resources development within the Commonwealth at this time are insufficient budget to carry out the necessary and important development of our water resources. Also, accompanying problem areas are personnel and manpower skills. The Commonwealth lacks highly qualified engineers, technicians, to promote the present status, whether it be manpower or system evaluations. The problem is typical at all island groups.

An appropriate programme recommendation is the facilitation of exchange of manpower resources of specialized skills and to centralize training facilities for the countries within the South Pacific Region.

VI. SOLOMON ISLANDS

INTRODUCTION

The population of Solomon Islands is mainly rural. The 1976 census recorded that less than 10 per cent of the population lived in Honiara or one of the provincial centres. The relatively low population density (7.5 people/km^2 in 1980) and the dispersed nature of the village settlements together with generally high rainfall has meant that serious water shortages have been infrequent or in isolated areas.

Relatively small projects, such as village scale water supply schemes, can be implemented with only a modicum of water resources information. However, projects which depend on the availability of large flows or which place costly investments at risk of flood or drought require more water resources information than is generally available. There is a serious shortage of skills in the areas of assessment of water resources and the planning and management of development projects. No doubt this meeting will make a valuable contribution to the development of those skills. In particular it is hoped that the meeting will promote some form of technical co-operation between countries of the Pacific region.

A. REVIEW OF WATER RESOURCES DEVELOPMENT

1. Existing Water Resources Development.

The extensive plains on Guadalcanal have been partly developed for large scale commercial agriculture undertaken by companies in which the Government has shares. The area is the only one in the country with a dry season (Hansell and Wall, 1976) and the seasonal rainfall deficit creates a water demand for some crops. Brewer Solomons Agriculture Limited (BSAL) grow rice under irrigation using water from the Mbalisuna River. As at 1981 BSAL had 1686 ha in production but exporting their product has proved uneconomic and the area has been reduced to 1016 ha which is sufficient to supply the local demand.

The Seventh Day Adventist Mission hospital at Atoifi, Eastern Malaita operate a 50 kVA micro hydro-electric installation using a governed pelton wheel. The plant was opened in January 1974 and operation has been trouble free except for occasional shortages of water. Construction of a 30 kW micro-hydro scheme on the Manakwai River at Malu'u, Malaita is nearing completion. Despite widespread interest in the potential for both small and large scale hydro-electric projects no other plants have yet been constructed.

Some of the large rivers crossing the extensive plains on northern Guadalcanal have caused substantial flood damage especially during cyclones and some river training and bank protection have been carried out to protect the BSAL irrigation works. In other places where road transport links or village gardens are threatened by floods, repair of damage is carried out rather than protective works. There is a lack of appreciation of the need for soil conservation techniques in the farming community and by commercial timber companies (Hansell and Wall, 1976).

Urban water supplies are the responsibility of the Works Division of the Ministry of Transport, Communications and Government Utilities (MTCGU). The reticulated supplies are mainly from spring sources or impounded surface water sources (see Table 10).

Table 10. Features of urban water supplies in Solomon Islands

Town	*Water source*	*System*	*Treatment*
Honiara	stream, spring, bores	pumped storage	surface supplies
Gizo	impounded stream	–	chlorinated
Auki	bore	pumped system	
Munda	bore	gravity feed	
	well	–	
Kira Kira	spring	gravity feed	filtered and chlorinated
Graciosa Bay	spring	pumped storage	
Tulagi	impounded stream	gravity feed	
Buala	stream	gravity feed	

Rural water supplies are the responsibility of the Provincial Assemblies (Figure 2). As at 1978 only 24 per cent of the rural population was served by safe water supplies (Ministry of Health and Medical Services, 1982). Since then the Rural Water Supply and Sanitation Project has made substantial steps towards the goal of providing safe water to all the population by the end of the decade. Technical support for the project is provided by the Environmental Health Division of the Ministry of Health and Medical Services and the Ministry of Home Affairs and National Development provides overall administrative control. By the end of 1981 the proportion of the rural population with safe water supplies had been increased to approximately 45 per cent.

2. Proposed plans for water resources development.

Many sites have been considered for hydroelectric development. The Lungga hydropower project which is designed to supply electricity to Honiara has been the subject of detailed study. A three stage development with an initial output of 5 mW growing to 20 mW by the year 2000 has been planned (Preece, Cardew and Rider 1977). Geological problems encountered at the site have resulted in cost escalations and at present further work on the project has ceased.

Small scale hydro-electric development has been proposed for many rural sites though only a few have given detailed consideration. An interim design has been completed for a minihydro scheme on the Jejevo River to supply Buala on Santa Isabel. Other prospective projects have so far appeared to involve difficult sites or too great a distance to centres of demand (Candy and Taylor 1979).

The proposal to develop a major port and industry (including a fish cannery) at Noro, New Georgia has caused concern about the adequacy of available water supplies. A series of studies of the potential for groundwater development at Noro suggest that known sources of groundwater can supply only about 40 per cent of the short term requirements (Buckley 1981). Further exploration of the groundwater resources and consideration of alternative surface water supplies will be required to ensure that the proposed development is not constrained by water supply problems.

3. Existing systems for collection of water resources data.

The Meteorological Service of MTCGU has the responsibility for the operation of a rainfall network and the collection of other climate data. The Service receives some technical guidance and training assistance from the Australian Bureau of Meteorology. Because the majority of raingauges are operated in coastal areas the Geology Division of the Ministry of Lands, Energy and Natural Resources (MLENR) with the support of the Institute of Hydrology (U.K.) proposes to install storage raingauges on a transect across Guadalcanal. Ash et al., (1974) published daily rainfall and monthly tables for all Solomon Island rainfall sites with at least one complete year of record. Of the total of 83 stations approximately half had runs of 5 years or less. There has been no subsequent publication of rainfall data.

Hydrological and geohydrological data collection is the responsibility of the Hydrology Section, Geology Division (MLENR). The section is equipped to perform waded stream gaugings and operates water level recorders on the Lungga River and Ngalimbiu River on Guadalcanal. River gaugings have been concentrated at sites where hydroelectric development has been proposed and except for the Lungga very little data analysis has been performed. No hydrological data has been prepared for publication but an adequate file of observations is maintained. At present plans are being formulated to establish a national network of river gauging sites and to obtain equipment for high flow gauging.

Collection of geohydrological data has been complicated by the fact that the well drilling equipment and the drilling staff are operated as part of the Transport Pool of MTCGU. Attempts by Geology Division to maintain adequate records of well drilling and to provide some expert supervision have been hampered by poor coordination between the two ministries. It is planned to transfer control of the drilling operation to Geology Division and it is hoped that substantial improvements in the collection of hydrogeological data will be possible as a result.

No routine water quality data collection is carried out though water from new boreholes is tested for potability. Water analyses are performed for occasional checks of effluent standards and a survey of sewage contamination of the Honiara coastline has been carried out. The Geochemical Laboratory of MLENR is equipped to do most of the required physical analyses and the Central Hospital Laboratory is able to perform bacteriological analyses.

The assessment of demand for water resources requires additional data and much of the necessary information is available in some form. The Village Resources Survey conducted by the Statistics Office, Ministry of Finance, has collected basic information on villages throughout the rural areas in respect of location, size and access to resources and services – including access to water supplies. The Lands Division of MLENR has produced 1:50,000 map cover of the whole of Solomon Islands except the outlying islands of Ontong Java, Rennell and Bellona, and Sikaiana. Regional geological mapping at the same scale has been completed for Choiseul, Shortland Islands, and New Georgia Group. The land resources study (Hansell and Wall 1976) has completed a reconnaissance study of environmental features and identified areas where the opportunity exists for large-scale agricultural development.

4. National policy, legislation and institutional arrangements for water resources development.

National water policy has been formulated in only general terms that call for balanced development of natural resources and promotion of self reliance. Legislation of particular relevance to water resources includes the Water

Supply Act, the River Waters Act and the Provincial Government Act.

The Water Supply Act deals with the reticulated supply of water to prescribed urban areas. It gives powers to extract water, to meter and charge for water supplied, and prescribes penalties for soiling water supplies. The Act is administered by MTCGU.

The River Waters Act applys to those parts of Solomon Islands declared by the Minister and empowers government to issue permits for the extraction of water for irrigation and other purposes, and makes it an offence to extract water or place obstructions in rivers without such a permit. Though government has exerted control over water extraction the provisions of the act have not been formally administered and there is no register of permits issued.

The Provincial Government Act is relevant because it provides for the devolution of statutory functions of both the above acts to provinces. The Act allows for agency agreements between a Province and another public authority so that a national water resources organisation could be expected to exercise some of its functions in collaboration with provincial governments.

Though the existing legislation recognises the need to allow the collection of data required to apply for a permit to extract water it fails to recognise the need for a national water resources organization to have statutory powers to enable it to collect data on the occurrence of water. In addition the existing legislation does not appear to provide any controls over the use of groundwater.

The present fragmentation of responsibility for water resource management has created a need for co-ordination of the various agencies involved. From May 1978 to January 1981 a Water Resources Committee met regularly to co-ordinate investigations and development of surface water and groundwater. There is now a need for new initiatives in this field.

5. Mapower development, education and training facilities, and public information/involvement in water activities.

For most of those employed in the water resources field training has been provided on the job. At one stage a geologist of the then Geological Survey provided some guidance to water well drillers. Subsequently training courses in Fiji and U.K. were attended by two drillers.

Training in basic hydrometric operations was obtained for staff of Geology Division and Solomon Islands Electricity Authority from the Snowy Mountains Engineering Corporation of Australia. A series of advisory visits by hydrologists from the Institute of Hydrology (U.K.) attempted to include staff training but the visits have been too short and too infrequent to achieve rapid improvements.

The appointment of a Water Resources Officer under the New Zealand Government Bilateral Aid Programme should assist the development of water resource assessment skills. Hopefully the appointment will establish a continuing link between the Hydrology Section of MLENR and the Water and Soil Division of the New Zealand Ministry of Works and Development.

The Rural Water Supply and Sanitation Project has involved training of provincial public health inspectors. A technical manual has been produced to assist in this training (Hazbun and Timar, 1982).

B. MAJOR PROBLEMS IN WATER RESOURCES DEVELOPMENT

Many of the Water Resources Development problems have been referred to in the previous sections. One of the major problems is the shortage of trained people particularly at the professional level. The apparent lack of suitable formal training courses for technicians in hydrology compounds this problem.

A particular problem in the Solomon Islands for water resources assessment work is the relatively large distances involved (from Balalai in the Shortlands to Santa Cruz is over 1300 km). This factor makes it very desirable to employ techniques of field data recording that do not require frequent visits.

The high cost of conventional approaches to hydroelectric developments has discouraged some development. It is clearly desirable to ensure that available information on alternative technologies is obtained.

C. RECOMMENDED PROGRAMME

I would like to suggest some areas where technical co-operation between countries of the Pacific region could assist in solving some of the problems described above.

(i) Information exchange, either on an informal basis as a result of personal contact with workers from other countries or through an information clearing house,

(ii) Training co-operation, by staff exchanges or the establishment of regional training courses for water resources technicians,

(iii) Co-operation in the application of specialised equipment and skills either through cost sharing or exchange, and

(iv) Establishment of a regional organisation possibly in the form of a Regional International Hydrological Programme Committee with UNESCO support.

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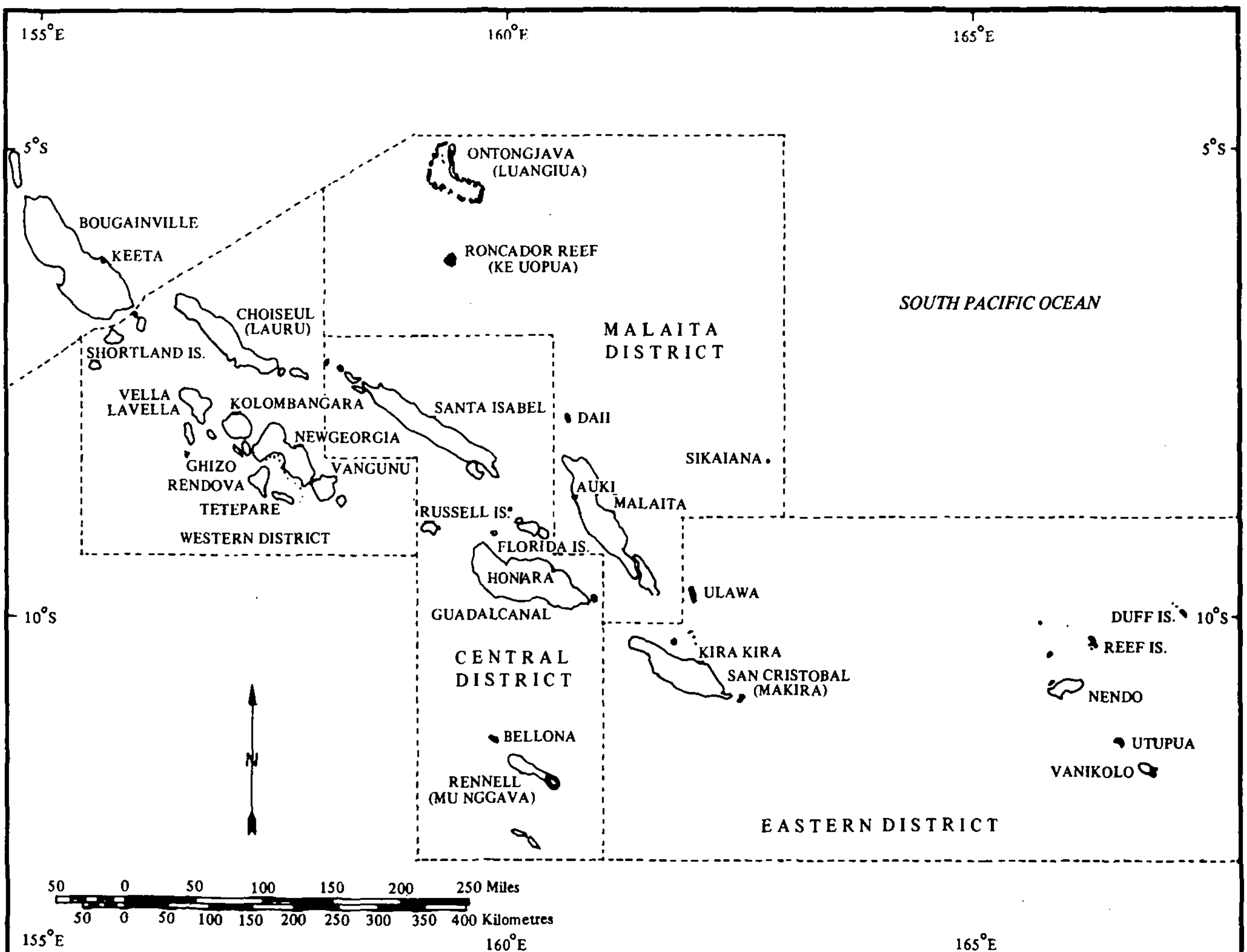
Figure 2. Map of Solomon Islands



VII. SAMOA

INTRODUCTION

Samoa lies in the South-West Pacific between 13° and 14° south latitude and 171° and 173° west longitude. It comprises two large islands, Savaii (approximately 1700 km^2) and Upolu (approximately 100 km^2), two smaller inhabited islands – Manono and Apolima, and a number of smaller uninhabited off-shore islands, islets and rocks. The total land area is about 2820 km^2. It is part of the 500 km long Samoan archipelago, the eastern group of islands comprise American Samoa.

The population of Samoa in 1981 census shows a total of 156,000 persons of all races. Villages, are located principally along the coast, and plantations of coconuts, bananas, taro, cocoa, coffee and the other crops extended up the commonly gentle slopes towards the higher volcanic core-studded central ridges.

A. PHYSIOGRAPHY

1. Climate

The drier parts of Samoa – the north-west areas of both Upolu and Savaii have annual rainfalls over 2200 – 2500 mm; the wetter parts in the highlands receive over 5000 mm in Upolu and over 6000 mm in Savaii. However, the islands are formed of very young basaltic lavas. Thus, only in areas of the oldest rocks, principally in eastern Upolu, and in small areas of western Upolu and eastern Savaii, has there been sufficient time since eruption from weathering, to have produced impermeable surface layers which will allow the presence of permanent streams and rivers. Such areas have the dual potentialities of surface water supply and of hydroelectric power generation.

2. Hydrology

The three main factors affecting the surface hydrology in Samoa are geology, rainfall and topography. Generally speaking the depth of weathering and infiltration capacity of the volcanic rocks forming the islands reflects their age. The eastern part of Upolu is composed of the oldest rocks – the Fagaloa volcanics, and these are largely overlain by the generally more permeable Salani volcanics in the south-eastern and central part of the island. On Savaii, Fagaloa and Salani formations are mainly restricted to the central northern and southern portions of the island. The relatively low permeability of the Fagaloa rocks and certain areas of the Salani volcanic, particularly where valley floors are formed by underlying Fagaloa, result generally in high water tables, and thus perennial stream flows. On the younger parts of the islands i.e. west Upolu and the western half of Savaii, where surface formations consist of Mulifanua or younger rocks, the high permeability results in rapid infiltration. Streams in these areas are rare to non-existent and generally only flow after heavy rainfall.

3. Geology

The Samoa islands are composed almost wholly of basic volcanic rocks which are divided into six formations on the basis of weathering and erosion criteria. A coral reef exists off-shore for nearly half the coastline, except where cliffs are steep, or where very young lavas have flowed into and filled the lagoon. Coral sand occurs along much of the coastline up to 5 m above sea level.

B. EXISTING WATER RESOURCES DEVELOPMENT

The present state of water assessment in Samoa with respect to adequacy and reliability is quite insufficient. Development of water resources is required for two purposes.

(1) To ensure a continuous supply of water meeting acceptable quality standards for domestic, commercial and industrial consumption; and

(2) To ensure the continuous supply of water for the generation of hydroelectric power.

Whilst 95 per cent of Samoa's population now have access to a piped water supply. Most Samoa schemes are gravity supplies, fed from inland streams and springs. The capacity of the reticulation systems, as well as the dry weather flows of the source are frequently inadequate.

The chemical and physical quality of the water is generally good except during periods of heavy rain, when turbidity loads are high. Most surface water supplies are bad bacteriological by WHO standards. In addition to the gravity supplies, there are a number of pumped supplies, extracting water from boreholes, dug well and coastal springs. These schemes exist in areas which lack adequate surface water resources. In areas lacking surface water and ground water, rain water collection from roofs of large buildings (churches and schools etc.) and individual houses is at present the only means of supply.

1. Source of water

Roof catchment are most suitable for providing relatively small quantities of water inland. Samoa received assistance (under rural water supply) in rainwater collection on a project funded by the South Pacific Commission which started on March 1982. South Pacific Commission supply plastic materials (gutters, downpipes etc.) for the collection of rainwater from corrugated iron roofs. The two specific areas to be covered by this project is North West Savaii (driest parts of Savaii because geologic conditions allow for no streams) and the island of Manono.

Over the past few years the main areas of activity receiving emphasis and priority is the maintenance of the existing domestic supplies. The existing system has been in existence in some form over many years and has been added to and modified from time to time in an endeavour to extend its life and improve the level of service. With the increase in population to be served, the reticulation and storage is unable to cope. Rationing system is done to some areas due to the very little discharge from a spring source.

In the last 20-30 years piped water supply schemes were installed and more recently when some of these have broken down pumped bores have taken over. Approximately 40 per cent of the population of Samoa is served by pumped water supply. A groundwater drilling programme funded by New Zealand Aid and UNDP Aid has been underway for several years. A large number of bores have been there without pumps due to either poor quality water or production head too great.

C. PROPOSED PLANS AND PROJECTS

The New Zealand Government under their bilateral programme to Samoa have already investigated into the proposed provision of adequate water supply and sewerage systems for Apia.

A new rural water supply project now under way at the western end of Savaii is funded by Australian Aid. They supply pumps and engines, pipes, fittings, vehicles and equipment. Staff training is also included.

A total grant of $US 800,000 has been made by the Netherlands for another rural water supply project on the north and south of Upolu. A portion of pipeline from three spring intakes, a break pressure tank and a reservoir is near completion on the north coast.

The Public Works Department request a further ten bores or so be investigated. About half of these are located in the higher areas of the west coast of Upolu where previous success with ground water bores has been negligible. However, it is where the water is wanted and with no reliable ground water sources available, the area deserves a thorough investigation before a final water source decision is made. A preparatory study by hydrologists geologists and engineers should be done of this area before actual drilling commences.

D. NATIONAL POLICY, LEGISLATION AND PLANNING

The principal legislation governing water management throughout Samoa is the Water Act 1965 and Amendments. Except for fire fighting needs and minor domestic water uses, this Act envisage that the Head of State, acting on the advice of Cabinet may grant to any person, company or committee the right to use water from any river, stream, lake or pool for the purpose of generating electricity or for the purpose of supplying water for domestic, agricultural, pastoral, industrial or commercial uses.

Revisions are under study with regard to water policies planning. Some includes a Water Resources Authority under consideration and a review and revision of the existing Water Act There is a need to ammend the existing legislation which is quite inappropriate and would not be very much use in protecting the resources at present. There is also a National Action Plan approved by the Government in principle to meet the goals of the International Drinking Water Supply and Sanitation Decade. Currently the Samoa Government have no comprehensive master plan for water resources development. It is believed that international assistance in the form of interdisciplinary missions by small teams could be useful if their objective is well planned in advance.

E. MAJOR PROBLEMS

The already on-going agricultural development activities in water catchment areas is endangering the availability and quality of the water to be abstracted for Samoa water supply projects. These developments have moved relatively fast inland due mainly to the construction of access roads. There have been noticeably lower dry season flows in all water supply catchments where clearing and planting has occurred.

The biggest problem in pumped water supply is the increasing fuel and power costs to run these pumps. The high cost of spare parts for diesel driven pumps means not only we are faced with high fuel power costs but also with high servicing and maintenance costs. Wells sited in young rocks are highly productive with water levels close to sea level, and subject to tidal fluctuations. The key problem is salinity, which often exceed the WHO maximum of 600 ppm chloride. Some of the constraints encountered in the formulation and implementation of national programmes for water development are mainly due to lack of qualified manpower, shortage of financial resources and lack of equipment. Manpower situation in terms of available and adequate skills has deteriorated. This is caused by migration of skilled workers to other countries, lack of suitable candidates for posts in the water resource fields and lack of funds to employ water resources specialists at all levels.

There is also the effect of land tenure system on decision making regarding the declaration of areas in water resource development, the management, and most important their control and policies.

F. RECOMMENDATION

The following measures are considered of immediate importance in extensive management of water resources.

(1) Establish a single body to be responsible for all water resources (management and control);

(2) Carry out a comprehensive survey of various land uses;

(3) Technical assistance in water resource development be sought from outside sources;

(4) Undertake field work on all existing hydrological data collected and analysed to produce a water resource report;

(5) Extensive public education to promote conservation awareness of land owners and users in clearing of catchment areas.

VIII. TONGA

A. GEOGRAPHY

The main island Togatapu lies between latitude 20° 00' and 21° 20' south and longitude 175° 1' and 175° 21' west. Its maximum length is 315 km and maximum width 18.7 km from Kolonga to the airport as compared to the minimum width of 1.6 km at Ha'avakatolo.

Eastern tip of the island is highest at Fua'amotu and Nakolo which exceeds 65 m. From this point the land slopes gently northward.

B. CLIMATE

Mean annual temperature on the island is 23.4° C (74.5° F). Maximum recorded monthly temperature was in February 1976 with reading of 32.2° C. Temperature may fall to 10.6° C during cool winter.

The maximum and minimum monthly rainfall at Nuku'alofa during the period 1945-1978 are shown in Table 11. The maximum monthly rainfall records are three to five times of the average monthly values. Records show that wet days of more than 0.25 mm exceed 150 days per year in average.

C. MAJOR PROBLEMS

Following major problems in water resources development have been identified:

1. Investigation of groundwater;
2. Continuous use of asbestos pipes;
3. Contamination of rainfall catchment tanks;
4. Management of fresh water of thin lenses;
5. Cracks of ferrocement tanks;
6. Water pollution by oil from engine-pump unit; and
7. Emergency water supply after cyclones and other natural disasters.

Table 11. Extreme low and high monthly rainfall at Nuku'alofa, Tonga

(Millimeters, 1945-1978)

	Low		*High*	
January	1946	9.7	1952	582.2
February	1959	61.0	1951	564.1
March	1966	83.8	1960	468.9
April	1946	33.0	1966	457.7
May	1950	17.3	1965	209.8
June	1967	8.1	1954	242.1
July	1968	26.9	1950	259.1
August	1969	16.5	1959	272.8
September	1946	11.43	1972	341.4
October	1953	21.1	1958	337.3
November	1949	6.6	1971	307.6
December	1951	3.3	1971	782.6

IX. VANUATU

INTRODUCTION

Vanuatu forms a north-south chain of eighty islands in the Southwest Pacific. It streaches over 800 km extending from latitude 13° to 22° south of the equator with a total land area of 11,870 km^2 (Figure 3). The islands have a volcanic origin and date from the Miocene to recent times. The islands are typically mountainous with a rugged topography though a coastal platform of raised reef is often developed. The area has a tropical oceanic climate with marked seasons. A wet summer from November to April and a drier winter under the influence of the south east trade winds from May to October. The average summer temperature in Vila is 26° C and the winter temperature is 23° C. The mean annual rainfall varies from 4100 mm on Vanua Lava in the north to 1600 mm on Tanna in the south. Vila has 2300 mm with a mean maximum in March of 380 mm and a mean minimum in October of 90 mm.

The Republic has a population of just over 120,000 of which an estimated 23,000 live in the two towns of Vila (17,000) and Santo (6,000) the remaining 80 per cent of the population live in villages spread throughout the islands though mostly located in coastal areas. This gives an overall rural population density of 8 persons per km^2. This figure is low by world standards though the growth rate of 3.2 per cent is above average. The villages are self-sufficient in food, producing a largely vegetarian diet at the subsistence level. Poverty is not a serious problem though income is very low or non-existent. As a result the requirements of this sector of the population are very limited and there is little demand for improvement. Nevertheless, it is essential to accelerate the development of water resources in order to improve the poor living conditions particularly in the rural areas.

Vanuatu is at present heavily dependent on aid and must look to some form of development to achieve self-sufficiency. At present agriculture, fishery and tourism are the most promising industries. The development of water resources is obviously an important early step in this growth.

A. EXISTING DEVELOPMENT OF WATER RESOURCES

1. Rural water supplies

The rural areas have a population of nearly 100,000 of these 12 per cent have water taps in their dwellings and a further 16 per cent have access to piped water outside. Another 28 per cent have a supply of water within 100 m of their dwelling. The remaining 44 per cent have to walk up to 5 km for their water. In terms of villages 150 have had a water supply constructed out of a total of 782. These supplies are designed to give a minimum of 30 litres per person per day. Apart from the initial assessment on site the water in such supplies is untested.

There are two basic systems of water supply installed in rural areas, roof catchment and gravity feed. Roof catchment, where gutters are fitted usually to tin roofs draining to a covered storage tank with a tap near the base, form the majority. Gravity water supplies use a river or spring source at higher elevation than the village. This feeds a covered tank sited above the village with reticulation to stand pipes in the community. PVC pipe laid on the surface brings the supply to the tank which can be a distance of 5 km or more. Steel pipe work is used within the village where it is buried. The stand pipes are supported with concrete bases which also act as stands and prevent soil erosion in the immediate area. Some village supplies use a surface water source at low elevation which necessitate the use of a pump, usually diesel powered, to lift the water to the tank. In less than 5 per cent of village systems ground water is used by means of a borehole or dug well and pump. Water rams and wind pumps have been used in a few installations though these are usually private schemes often associated with plantations.

2. Urban water supplies

Urban water supplies serve Vila and Luganville and the Government stations at Lakatoro, Norsup and Isangel. It provides a piped and metred supply to individual households. The Vila supply is the largest and serves as an example. The supply is fed by a gravity reticulation system from several covered steel tanks within the town. These include a tank at the wharf with facilities for cargo and visiting cruise ships. Water is pumped to these tanks from the pumping station 3 km north of the town at Tagabe where the water is drawn from three boreholes. The system was modernised in 1977 and an older borehole and spring are linked to the new system as a back up. The two new production boreholes are 25 cm in diameter and 15 m deep, extending 10 m below the rest water level, they are sited in the edge of the Mele alluvial plain at its junction with the reef limestone. The aquifer has an estimated yield of 1,000 m^3 per hour. Peak season demand at present is 400 m^3 per hour. The boreholes are fitted with helical rotor submersible pumps which produce 120 m^3 per hour each, with powerful centrifugal pumps distributing the water to the storage tanks. There is a total reserve of 6,000 m^3. This whole system is powered by electricity and produces approximately 5,000 m^3 per day to 2,100 metres which gives an average of 300 litres per person per day. The scheme is automated with good standards of filtration and treatment which include chlorination. However, the system is working almost at capacity and would be unable to cope with any further expansion of the town.

Luganville has a comparable system on smaller lines the water originating from a 3.5 m diameter well in raised reef limestone. Though the system is unchlorinated the water is of a very high bacteriological standard. The three small 'urban' water supplies at Lakatoro, Norsup and Isangel run on a very much smaller scale and are also untreated.

3. Sanitation

In the rural areas 74 per cent of the population have access to sanitary facilities. These are mainly pit latrines outside the dwelling, mostly an open hole in the ground. It is estimated that only 25 per cent have proper latrines, the remainder are inadequate and require upgrading.

Urban sanitation, the present sewage of Vila, Luganville, Lakatoro, Norsup and Isangel is dealt with by individual septic tanks and soak-away pits for each property. Of the total urban population 96 per cent have facilities either inside or outside their dwelling. This system gives no cause for complaint due to the low density of housing and good soakage properties of the subsoil though there is a limit to which it can be extended. There are private services for pumping out tanks and disposal of waste but many tanks are overflowing virtually untreated sewage into the local ground water and there is obvious concern over the possibility of pollution.

4. Flood control

There are facilities for storm drainage in Vila and Luganville and there is also a sea wall built in the capital which offers some protection from high seas. The only controls on river flooding are at road crossing points where bridges and ramparts have been elevated above flood levels. Bridge spans are designed on the basis of size of water shed times maximum rainfall.

5. Irrigation

The Department of Agriculture's nurseries, situated on several islands within the group, have facilities for watering by hand. Several villages on the western coast of Santo and on Aneityum grow water-taro. Such systems require considerable engineering, cutting channels to divert water from the local river and building water beds for the taro. Cattle rearing in the coconut plantations has developed the meat trade along with numerous small village schemes which all require watering facilities. There are several market gardens serving the urban population. These use simple watering techniques on the whole though one advanced scheme is using hydrophonics.

B. PROPOSED PLANS FOR THE DEVELOPMENT OF WATER RESOURCES

1. Water supplies

Applications for rural water supplies greatly exceed the present level of finance and manpower with the result that about 20 villages systems are built each year and there is a waiting list of two to three years. However, the Government in its five year plan (1982-86) has adopted the United Nation Decade for Drinking Water and Sanitation and devised as programme of water supply installation (Table 12) which should supply all villages by the end of 1990 to achieve this objective the present level of operations has to be considerably enlarged. The plan also includes the upgrading of existing rural water supplies which do not meet basic standards. The main emphasis is obviously in the rural supplies though the plan also allows for an increase in domestic piped water as well as greater control on water quality.

2. Sanitation

The Government plan allows for the improvement of village sanitation. The proposed programme for installation of improved latrines is given in table 13 but will fall seriously behind unless staff can be trained and funding located. It is also envisaged that by 1986 a plan should be devised for the rebuilding of Vila's existing sewage system.

3. Irrigation

A proposed was put forward for the growing of rice in the Jordan alluvial flat land just south of Big Bay on Santo which would cover a large area. However, this project has been rejected on economic grounds. This is unfortunate because there is only a limited area of dryland rice grown in Vanuatu, though it forms part of the staple diet in the urban areas and is one of the few subsidised foods.

4. Hydropower

Electric power in Vanuatu is one of the most expensive in the world. It is generated in the urban centres from diesel power. The Vila scheme is fully streched at present with a high proportion being consumed by the hotels. As a result other sources of energy are being considered and hydropower is being studied for use in the longer term. We are in the first year of data collection (flow measurements) on three rivers. The la Colle and Teuma near Vila and the Sarakata near Luganville. The Japanese have shown an interest in developing hydropower in the Banks Islands apparently with a view to using the power for smelting imported nickel ore.

On a smaller scale the energy unit is trying to promote micro hydro-electric schemes using small rivers for village supplies. Such schemes are low cost, using a centrifugal pump and electric motor in reverse with minimal installation costs. It is also envisaged incorporation such scheme in some gravity fed water supplies replacing existing check valves which break the force of the falling water.

C. COLLECTION OF DATA ON QUANTITY AND QUALITY OF WATER RESOURCES

Apart from the collection of data for certain projects such as the hydropower the general collection of data is minimal. The initial survey for rural water supplies gives an approximate idea of quantity from a particular river or spring. Boreholes are logged with the depth of the rest water level recorded. Data from test pumping and piezometers is included where available. The urban water supply collects data on volumes extincted and it monitors the chlorination process, but there are few chemical tests at present.

D. NATIONAL POLICY AND INSTITUTIONAL ARRANGEMENTS FOR WATER RESOURCES DEVELOPMENT

The Vanuatu Government attaches very great importance to the development of water supplies and sanitation, as is evident from the five year plan. Unfortunately as a result of the country only recently gaining independence the legislation governing water resources is incomplete.

The urban water supplies are administered and controlled by the Public Works Department; while rural water supplies to communities of over 50 people are the responsibility of the Ministry of Lands and Natural Resources through the Department of Geology, Mines and Rural Water Supplies. Small schemes come under the Ministry of Health and its Environmental Health Section. Applications for water supplies generally come from individuals, village chiefs, politicians and the Health Department. These are passed to the relevant department for planning and installation, with the majority of the work going to the Rural Water Supplies Section. This has a management of British and Australian personal supplied under aid. Installations are carried out by several teams of local personal. The department also includes a small drilling section with one drilling team at present. All the projects are individually aid funded with finance coming mainly from Australia, Britain, New Zealand, France, SPC, UNICEF and WHO. The Environmental Health Section is currently experiencing severe problems with the financing of personnel and funding. In contrast the Public Works Department, administered by aid personal, charges for connections and supplies in the urban system; the revenue from which produces a healthy profit.

Urban sanitation requires all building projects to construct septic tanks and soak away pits. The Public Works Department is responsible for seeing the implementation of this legislation. Rural sanitation comes under the Environmental Health Section.

E. MANPOWER DEVELOPMENT

In all the departments concerned the management is imported under aid with support staff recruited locally. Due to a lack of the relevant educational experience it would not seem possible to localise any of the aid positions at present. In-post training is an important element of the work but is a slow process.

The Environmental Health Section ran a training programme from 1968 to 1980, training Health Inspectors and village sanitarians who are also responsible for small water supply schemes. Unfortunately this aid programme has finished.

The Rural Water Supplies Section is moving towards greater village involvement at present, with the intention that only team leaders would be sent out on each project. The team being recruited locally from the village concerned. This has the dual advantage of greater village participation which increases their appreciation of the supply as well as increasing their understanding of its operation. Secondly it reduces the manpower costs considerably. However, we are experiencing difficulty here with a general reluctance of the villagers to assist with the work.

F. MAJOR PROBLEMS IN WATER RESOURCES DEVELOPMENT

Funding for the various projects is the major problem particularly in the rural areas. Because of the very low income in these areas all capital works have to be heavily subsidised or completely grant aided.

Raised reef platforms form one of the more densly populated rural areas. However, such areas generally lack surface water sources with the result that roof catchment schemes are the most widely used. These are wholly reliant on a constant rainfall and many run dry during prolonged dry spells in the winter months causing severe shortages of water. Even some gravity supply systems use an unreliable water source which gives rise to water shortages.

While the reef limestone retains little surface water it is of course a good aquifer. The use of ground water would seem the most appropriate system of water supply in these areas. Hand pumps have been used, but in village locations a motorised pump (diesel powered) is usually fitted. However, village communities are reluctant to accept such systems due to the cost of running the pump and maintenance.

The fresh water lense proves a good water resources in the reef limestone and can usually stand high pumping rates, though some coastal areas suffer from brackish ground water to a distance of up to 3 km inland. The youngest islands some of which are still forming are mostly composed of exposed volcanic rocks. Here the ground water is often of poor quality. What limited borehole data is available shows that salt water is often a problem at least in the coastal areas and hot sulphorous water has been reached on a couple of occassions.

Maintenance of rural water supplies is a serious problem in Vanuatu. Most villages lack the skills and tools to effect their own repairs. As a result many systems fall into discuss even when the work involved and cost of parts is minimal. Gravity systems have been known to fall into discuss due simply to clogging at the intake by leaves. In some cases the village people are not sufficiently motivated to clear the system regularly even when this is explained to them. At present the maintenance system is highly inefficient and costly. A plumber often has to make two trips usually by air to complete the work. The first visit being to find the source of break-down and decide what spare parts are required. Unfortunately Vanuatu has a multiplicity of makes and sizes of installed plumbing equipment, which gives rise to further difficulties as they are usually incompatible.

To sum-up, Vanuatu has the advantage of good water resources on the whole. However, this newly independant country is at a very early stage of development in this field. The legislation has still to be drawn up to safeguard the resource. On the whole the urban water supply systems operate satisfactorily. The construction and maintenance of rural water supplies for village communities is dependent on aid finance. This work is given high priority by the administration. Such work is fundamental to the raising of living conditions for the rural population. There is a considerable amount of work still to be undertaken in this area.

Table 12. Proposed rural water supply programme in Vanuatu, 1982-1990

Year	*Population Forecast*	*Proposed Implementation*	*Population Served*		*Estimated Cost (million VT)*
			Total	*%*	
1982	101 000	5 000	30 000	30.0	22.5
1983	104 000	8 000	38 000	37.0	36.0
1984	107 000	10 000	48 000	45.0	45.0
1985	111 000	12 000	60 000	54.0	54.0
1986	114 000	12 000	72 000	63.0	54.0
1987	117 000	14 000	86 000	73.0	63.0
1988	121 000	14 000	100 000	83.0	63.0
1989	125 000	14 000	114,000	91.0	63.0
1990	128 000	14 000	128 000	100.0	63.0
TOTAL	128 000	103 000			463.5

Table 13. Proposed latrine construction programme in Vanuatu, 1982-1990

Year	Forecast[a]		Proposed Implementation			Estimated Cost Thousand[b] Vatu
	Population	*Households*	*No. Constructed*	*Total Coverage*	*Coverage %*	
1982	101 000	20 200	500	5 500	27	1 000
1983	104 000	20 800	1 000	6 500	31	2 000
1984	107 000	21 400	2 000	8 500	40	4 000
1985	111 000	22 200	2 500	11 000	49	5 000
1986	114 000	22 800	2 500	13 500	59	5 000
1987	117 000	23 400	3 000	16 500	70	6 000
1988	121 000	24 200	3 000	19 500	80	6 000
1989	125 000	25 000	3 000	22 500	90	6 000
1990	128 000	25 600	3 100	25 600	100	6 200
TOTAL			20 600			41 200

[a] Based on 3 per cent average annual growth rate and an average of 5 persons per household.

[b] Based on Vt 2,000 per latrine – not including labour and local materials.

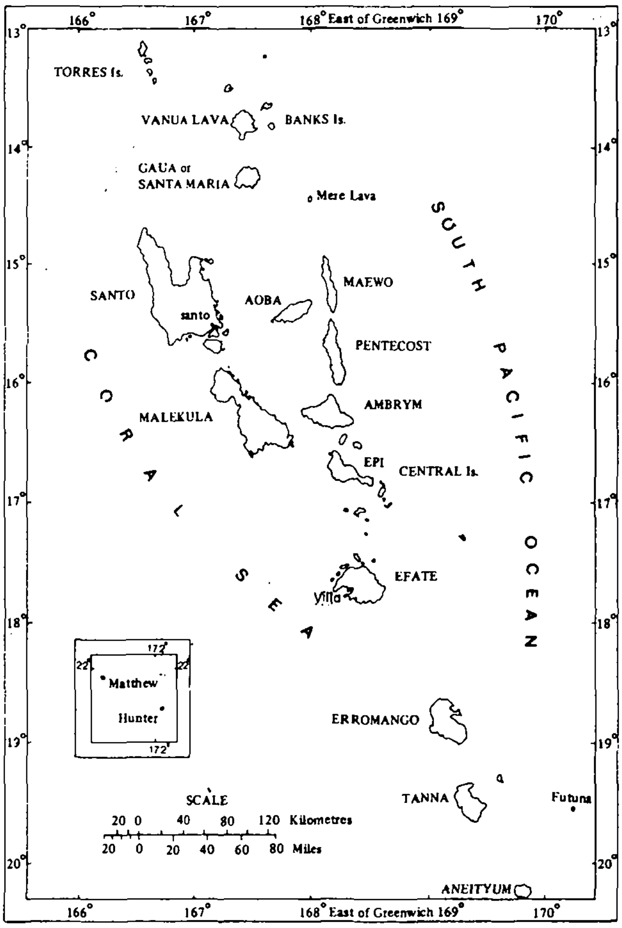


Figure 3. Map of Vanuatu

Part Four

PAPERS PRESENTED AT WORKSHOP SESSIONS

I. SURFACE WATER INFORMATION NETWORK DESIGN FOR TROPICAL ISLANDS

INTRODUCTION

The establishment and operation of hydrological networks in the tropics often presents additional problems to those encountered in the temperate zones upon which most of the literature, experience and equipment development are based. These problems may be compounded on tropical islands which are often rugged and mountainous resulting in many short streams of steep slope and high stream velocities. Usually of volcanic origin, the young geological formations have shallow soils leading to comparatively low volumes of baseflow. Combined with small drainage areas the streamflow on tropical islands varies considerably from wet to dry seasons and it is only on the larger islands that perennial streams exist.

Water and water data are vital to the further developments of most countries. Although rainfall and streamflow tend to be less variable in tropical areas (i.e. from one wet season to another), permanent streams are few and they are still subject to drought and large and devastating floods. Those areas subject to tropical cyclones tend to be the worst affected by these two extremes.

Due to the temporal and areal variability of rainfall and streamflow many decades of these data at numerous sites and a quantitative understanding of the hydrology of each region/island are necessary to meet the important needs of surface water information. The requirement to collect data many years in advance of its eventual use emphasises the importance of developing well designed networks that are in balance with the future needs for information.

The following material is largely taken from a recent review undertaken in Australia (AWRC, 1982). This material is applicable to most countries and certainly to the larger of the tropical islands.

A. ACTIVITIES THAT REQUIRE SURFACE WATER DATA

Water and water information are of vital importance to nearly every activity and development so a detailed list of activities requiring surface water data would be virtually endless. Accordingly broad categories which represent the breadth and importance of activities requiring surface water data have been listed.

Agricultural and pastoral pursuits
Drainage: rural and urban
Environmental studies
Fishing
Flood forecasting
Flood mitigation
Forestry
General industry
Irrigation
Mineral developments
National policy
Navigation
Planning: water resources, land use
Power generation: hydropower, steam turbine
Recreation
Resource management for future utilization
Transport: roads, railways (particularly bridge and culvert design)
Waste disposal
Water supply

Under most of these headings separate uses of the data occur at the planning, investigation, design, construction and operational phases.

Within each category there are many different activities requiring data. For example the irrigation category could include:

Derivation of the yield of a storage system under various possible operating rules

Estimation of net losses caused by evaporation

Derivation of catchment loss rates

Derivation of the spillway design flood

Study of the changing quantity and quality of inflow due to changes in catchment conditions or land use

Estimation of the progressive reduction in capacity of a reservoir through sedimentation

Assessment of the effect of effluent water from the irrigation area on river water quality downstream

By A.J. Hall, WMO Consultant, Hydrologist Bureau of Meteorology, Melbourne, Victoria, Australia.

Study of flooding problems due to local runoff or backwater from a major river.

B. INFORMATION REQUIREMENTS

Although the requirements for water information are both broad and diverse they are amenable to solution through hydrologic study if there is a well planned basic set of data available and a quantitative understanding has been developed of the hydrologic response of the region.

Table 14 provides a simple presentation of how information requirements from a wide range of users can be grouped into a limited number of classes of information. For each group of users and class of information, the combined value of information and frequency of use is represented in the table by the number of asterisks given. Obviously this coding will vary to some extent from region to region. Within the classes of information listed there are a range of time scales, space scales and attributes to be measured and considered.

For surface water information, the concern of this report, the requirements and items of information to be collected are many and varied. An appropriate approach to rationalize these data needs is to consider them within the type of hydrologic study involved in providing the required answer. These hydrologic studies can be grouped into the following broad categories:

Water Quantity

Flood

Water Quality

1. Water Quantity Studies

Water quantity studies can be related to:

The assessment of the quantity and variability of the surface water resources of individual streams, river basins of drainage divisions.

The assessment of inflows to, and level variations within, wetlands, or natural water bodies for environmental studies.

The recharge of groundwater systems.

The yield of aquifers or man-made storages.

The changes in runoff that occur as a result of natural or man caused changes in catchment condition or landuse.

The range of possible studies is large. For example storage yield studies can be for a single surface reservoir, an integrated system of surface reservoirs, a surface storage and groundwater aquifer used conjunctively, a groundwater aquifer that is recharged by riverflow or rainfall and river flow, a small run of river scheme, an offstream storage system etc, and can vary from major water supply schemes to individual farm supplies.

For water quantity studies some or all of the following activities are necessary:

Study of the available historic flow and rainfall record

Development of a long sequence of daily or monthly flows (using modelling and stochastic generation methods).

Development of an associated sequence of rainfall and evaporation data to calculate net losses by evaporation or evapotranspiration or recharge to aquifer systems.

Development of a quantitative understanding of past or likely future changes in catchment runoff due to changes in vegetation conditions or land use to allow modification or correct interpretation of the yield modelling study.

Development of chemical quality loads, sediment loads and an understanding of other water quality characterisitcs of inflow such as turbidity, colour, pH, temperature, or toxic chemicals.

For studies involving a number of rivers the long sequences of flows, rainfalls and evaporation may need to be cross correlated to represent a related sequence of events within the particular system.

Data requirements for the water quantity category of hydrologic studies can be summarised as:

Reliable daily flow records for a range of hydrologically significant catchments and of sufficient length to allow synthesis of long term data through correlation, catchment modelling and/or stochastic generation,

Daily rainfall records at sufficient sites to represent the rainfall across the catchment or region and at any specific sites of interest for catchment modelling, catchment water balance calculations and storage water balance calculations,

Data on changes in catchment land use or vegetation condition that could effect hydrologic response and,

Data sufficient to allow a reliable estimate of evaporation and/or evapotranspiration.

Table 14. Information required by users

Classes of information	*Users*									
	Water authorities public & private	*Rail & rail authorities*	*Private enterprise & consulting engineers*	*Research & educational institutions*	*Local govt.*	*Forests authorities*	*Agriculture authorities*	*Conservation environment & recreation authorities*	*Public health*	*General public*
Meteorological										
Rainfall	***	**	**	*	**	**	***	–	–	*
Evaporation & Meteorological	***	–	*	*	–	***	***	*	–	*
Surface Water										
Catchment characteristics and land use history	***	*	*	*	–	***	*	**	–	*
Yield	***	–	**	*	–	**	**	–	*	*
Flood	***	***	**	*	***	*	**	**	*	*
Rainfall-runoff	***	**	*	**	*	***	**	–	–	–
Water quality	***	–	**	*	**	**	**	*	***	*
Groundwater										
Location	***	–	**	–	*	–	**	–	–	**
Stratigraphy	***	–	*	*	*	–	**	–	–	*
Yield	***	–	**	*	**	–	**	–	–	*
Behaviour	***	–	*	*	*	**	*	***	–	*
Quality	***	–	**	*	**	–	**	**	***	*

Note: Geological survey organisations are included in water authorities.

*** High value and activity level
** Moderate value and activity level
* Small but significant value and activity level
– Not significant.

2. Flood Studies

Design flood estimation is a primary and critical step in the design of all hydraulic structures and works used in floodplain management. In terms of money invested by countries the amounts involved are of considerable national significance. The estimated average annual expenditure in works sized by design flood estimates in Australia in 1979 is equivalent to roughly $ 40 per person in 1983 values (Cordery and Pilgrim, 1979).

The collection of hydrologic data during periods of extreme floods is always difficult and sometimes impossible because floods frequently occur during tropical cyclones. The concern for public safety, the stress on communication and transport systems, and the usually flashy nature of the small streams of tropical islands during cyclones are responsible for the hydrographer's difficulties.

The steps in planning for flood-data collection, data collection during the flood event, post-flood data collection and the preparation of reports on a tropical island are discussed for Puerto Rico (8,900 km^2) by Cobb and Barnes (1981). Flood data/information are provided for Puerto Rico in several types of reports:

> Areal reports describing the water-resource characteristics of a specific basin or area of study.
>
> Floods resulting from a specific event. Rainfall, peak discharges, flood hydrographs, areas of inundation, and frequency of recurrence data are presented in tabular and plotted form for individual stations and are analysed on a regional scale.
>
> Frequencies of floods of various magnitudes throughout the country. Regression analyses are presented for floods of specific recurrence intervals. This provides a bases for transferring flood-frequency information to ungauged sites throughout the island.
>
> Hydrologic atlases, showing in map form, areas which have been inundated by historical floods. A brief text, with some analyses of the floods shown, is included in these reports. Hydrologic atlases may also be prepared showing areas which are predicted to be inundated by a flood of a specified recurrence interval.
>
> Flood insurance studies are made showing areas inundated by floods having an average recurrence interval of 100 and 500 years. Flood profiles are also prepared for these and other recurrence-interval floods.

For rivers with very long records and stable catchments simple flood frequency studies based on annual peak discharge or peak height can be carried out. Then, if there are many stations in a region with long records that represent the full range of catchment size, relief and vegetation types, regional flood, frequency relationships can be developed simply from the peak flow data alone.

However, in practical terms this length of record is rarely available over large areas. It is not economically feasible to gauge every major stream and a large proportion of the medium and small sized basins need to be gauged for a very large number of years. (These sizes are relative to the size of the island itself). Thus, it is necessary to adopt an approach based on a selective network of gauging stations being fully utilized through the application of advanced hydrologic techniques.

Many studies need flood volume and hydrograph shape in addition to the flood peak. In these situations and when extreme estimates are required, studies based on rainfall runoff modelling become necessary. Loss rates for various catchment types and hydrologic conditions can become very important to these studies.

Data requirements for the flood category of hydrologic studies can be summarized as follows:

> Many years of annual peak flow data on many major rivers and a representative set of minor rivers and small catchments, both rural and urban
>
> An adequate sequence of continuous flow records on major rivers and on catchments that represent the full range of catchment sizes, relief and land use
>
> Rainfall records at a recording interval appropriate to the catchment size for the same set of catchments
>
> Regional meteorological data for rainfall depth duration studies and probable maximum precipitation studies.

3. Water Quality Studies

With increasing development involving population growth, land use changes (particularly forest clearing), industrialization, the deterioration in water quality and pollution are some of the critical problems facing water management in many countries. Often a major contributing factor to this situation in the past was the lack of appropriate and reliable water quality data. Network designers now have the responsibility of ensuring that lack of appropriate data is not the cause of similar very costly errors in future.

Water quality is of importance in all regions, however the quality parameters of critical importance can vary from region to region and sometimes from stream to stream. Also the intensity of monitoring that is required to adequately quantify the important quality parameters varies from region to region. To be effective, the design of the water quality component of the assessment programme must be based on studies of data already collected and tailored to the hydrologic conditions of each particular region. However, reliable base line data are essential for all regions.

To be meaningful, water quality samples for surface streams must have an associated flow rate and sampling at any site must take place through all seasons and flow rates. For many quality parameters monthly or annual load is required in addition to the concentration at a limited set of times. For many quality parameters monitoring through flood events is of critical importance.

Also of critical importance is the development of a quantitative understanding of the factors that affect the quality of catchment runoff so that future trends can be anticipated.

Water quality data are important in relation to the use or potential use of water (human consumption, domestic, stock, irrigation, industrial, construction), its instream or storage effects (e.g. eutrophication of lakes, estuaries, storages) or as a reflection of excessive deterioration of the water catchment (e.g. high sediment loads).

Due to variations in quality characteristics and issues from region to region there will be some variations from the following summary of data needs.

For major rivers and for gauged catchments sampling a full range of climate, soils, vegetation and land use history the following data are required for a full range of years:

(a) T.S.S. concentrations and loads,

(b) pH, temperature, colour and turbidity concentrations,

(c) Nutrient concentrations and loads (for disturbed catchments),

(d) Major ions for samples that cover the full range of hydrologic conditions,

(e) Metals for a limited but representative set of samples and,

(f) Substantial sampling of any problem parameters.

For a typical set of catchments a measure of monthly and annual sediment loads through a full range of years (wet, average, dry) is required.

For significant water resources where quality is changing due to changes in land use or vegetation, on going sampling is required to reliably monitor the important quality properties that are changing.

The sampling frequency must be carefully selected so that the results truly represent the variation in the parameter being measured and, where indicated, allow loads to be calculated.

For pollutants, specifically designed data collection programmes are necessary. However pollution monitoring is outside the scope of the assessment programme and this paper.

C. NETWORK DESIGN

1. Integration

a. *Integration of networks*

To provide the information identified in section B in a cost effective manner, an integrated hydrologic data collection programme must be developed that incorporates the following:

Streamflow	– continuous flow – water quality including sediment – peak flow or low flow partial records
Natural water bodies (lakes)	– level – water quality
Rainfall	– daily – pluviograph
Meteorological	– evaporation, dewpoint and other meteorological data
Catchment	– relief, geology, soils and natural vegetation – history of landuse and vegetation condition

Depending on the institutional arrangements within the country, the meteorological agency may be separate from the water resources agency. Meteorological agencies usually operate a general network of rainfall and climatological stations which are essential to the water resources network.

Detailed monitoring of rainfall within gauged catchments to provide catchment rainfalls is exceedingly important to the integrated surface water network. Where the meteorological agency does not require this more spatially intense monitoring, the river gauging authority should operate the necessary rainfall stations. These data should be provided to the meteorological agency to enable a national meteorological data bank to be established.

Water quality assessment of surface waters should be fully integrated with the stream flow assessment programme. The stream gauging network design must therefore reflect water quality data needs as well as water quantity and flood flow data needs.

b. *Integration of activities*

Network design is not a once only activity that has intrinsic value of itself. It forms a small part, albeit an exceedingly important part, of an integrated hydrologic information system. A schematic representation of this system from Whetstone and Grigoriev (1972) is presented as figure 4.

Network design is an on going iterative activity which operates on information fed back from the other components (sub systems) of the total hydrologic information system. The network must be considered as a dynamic, evolving, information gathering system that is responsive to improvements in understanding of the hydrology of the various regions of Australia and to changes in the perceived long term needs for information.

2. Streamflow Network Design Concepts

The considerations and concepts to be kept in mind in designing a hydrologic network are discussed in some detail in Langbein (1965), Carter and Benson (1970), Davis and Langbein (1972), Hofmann (1976), Rodd (1972), WMO (1972, 1981), Moss (1978, 1982), Brown (1980) and others.

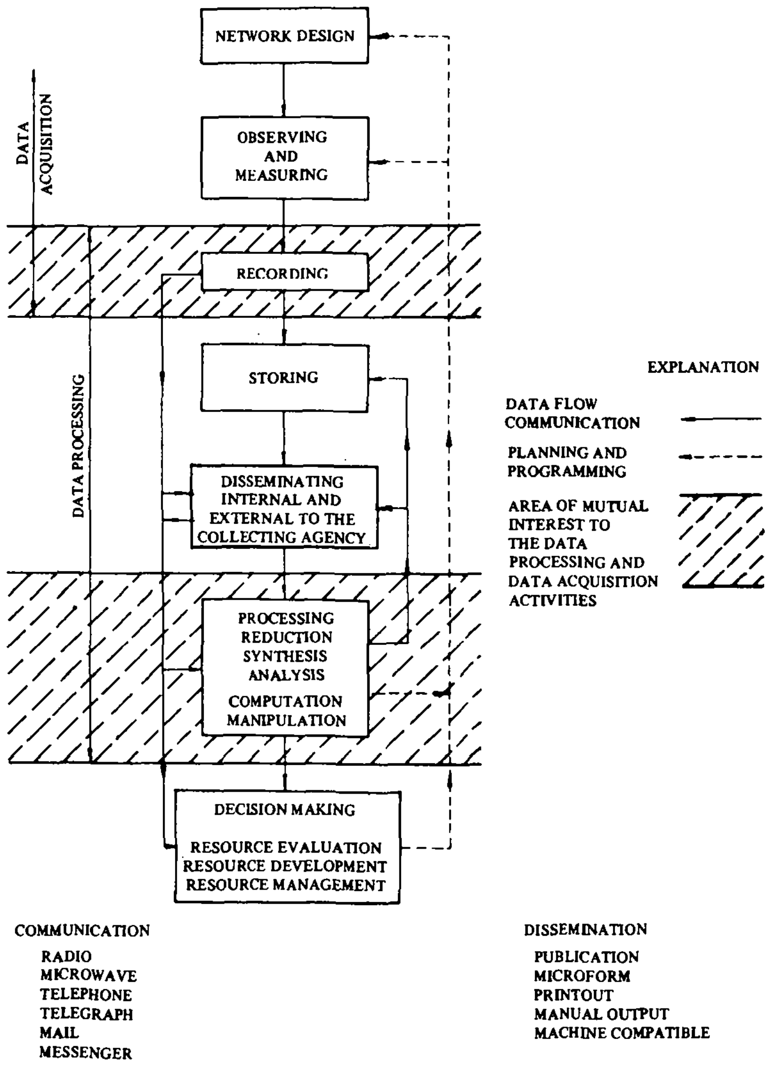


Figure 4. Schematic chart of the major elements of water data acquisition, transmission and processing systems.

There are two main classes of networks: the national multipurpose network (water resources network) and the user-specific network (specific purpose network). The former provides information on the water resources of a region, drainage division or country for general planning and design, the detection of long term trends and provides information for the many unanticipated data demands. The latter provides information for specific projects. Langbein (1965) also saw hydrologic networks as serving these two basic roles:

> "One division of the network would appraise the basic hydrology, with density of coverage that reflects chiefly the hydrologic diversity and the potential hydrologic significance of the data to water development. The second division would be responsive to present and imminent project needs. The first division is a basic network, the second is a project network. The basic network explains the regional hydrology; the project network provides point data. The basic network looks to the future, the project network serves the present."

The specific purpose network, or project network is an ad hoc network with stations established at the time of need for a particular project and not for their value in a general network. The network of prime concern to this paper is the national multi-purpose network (the water resources network) that must be in place and operating for many years prior to the use of the data.

In considering this water resources network it is necessary to remind ourselves that stream discharge data are random in nature and vary greatly both in space and time. The magnitude of these variations are important in designing the network.

The network must be designed to provide a quantitative understanding of both the temporal and spatial variability. This is most efficiently achieved by having a mix of primary stations that operate for a very long time (or indefinitely) and additional secondary stations that operate for a finite period to sample the spatial variability. When a secondary station has sufficient record to allow satisfactory correlation with the primary network it is closed and moved to sample a different catchment type or size. The terminology refers to the duration of the recording period and not to the importance or value of the hydrologic data obtained.

To design and review the network effectively there is need for a classification system that reflects the purpose of each station. Although a number of classifications have been used by different groups from time to time the classifications have differed mainly in the terms used rather than the philosophy adopted.

Table 15 is an amalgamation of various classifications used and it is considered appropriate for large tropical islands where the gauging networks in many regions are still embryonic and little or no water development has taken place while in other areas the gauging network has been in place for many years and substantial development and regulation of water has taken place. The classifications are equally appropriate for initial design and detailed review.

Table 15. Network design, classification of gauging stations

1. WATER RESOURCES NETWORK:	Catchments to assess regional water resources and to monitor and understand time trends and spatial variations in the runoff characteristics.
1.1 Primary stations:	Base stations to measure time variance.
(i) Bench mark stations:	Selected primary stations with stable or protected catchments in which long term variations are attributable to climatic factors alone.
(ii) Mainstream or principal stations:	Generally catchments >1000 km^2 which measure significant resources. (The number and location of these stations dictated by topography and drainage patterns).
(iii) Areal or index stations:	Catchments <1000 km^2 which measure runoff (quantity and quality) characteristics from significant variations in the physical environment – i.e. rainfall, landforms, vegetation and landuse.
1.2 Secondary stations:	Stations with a finite period of operation to measure spatial variance.
(i) Mainstream or principal stations:	Usually catchments >1000 km^2 measuring significant resources: – operate until an adequate estimate of the flow and quality characteristics can be obtained, either directly or by correlation.
(ii) Areal or index stations:	Catchments <100 km^2 measuring runoff (quantity and quality) characteristics from particular types of landscape or landuse. Important to have a range of catchment sizes, including small catchments to provide storm runoff data from natural, agricultural and urban environments. Operate until and adequate estimate of the flow and quality characteristics can be obtained, either directly or by correlation.

Table 15. *(Continued)*

(iii) Partial record stations:	Stations recording either peak flows, low flows or water surface levels which can be used for flood or drought frequency studies.
(iv) Landuse – hydrologic response stations	Small catchment measuring the effects on runoff (quantity or quality) characteristics of specific types of, or changes in, landuse or land treatment
2. SPECIFIC PURPOSE NETWORK:	Stations established for a specific purpose, to operate for periods determined by that purpose.
2.1 Project investigation station:	Stations for specific investigations such as proposed damsites, diversions or flood control systems, or other water resources development or water quality investigation. (Either discontinued or reclassified at the end of the specific investigation).
2.2 Project research:	Stations operated for research related to a specific project.
2.3 Operation stations:	Stations required for operating water storage or distribution systems.
(i) System flow stations:	Stations recording regulated flows for compiling flow budgets or for systems analysis.
(ii) Current use stations:	Stations providing information for management and operation functions as distinct from flow recording purposes. (Records not kept).
2.4 Statutory accounting stations:	Stations providing water data for accounting purposes under legal or statutory agreements or obligations (probably operate indefinitely).
2.5 Flood warning stations:	Stations operating solely for flood warning purposes.

Footnotes:

(a) Multipurpose stations fulfilling more than one function should be listed in the classification in which they provide most value, not necessarily that for which they were installed.

(b) There are instances where more than one recording installation is required to determine the natural flow at a given locality.

3. *Network Design Process*

a. *General*

The ideal network could be described as one which provides at least cost, sufficient information to adequately satisfy all justifiable needs at the time that these needs for information arise.

Surface water data must be collected over many decades for it to satisfy most information needs. This long lead time makes network design a very challenging and important activity. The network design team must include or have ready access to experienced hydrologists who have a good working knowledge of the hydrologic characteristics of the region under consideration. The team must also have ready access to advice from water planners and other potential users to better understand the possible scope of future data needs and the possible timing of these needs.

However, because it is impossible to accurately predict future specific data requirements the network must be designed to provide multi-purpose data and to provide a quantitative understanding of the factors that affect the hydrologic response of the region.

b. *The design process*

Design of the network must be based on the best current understanding of the various factors that are likely to affect the hydrology of the region. This requires compilation of information in map form of various aspects including:

Climate and rainfall distribution
Geology)
Soils) or landforms
Topography)
Natural vegetation
Land use and land use history

Geomorphological regions are then delineated and grouped into areas considered to have similar hydrological characteristics to provide a guide to spatial variability.

Available rainfall, climatological and stream quantity and quality data are assessed together with any available hydrologic studies to gain an understanding of temporal variability and a first estimate of the likely minimum record length required for the development of reliable statistics or for various correlations.

The major rivers are identified and their likely hydrologic behaviour assessed in order to estimate the number of mainstream catchments required in the network to quantify these major resources. As these catchments are generally too large or too complex to provide information about runoff characteristics which could be transferred, areal catchments to sample the environmental factors also need to be identified.

Existing stations are classified and assessed for suitability in any ongoing network.

With all available information relevant to the hydrology of the division absorbed by the designer, gauging sites are identified to provide a balanced sampling of the major rivers and the various hydrologic regions. Care must be taken to ensure that a full range of catchment sizes are represented together with all major relief, land form, vegetation and climate types.

Station density will depend on spatial variability and the relative information needs of the area. This is discussed further in Section 4.

Station types should be identified according to the classification summarized in Table 15. For well developed networks it should be possible to identify the primary and secondary stations in the network. However for the embryonic networks in some of the more remote areas of Australia virtually all stations are primary or long term.

The design must take cognizance of any practical problems involved in establishing and operating stations in the area under consideration. The selective use of nested catchments should also be considered from the viewpoint of maximising information gained for resources expended.

A number of alternative network designs should be developed and compared as the design team searches for the most cost effective network. The network adopted must be the best synthesis of current understanding.

The level of understanding required for network design is well summarized in the following quotation from Benson & Carter (1973).

> "Planning the surface water information system cannot be done by formula. It must be done by hydrologists who are familiar with the hydrology of the region, the needs for information, the information currently available, and methods of hydrologic analysis."

4. Network density

As discussed in the previous section there are many variables that must be considered when deriving the appropriate density of stations in the design network for each region. These variables include:

(a) Volume of information and level of hydrologic understanding already available

(b) Hydrologic diversity of the region (spatial variability)

(c) Level of development of available resources that will be necessary in future decades (a measure of the level of understanding that will be required)

(d) Level of social and economic development in the region

(e) Special regional characteristics or problems that will demand hydrometric data.

The network design team is best placed to establish the appropriate network density for a given region after they have studied all available information.

However there still remains a need for an independent guide as to the minimum density that could be tolerated without causing undue economic loss or restriction to the future development of that region.

The only known general guide to network densities is that provided by the World Meteorological Organisation (WMO, 1981) in the publication 'Guide to Hydrological Practices'. For small tropical islands less than 20,000 km^2, with very irregular precipitation and very dense stream network, the following ranges of norms for a minimum network are given:

	Area in km^2 for one station
Precipitation	25
Evaporation	50,000
Streamflow	140–300

At least 10 per cent of the precipitation gauges should be recording gauges. Sediment sampling should be carried out at a minimum of 15 per cent of the streamflow stations. The chemical quality of the water should be assessed at a minimum of 5 per cent of the stations.

As a general guideline networks developed to these criteria will help evolve a minimum network which will avoid serious deficiencies in developing and managing water resources on a scale commensurate with the overall level of economic development of the country.

Appendix 1 is an update of the information contained in WMO (1977), Statistical Information on Activities in Operational Hydrology and other information of current networks on small islands. The network densities reflect a number of the points made earlier, but do show a general trend of decreasing density in relation to increasing area, Figure 5. That is, in terms of streamflow stations, the island size will tend to reflect the density of the stream network and the number of stations required to cover these.

5. Network Evaluation

All networks must be evaluated at regular intervals and modifications made to improve the effectiveness of the network as necessary.

There is no one simple test that can be applied to ensure that a station is adequately serving its purpose or to indicate that a given secondary station should be closed.

An essential starting point is to have all data collected in the Division reliably processed and readily available. Also it is highly desirable that these data should have been analysed to improve the general understanding of the hydrological characteristics, particularly spatial and temporal variability, of the region.

With this improved understanding, the previous network design should be reviewed and revised as necessary or a new network design produced as discussed in the previous section.

Each station is then reviewed with the following aspects considered:

Percentage data capture
Accuracy of processed data
Reliability of the record generally
Consistency of data collected through the years
Any operating difficulties
Is the station reliably serving its purpose within the network?

For secondary stations as well as reviewing the adequacy of the data collected the need for further record must also be reviewed. This is best done by attempting to correlate the monthly or daily flows (and water quality characteristics if important) at that site with a nearby primary station and/or attempting to model the flows (and quality) using other available hydrologic records. If the perceived data need to simulate a long term distribution can be achieved by correlation of appropriate accuracy, the station can be closed, unless there are other important data requirements still unfilled. There will be situations where further operation of a gauging station will be required to support the water quality monitoring programme even though the station could be closed as far as quantity statistics are concerned.

D. PROCESSING AND ANALYSIS

With the decision to expend funds on the design and establishment of a gauging station within the water resources network goes the responsibility to collect data of an appropriate accuracy and reliability, to process and analyse these data and to make the data readily available to all users.

As discussed in AWRC Technical Paper No. 52 it is a "hydrologic information system" that is required and not simply a set of gauging stations. The raw data has no intrinsic value, the data only becomes valuable when it has been processed, analysed and put to work. Prompt analysis of the processed data is also essential to review the quality and value of the data and provide timely feed back to the field so any necessary corrective action can be taken.

The following activities are considered important to ensure an efficient and cost effective surface water data collection activity.

1. The records for all water resource network stations should be processed and readily available on computer media and as hard copy or microfiche within 12 months of the end of each water year. The form of output to include daily flows, daily rainfalls (where appropriate) and a summarised presentation of all water sampling analysis results.

2. Collecting authorities should make every endeavour to carry out simple hydrologic analyses of the data collected at each station every five years, or preferably more frequently. This study should assess the adequacy and value of data collected, highlight any improvements necessary or show that the station could be closed.

Stream-stream correlations and/or catchment rainfall – runoff modelling studies utilizing daily or monthly data may be appropriate together with a general study of the water quality characteristics and trends.

3. Gauging authorities should move towards development of the ability to reliably fill in missing record utilizing modelling and correlation techniques appropriate to their regions. Both the uncorrected and corrected records should be readily available.

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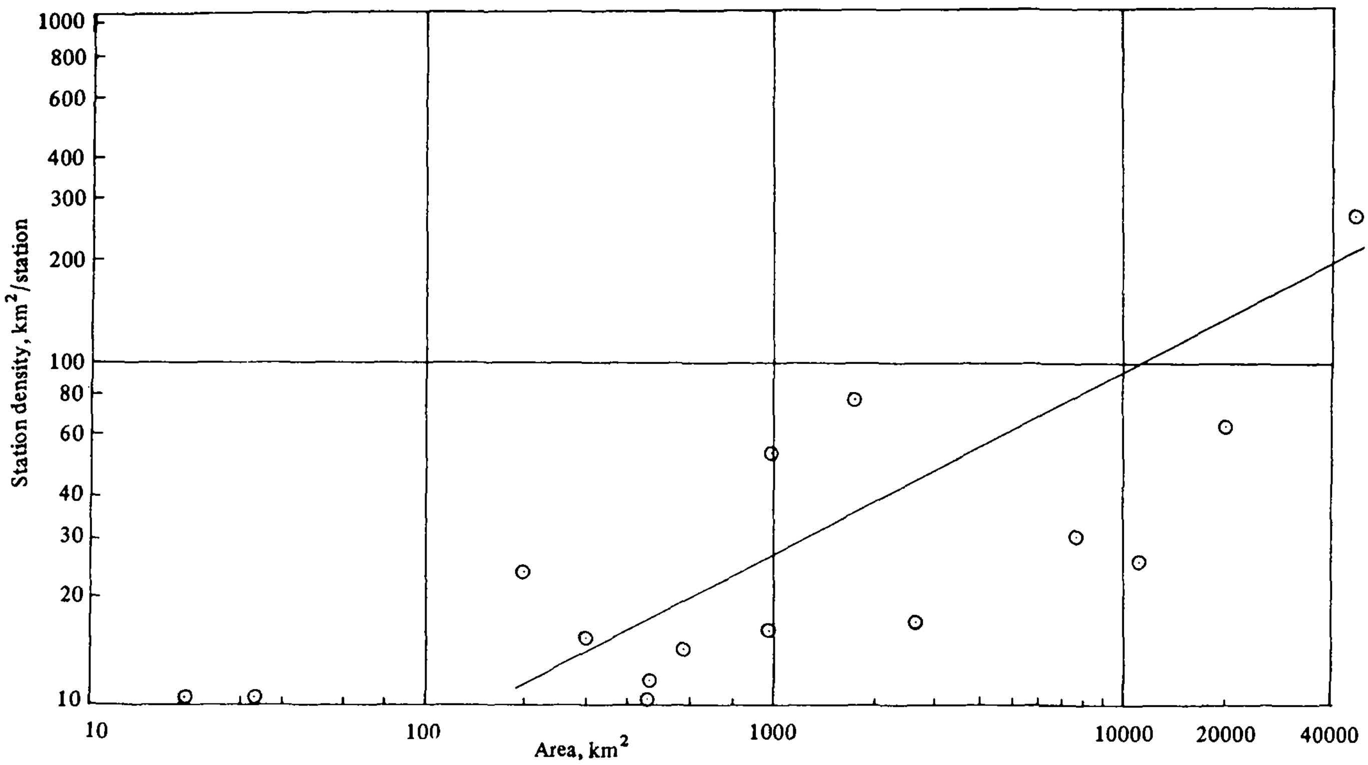
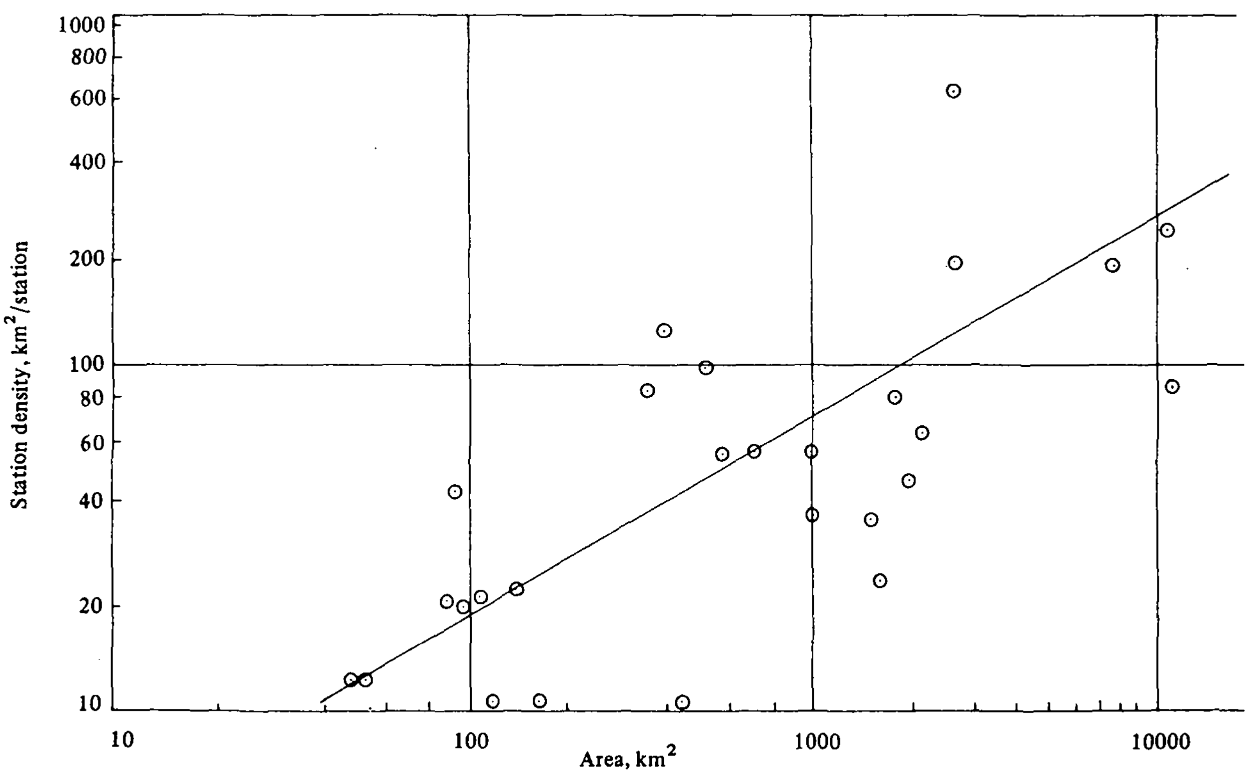


(a) Rainfall station densities for tropical islands



(b) Discharge station densities for tropical islands

Figure 5. Hydrological network station densities for small tropical islands

Appendix 1. Hydrological networks on tropical islands

Island	*Area km²*	*Number of stations*					*Station density km²/stn.*				
		Precip.	*Record. Precip.*	*P + RP*	*Evap.*	*Dis-charge*	*P*	*RP*	*P + RP*	*E*	*D*
REGION I (Africa)											
Canary Islands	7230	237	3	241	4*	38*	31	2410	30	1808	190*
La Reunion	2510	124*	28*	152	3*	15*	20	90	17		200
Mauritius (Total)	2045	257*	6*	263*	6*	38*	8	341	8	341	54
(4 basins)	416	52	7	59		40	8	59	7		10
REGION IV (North and Central America)											
Panamas (Total)	13935	134	1	135	3	0*	104	13935	103	464	
Barbados	430	42	3	45	3	0*	10	143	10	143	
Dominican Republic	47939	133	56	189	34	51	360	856	254	141	940
France											
. Guadalupe	1700	22		22	2	21	77		77	850	81
. Martinique	1000	4	15	19		18	250	67	53		56
Jamaica	10990	430	14	444	14	129	26	785	25	785	85
Netherlands											
Antillas											
. St. Maarten	37	3	1	4	1		12	37	9	37	
. Bonaire	288	18	1	19			16	288	15		
. Aruba	193	7	1	8			28	193	24	193	
. Curacao	444	38	1	39	1		12	444	11	444	
. Saba	13	3		3			4		4		
. St Eustatius	21	3		3			7		7		
REGION V (South-west Pacific)											
Australia											
. Norfolk Is. (Extra-tropical)	35	3	1	4		8	12	35	9	4	
Fiji (Total)	18234	156	97	253	5	89	117	188	72	3647	205
French Polynesia											
. Tahiti	1000	45	17	62	3	27	22	59	16	333	37
United States											
. Hawaiian Is. (Total)	18227	231	73	304	2	241	79	250	60	9113	76
. Guam	560		4	4		10		140	140		56
. Hawaii	10460					42					249
. Kauai	1437	5	2	7		40	287	719	205		36
. Kosrae	109	5	1	6		5	22	109	18		22
. Mariana	375		2	2		3		188	188		125
. Maui	1890		4	4		41		473	473		46
. Molokai	676	2	1	3		12	338	676	225		56
. Oahu	1575	4	12	16		66	394	131	98		24
. Palau	485		3	3		5		153	153		97
. Ponape	334		4	4		4		84	84		84
. Truk	91					2					46
. Tutuila	137	1	2	3		6	137	69	46		23
. Yap	98		1	1		5		98	98		20

* Figures from WMO (1977).

Note: Individual Hawaiian Islands climatological station numbers are thought to include only those operated by the USGS and do not include the NWS Stations shown under the Hawaiian Islands (total).

II. SURFACE WATER RESOURCES ASSESSMENT – ITS PROBLEMS AND RESOLUTIONS

Of all the natural resources of a country, the most precious is water, being essential for all forms of life. Unlike other natural resource water is a renewable resource. Generally water is available at certain places, at certain times, in certain quantities and qualities. But it is required at other places at other times in other quantities and other quality criteria. Hence it is the responsibility of the Engineer-Hydrologist to harness the available resource so as to meet demands.

With greater demands for water the engineers have been compelled to harness the water resources despite the lack of adequate data. In the process of development it is not possible for the engineer to wait till adequate data is gathered. He has therefore to take short cuts to meet the amenities and facilities demanded by the development. Despite the Engineer-Hydrologist using his wealth of experience and better judgements to supplement the shortfall of adequate data there have been errors in some of the water resources assessments.

The data necessary to assess the surface water resources may be broadly classified under two heads:

(A) Meteorologic

(B) Hydrologic

, each of which can be subdivided into:

A_1 Rainfall

A_2 Evaporation

A_3 Transpiration

etc. and

B_1 Stream flow

B_2 Catchment characteristics

B_3 Soil moisture

etc.

The data for the fore-mentioned natural phenomenon are derived from historic records. In developing countries it is found that:

(i) There are no records at all.

(ii) The records have been obtained by non-conventional methods and doubtful in accuracy or are inaccurate.

(iii) The records are of very short duration or fragmented and of little value.

(iv) The records related to only some of the necessary parameters.

(v) The records are not available at the required site.

These problems can be summarised into two broad sections:

(a) Errors in data

(b) Inadequacy of data.

Hydro-meteorologic data is very variable and generally stochastic in nature. Hence the data must be unbiased, independent and homogeneous.

To be unbiased the sample must be as representative as possible of the total population.

To be independent any one event should not have any influence on any other event either preceeding or succeeding.

The questions whether the records in a group are homogeneous may be answered in a statistical sense by determining whether they differ from one another by amounts that cannot reasonably be expected by chance (ref. 1). Walter Langbein of the United States Geological Survey (USGS) has developed a homogeneity test which is described in USGS., WSP 1543A.

Though precautions may be taken to ensure that the data obtained is unbiased, independent and homogenious errors creep in during observation. Errors of observation may be from two sources instrumental and human. Such errors may be considered of two kinds, namely accidental and systematic errors, although it is sometimes difficult to distinguish between them and many errors are a combination of the two kinds. *Accidental errors* are usually due to the observer and sometimes due to the uncertain nature of the measuring instrument. Such errors may be considered random errors; they are also disordered in their incidence and variable in magnitude, positive and negative values occuring in repeated measurements in no

By H.M. Ernest, Principal Engineer, Ministry of Agriculture and Fisheries, Fiji.

ascertainable sequence. On the other hand, *systamatic errors* may arise from the observer or instrument. Such errors are not random: they may be constant and create a trend, or vary in some regular way and produce periodicity (ref. 2).

Before use raw data should be adjusted according to the various methods available such as serial correlation analysis for persistence, moving averages for trend, and Fourier or harmonic analysis for periodicity. Missing data may sometimes be estimated by regional analysis, by correlation with other hydrologic data in the neighbourhood (ref. 2). Regionalization is the technique of relating hydrometeorological parameters to the physiographic characteristics of the basin.

To get a better knowledge of the areal distribution of rainfall, it is obvious that the number of rain gauges must be considerably large. But not only is this practically not feasible but also uneconomic. Hence the number of gauges and their distribution in a catchment would depend on the accuracy to which an assessment is necessary. The principles of design are considered later.

The errors of measurement of precipitation fall into two main classes:

(a) Cumulative

(i) Observational errors e.g., neglecting tracers.

(ii) Creep up the dip stick due to extended immersion.

(iii) Instrumental errors.

(iv) Dents on rim or receiver.

(v) Wetting and evaporation of collector.

(vi) Outsplash.

(vii) Slope of the ground.

(viii) Accumulation over more than one day (sometimes indicated but quite frequently entered as normal daily readings.)

(b) Compensating errors mainly due to errors in reading e.g. (i) Misreadings, (ii) Misplaced decimals, (iii) Mistakes in copying, (iv) Mistakes in arithmetic (v) Inadvertent ommission (observations made but not written).

Other errors in the measurement of precipitation are:

(i) Systematic errors due to faulty exposure, (ii) Occasional errors due to temporary disturbance of explosure or mischeivous interference, (iii) Displacement of correct readings to incorrect days, only occasionally and erratically or fairly often but irregularly, or persistently, (iv) Displacement of partial amount due to deviations from standard times of observations.

In an effort to standardize methods of measurements, and instruments the World Meteorological Organization has put a "Guide to Hydrological Practices", WMO No. 168 of 1974. This guide contains a detailed discussion on exposure-errors types of gauges etc.

Before point rainfall could be used they have to be checked and corrected where necessary.

The adjustment of point rainfall data consists of two operations: (a) *Filling in missing data*, and (b) Checking the consistency of the data. This is done by correlation of the rainfall at the station under consideration with the rainfall at the neighbouring gauges which are in a meteorological homogenous area. Missing records are usually filled in by the method of weighted mean with respect to the neighbouring index stations. If P_x is the missing record and P_1, P_2, P_3, P_r are corresponding records at r index station and N_x, N_1, N_{2_1} - - - N_r the mean annual rainfall at the stations then

$$P_x = N_x \left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \cdots\cdots + \frac{P_r}{N_r}\right]$$

This method is quite satisfactory for annual or seasonal totals. It may be extended with caution to monthly totals but could not be used for shorter periods as weeks or days.

Consistency of record at a station is checked by double-mass analysis. It tests the consistency of a station by comparing its accumulated annual or seasonal precipitation with the concurrent accumulated values of mean precipitation for a group of surrounding stations.

The hydrologist has very little use of point rainfall as such. He is more interested in the spatiotemporal distribution of rainfall. There are numerous methods used for the determination of the mean depth of rainfall on a catchment area, of which the most common are: (a) Unweighted mean, (b) Thiessen Polygon, (c) Isohyetal Method. These methods are generally dealt with in all hydrology text books.

Other methods of determining the mean aerial depth of rainfall are such as:

(i) Grouped area – Aspect weighted mean

(ii) Individual area – Altitude weighted mean

(iii) Triangular area – weighted mean

(iv) Meyers grouped mean – weighted for distance and altitude.

(v) Vegetation index

(vi) Multiple regression etc., are discussed by Whitmore, Eaden and Harvey (ref. 3).

While correcting the point rainfall data and determining the mean annual rainfall a major question arise. Have I enough data to get the mean annual rainfall? What confidence could I place on these estimates?

This problem was treated in considerable detail by Sir Alexander Binnie in a paper to the Institution of Civil Engineers (London) in 1892 and he reached the following conclusions as regards the relationship of the averages of different periods to the true mean for long period.

Overall period of observation (years)	*Per cent deviation of the average for the period from the long average rainfall*		
1	+51	to	−40%
2	+35	to	−31%
5	+15	to	−15%
10	+8.22	to	−8.22%
20	+3.22	to	−3.22%
30	+2.26	to	−2.26%

From the above analysis it will be seen that little advantage is gained by taking more than, say, 30-35 years of record as inaccuracies of gauging are of the order of 2 per cent.

The most important single variable to assess available surface water is runoff.

In the ideal case runoff records should be available at least at three points along the course of a river:

(a) In the extreme upper reaches – for hydroelctric power development.

(b) In the middle and upper reaches for irrigation storages, and for diversions for irrigation or water supply either by gravitation or pumping.

(c) In the lower reaches – for design of flood protection works or for general hydrologic information.

Two operations are necessary to determine runoff, (a) Stage-height measurement and (b) discharge measurements.

Recording gauges are preferred in inaccessible places or where a continuous record is necessary. Here too errors arise due to sticky pens, clocks and floats; failure of the clock or the blocking of the inlet to the stilling well. In all these cases loss of record could be as long as the interval between periodical visits to the site. Hence frequent checks on recording gauges are necessary to minimise loss of valuable records.

There are numerous methods by which discharge is measured; the following being some of the methods generally used:

(a) Volumetric or gravimetric methods

(b) Control structures

(c) Velocity-area method

(d) Dilution methods

(e) Electromagnetic methods

(f) Accoustic methods.

Of these the Velocity-area method is the most popular and requires:

(a) Correct evaluation of the stream obliqueness

(b) Accurate area determination of the stream cross-section

(c) Accurate measurement of flow velocity.

Where the gauging site is not perpendicular to the general direction of flow, correction for skew can be made by multiplying the area of the stream cross-section by the cosine of the angle of skew. But where river's activity has developed flow obliqueness either across the whole stream or across a part of the stream the correction for the obliqueness has to be applied.

In a wading measurement the presence of the observer changes the configuration of the flow and the measurement of the mean velocity at any section does not accurately reflect the mean velocity in the undisturbed condition. Similar errors are found in velocity measurements from a boat. If a current mater is lowered between two boats coupled together as a raft or between a catamaran to a depth less than one meter the velocity measured be as much as 26 per cent higher. Similarly current meters depths of over meter the error could be about 4 per cent higher. The use of a sinker creates a backwater pressure which could under-estimate the velocity by about 4 per cent when the vane is 9 cm in front of the front end of the sinker. But when this distance is about 37 cm the effect is eliminated.

Other errors are due to the type of current meter used, lubricant viscosity, environmental temperature etc.

The more popular methods of current metering are the mid-ordinate or the mean ordinate methods. The question then arises into how many sections the cross-section must be divided. The USGS (ref. 4) suggests 20 verticals should be used. It is also recommended that the discharge be between 5 per cent and 10 per cent between each pair of verticals. The ideal case is when the discharge between each pair of verticals is equal.

In the plotting of the rating curve problems are encountered due to:

(a) Aluvial stream bed with shifting natural control.

(b) Loop rating curves due to different slopes at rising and falling limb of the flood.

(c) Effect of the growth of aquatic vegetation.

(d) Back water effects due to confluences downstream.

(e) Effects of tides.

Using the rating curve or rating curves for different time intervals of the stage height the stream flow can be determined daily, monthly, annually, etc.

We often find that the length of the stream flow record at the given point is inadequate for design purposes. Techniques are available for extending the stream flow records in time. The more frequently used methods are (ref. 5 and 6).

(1) Runoff-runoff relation i.e. by correlation to another station with longer records.

(2) Runoff-precipitation relation is suitable if a long period rainfall over the catchment is available.

(3) Runoff-runoff-precipitation relation.

The above methods yield a stochastic sequence of flow. Similarly there are methods for the statistical simulation of flow at a point for design needs which may be either by single station analysis or multivariate analysis.

The problem more frequently encountered is that flow records are available at one point but the data is required at another point. If the distance between the two points is not large and the difference in areas between the two points small then a weighting directly proportioned to the areas is applicable. Otherwise factors of rainfall, slope, soil type etc. have to be taken into consideration in addition to area.

The hydrologist is at times requested to estimate the probable flow in an ungauged catchment. Methods of "Streamflow Synthesis for Ungauged Rivers" has been derived by the United States Geological Survey (ref. 7). This method have been extensively tested by the United States Geological Survey.

Numerous other methods are available at research institutions involving sophisticated techniques and large amounts of data. A beautiful scientific solution in the hands of an academic has little attraction to the practicing hydrologist or engineer if it is not readily applicable to practical problems usually encountered, especially in developing countries. Any solution must be readily applicable and must be simple and quick to use.

In conclusion it must be said a little good data thoroughly analysed has far more value than a large volume of observations inadequately processed.

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III. ASSESSMENT OF SURFACE WATER RESOURCES IN CATCHMENTS WITH LIMITED HYDROLOGICAL DATA - A CASE STUDY

INTRODUCTION

1. Purpose of Report

Work has started on the construction of a major impounding reservoir on the Upper Nadi River at Vaturu. The reservoir is part of the Nadi-Lautoka Regional Water Supply Scheme that will provide the area with a gravity supply by 1982/83 (ref. 1). The design capacity of the scheme is 91 Ml.d or 1.05 m^3/sec.

Initial estimates of yields from the Vaturu (Magodro) Catchment were carried out by Fawcett & Partners (ref. 1) and IJzermans (ref. 2). These estimates were based on limited hydrological data. They indicated, however, that there will be surplus water available during part of the year. Fiji Electricity Authority is at present investigating the possibility of utilizing this surplus water for power generation (ref. 4).

The purpose of this report is to review the general hydrology of the area and to update the earlier analyses, making use of an extra two years of data.

2. Description of Area and Station Network

The Vaturu Catchment (40 km^2), which forms part of the Magodro Plateau, is a moderately steep drainage basin with average slopes ranging from 15 to 25 per cent. It ranges in altitude from about 490 m (1600 ft) to over 1000 m (3300 ft). The area is drained by 3 main creeks and numerous smaller tributaries (see Fig. 6).

The geological formations consist of Upper Pliocene basaltic agglomerates belonging to the Ba Volcanics. At the surface they are deeply weathered to clayey soils. The catchment is almost entirely covered by native forest.

The hydrological station network is shown on Fig. 6 and consists of 3 rainfall recorders, one manual raingauge and a waterlevel recorder station. The latter is equipped with overhead cableway for floodgauging and is located immediately upstream from the dam site. The difference in catchment area between the two sites is considered negligible. Details of the stations and their record are given in table 16.

3. Earlier Work

Earlier work by Fawcett & Partners on catchment yield and storage requirements was carried out on a theoretical basis using long term Nadi Airport rainfall figures and taking into account evaporation and an increase in precipitation over the catchment. Low-flow predictions were based on an assumed groundwater depletion rate. The 1977 dry season recorded flow was modified to simulate a design situation (ref. 1).

IJzermans, on the basis of 1½ years of data, devised a simple mathematical model to relate monthly catchment rainfall to runoff. The model takes into account losses and delays in runoff. In order to generate long term monthly runoff values he used Nadi Airport rainfall figures, converted these to catchment rainfall (with the relationship he established), and applied these to the runoff model (ref. 2).

Estimates of peak flows have been made by IJzermans (ref. 2) and the Institute of Hydrology (ref. 3). Both used the unit hydrograph method.

By D. Kammer, FAO Hydrologist attached to the Hydrology Section, Public Works Department, Fiji.

A. DATA USED

Automatic water level records from the Vaturu (Nanukunuku) gauging station are available from May 1976. Stage discharge curves have been produced for the period May 1976–October 1980 and the quality of the mean daily discharge figures for that period is considered to be good. Vaturu is the station with the longest and most reliable record in its part of the country.

Rain gauges have been installed in the catchment since late 1976. Initially the information they provided was not very satisfactory as there were significant gaps in the records. Mid 1977, however, the quality improved, and at present there is about 3½ years of satisfactory rainfall information from the catchment available.

Data from nearby long term rainfall stations have been used to correlate the short term record to. These stations include Nausori Highlands (installed January 1971), Navilawa (installed January 1972) and Nadi Airport (installed March 1942).

A summary of all data used is given in table 16.

B. ESTIMATE OF CATCHMENT RAINFALL

Rainfall from individual stations in the catchment has been used to compute the catchment rainfall (CRF) by applying the appropriate Thiessen weighting factors. This was possible only from May 1977 onwards. Prior to that records were very incomplete and suspect.

For the period prior to May 1977 estimates of catchment rainfall were based on correlation to nearby stations. Firstly, the sketchy information from two stations in the catchment (mostly incomplete, and sometimes suspect accumulated totals) was compared to daily rainfall figures from Nausori Highlands and Navilawa. This produced one set of monthly totals. However, since the figures from Nausori Highlands are suspect, another set of figures was produced by applying the ratio Navilawa = 0.98 CRF (obtained by double mass analysis of 44 months of available record) to monthly totals observed at Navilawa.

These two sets of figures were subsequently averaged, providing, what is considered to be, the most acceptable estimate of monthly catchment rainfall figures for the period September 1976–May 1977 (see table 17)

C. ANALYSIS OF MEAN DAILY DISCHARGE

Mean daily discharge figures are available from May 1976 to September 1980. There are a number of days of record missing, but estimates for these were made on the basis of catchment rainfall.

A flow duration curve was derived for the period September 1976 to August 1980, this period reflects the least difference in groundwater storage (fig. 7). Rainfall during this period was below average.

In order to obtain a first estimate of long term flow-duration characteristics of the catchment, the 4 year values were multiplied by 1.18, which is the ratio short term to long term rainfall at Nadi Airport and Navilawa for the respective period. The data produced this way are given in the table below:

Estimated discharges of specific % duration for Upper Nadi River at Vaturu in m^3/sec.

	% of time equal or exceeded									
	10	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*
Sept. '76/ Aug. '80	4.81	2.66	1.60	1.00	0.70	0.49	0.32	0.21	0.16	0.08
Long-term	5.78	3.14	1.89	1.18	0.83	0.58	0.38	0.25	0.19	(0.09)

D. WATER BALANCE STUDIES

Assuming that differences in storage of water in the catchment at the end of each dry season are negligible, the water balance equation can be written as follows:

Runoff = Catchment Rainfall – Losses.

To assess the water balance of the catchment the record was split up in September to August water years. Monthly rainfall and runoff figures used are given in the table 17, the result of the analysis is summarised in the table below:

Water Balance Studies Nadi Catchment at Vaturu

Sept./ Aug.	*CRF*	*R*	*L*	*r.c.*	*R'*	*A%*
1976/77	(3277)	2105	(1172)	(0.64)	(2017)	- 4.2
1977/78	1623	709	914	0.44	663	- 6.5
1978/79	3375	2036	1339	0.60	2098	+ 3.0
1979/80	2074	967	1107	0.47	1032	+ 6.7
Mean	2587	1454	1133	0.54	1452	

Where:
CRF = Catchment rainfall (mm)
R = recorded runoff (mm)
L = total losses (mm)
r.c. = runoff coefficient
R' = predicted runoff (mm)
A% = differences recorded and predicted runoff in per cent.

From the table it can be seen that the catchment runoff and losses (evapo-transpiration and deep seepage) fluctuate with the rainfall: the higher the rainfall, the higher the runoff and the losses. The same applies to the runoff coefficient.

On the basis of the above four years of data it has been possible to establish the following relationship between catchment rainfall and runoff:

$$R' = 0.819\,CRF - 666 \qquad (1)$$

Where: R' = predicted runoff (mm)
CRF = catchment rainfall (mm)

This equation provides a good fit of predicted (R') to observed runoff (R), each predicted value being within 7 per cent of the measured value.

E. LONG-TERM RUNOFF

An attempt was made to update the long term monthly runoff from the catchment using IJzerman's approach (ref. 2), but this had to be abandoned because of the fluctuations of losses with rainfall mentioned above. Because of the paucity of data, it was considered that a new and more complicated rainfall-runoff model, to incorporate this effect, was not warranted.

It was therefore decided to estimate long-term runoff on an annual basis using the simple water balance model (equation 1) derived above. For this it was necessary to establish a relationship between catchment rainfall and rainfall at a long-term remote index station. Nadi Airport was selected as the remote index station. The relationship, derived by double mass analysis of 44 months of observed rainfall totals, was as follows:

$$CRF = 1.68\ NAR \qquad (2)$$

where: NAR = rainfall at Nadi Airport (mm)

Incorporating this equation(2) in equation(1) gives:

$$R'' = 1.376\ NAR - 666 \qquad (3)$$

where: R" = computed runoff (mm)

Applying this equation to Nadi Airport water-year rainfall totals, produces the 37 years of estimated catchment runoff (R") given in table 18.

Comparison of the last 4 years of these synthetic runoff figures to the observed ones (Section D) shows that, with the exception of one-year (79/80), there is a fair correlation between the two. It is expected that the derived figures provide a good first estimate of the distribution of runoff over the years.

In order to obtain an idea of the long term distribution of annual runoff, the predicted figures were plotted on log-probability paper. By drawing a smooth curve through them the following estimates could be made:

Estimated long-term annual runoff distribution
Upper Nadi River at Vaturu

Annual runoff	Exceedance probability in % *1*	*10*	*30*	*50*	*70*	*90*	*99*
mm	(3800)	2800	2220	1910	1590	1100	(500)
m^3/sec.	(4.82)	3.55	2.82	2.42	2.02	1.40	(0.64)

F. LOW-FLOW ANALYSIS

The lowest flows recorded so far are as follows:

Year	*Date*	*Minimum Flow (m^3/sec.)*
1976	3/9	0.173
1977	26/11	0.083
1978	2/10	0.194
1979	18/12	0.105
1980	5/9	0.141

Attempts were made to estimate the frequency of occurrence of these low flows, but this produced no acceptable results since the period of record is too short.

An indication of the low-flow duration can be obtained from the table in Section C.

A useful tool for the prediction of low-flows is the baseflow recession (or groundwater depletion) curve. The curve, which represents the typical withdrawal of groundwater from the catchment after surface runoff has ceased, was derived from various recession segments of the runoff hydrograph and is shown in fig. 8.

It can be expressed by the following equations:

For:

$$Q > 0.3 \qquad Q_t = Q_o\ 0.9755^t$$
$$0.3 > Q > 0.11 \qquad Q_t = Q_o\ 0.9819^t$$
$$Q < 0.11 \qquad Q_t = Q_o\ 0.992^t \qquad (4)$$

Where: Q_t = discharge at time t (in m^3/sec.)
Q_o = initial discharge (in m^3/sec)
t = time (in days)

The above equations can be used to predict the decrease in baseflow over a period of time with no significant rainfall.

G. PREDICTION OF FLOODS

In the absence of sufficient records, a common technique to predict flood peaks and flood volumes is the unit hydrograph method. Since considerable work has already been carried out on this by others (ref. 2 and 3) it is not repeated here.

Instead, an attempt was made to estimate peak flows by way of correlating particular flood and rainfall events and extrapolating the results. Experience gained in other catchments was also taken into account. Although this is a subjective method of approach, it is expected to produce acceptable results as it is based on actually measured events.

The most severe flood on record is that produced by Cyclone "Meli" (28 March 1979), which had an estimated peak flow of 330 m^3/sec. On the basis of the associated rainfall intensities, and assuming a time of concentration of 3 hours, this flood has a return period between 5 and 8 years. Other floods were examined in a similar way.

The above results were compared to those of other catchments taking into account the physical and climatological differences between the catchments. This resulted in the following estimate of floods from the Vaturu Catchment:

	Return period (years) *10*	*50*	*100*
Peak flow (m^3/sec)	380	550	640

CONCLUSIONS AND RECOMMENDATIONS

With more than four years of data available it has been possible to review the hydrology of the Vaturu (Magodro) Catchment and to update earlier hydrological analyses. There are a few significant conclusions and recommendations to be made.

Mean, annual catchment rainfall is now being estimated at 3130 mm, mean annual runoff at 1910 mm or 2.42 m^3/sec. (section E). This latest estimate of long term runoff is about 12 per cent lower than that estimated by IJzermans (ref. 2) but still well above the design capacity of the water supply scheme (1.05 m^3/sec.).

In order to establish more accurately the volume of surplus water available from the reservoir (and its distribution in time), it will be necessary to continue intensive hydrological investigation in the area. It is recommended that provisions be made to ensure a continuation of the streamgauging programme at the dam site.

It is also recommended that one or two secondary gauging stations be established in the main tributaries of the catchment above the future reservoir, and that baseflows at these stations be correlated to the baseflow at the dam site. This, together with the baseflow recession characteristics established in section F, will make it possible to predict minimum dry season inflows into the reservoir – information essential for a combined future water supply and power generation operation of the reservoir.

Finally it should be noted that the estimates of design floods in this report (section G) are considerably higher than those in earlier reports. They exceed the ones in ref. 3 by almost 50 per cent.

References

1. "Nadi and Lautoka Regional Water Supply Scheme – Feasibility Report", Supplementary Volumes IV, V and VI, April 1978, Fawcett & Partners, Consulting Engineers.

2. "Hydrological Studies of Fiji – Investigations for the Nadi-Lautoka Regional Water Supply Scheme" Volume I and II, December 1978, J.L. IJzermans, FAO Hydrologist.

3. "Revised Construction and Spillway Design Flood Estimates for the Magodro Dam, Fiji", February 1980, Institute of Hydrology, Wallingford, United Kingdom.

4. "Fiji Electricity Authority Power Development Programme 1977-2001 – Report on Power Project 3 and Future Schemes", October 1980, Sir Alexander Gibb & Partners, Australia.

Table 16. Details of data used in Vaturu hydrological study

Station name	*Station type*[a]	*Location grid. ref.*	*Type of record*[b]	*Period of record*	*Quality of record*
Nanukunuku (Vaturu)	AWLR	WF710 379	MDD	May 76–Sept. 80	Good record, only 22 days missing.
Nanukunuku (Vaturu)	RR	WF710 379	HR	Sept 76–Dec. 80	Prior to June 1977 incomplete, afterwards fair to good.
Magodro	RR	WF687 410	HR	Dec. 76–Dec. 80	Prior to June 1977 very incomplete, afterwards fair.
Savuanaba	MR	WF703 375	AT	Sept. 77–Dec. 80	Only accumulated totals, some months missing.
Waidamu	RR	WF660 379	HR	Dec. 77–Dec. 80	Prior to April 1978 very incomplete, afterwards fair.
Nadi Airport	RR	WF482 371	HR	Mar. 42–Dec. 80	Very good.
Navilawa	MR	WF625 441	DR	Jan. 72–Dec. 80	Acceptable.
Nausori Highlands	MR	WF637 312	DR	Jan. 71–Dec. 80	Incomplete and suspect.

[a] AWLR = automatic waterlevel recorder; RR = rainfall recorder; MR = manual raingauge.

[b] MDD = mean daily discharge; HR = hourly rainfall; AT = accumulated total; DR = daily rainfall.

Table 17. Monthly rainfall and runoff totals in Vaturu (Magodro) catchment

(in mm equivalent depth)

Month	*1976/1977*		*1977/1978*		*1978/1979*		*1979/1980*	
	CRF	*R*	*CRF*	*R*	*CRF*	*R*	*CRF*	*R*
September	(430)	104	75	10	54	18	192	31
October	(200)	85	68	11	279	56	17	15
November	(155)	78	57	7	269	86	112	16
December	(292)	(127)	122	10	148	94	52	9
January	(637)	(509)	428	201	692	(308)	472	70
February	(508)	(387)	151	135	505	278	470	305
March	(708)	514	206	96	983	709	335	267
April	(187)	159	163	81	229	293	209	140
May	(52)	74	133	59	119	103	5	48
June	4	35	89	41	45	51	73	29
July	11	19	82	34	20	25	79	22
August	93	14	49	24	32	15	58	15
Year	(3277)	2105	1623	709	3375	2036	2074	967

Notes: 1 CRF = denotes catchment rainfall. R = denotes catchment runoff.

2 Values in brackets are estimates.

Table 18. Nadi Airport rainfall (NAR) and estimated runoff from Vaturu catchment (R"), in mm

(September to August Water Years)

Year	*NAR*	*R"*	*Year*	*NAR*	*R"*
1942/43	1397	1256	1962/63	1978	2056
1943/44	1834	1858	1963/64	2204	2367
1944/45	1683	1650	1964/65	2058	2160
1945/46	no record		1965/66	1280	1095
1946/47	(1585)	1515	1966/67	1636	1585
1947/48	1816	1833	1967/68	1646	1599
1948/49	1562	1483	1968/69	1001	711
1949/50	2100	2224	1969/70	1653	1609
1950/51	2130	2265	1970/71	2129	2264
1951/52	1384	1238	1971/72	1907	1958
1952/53	1982	2061	1972/73	2082	2199
1953/54	2260	2444	1973/74	2792	3176
1954/55	2379	2608	1974/75	1817	1834
1955/56	3087	3582	1975/76	2112	2240
1956/57	2345	2561	1976/77	2107	2233
1957/58	1063	797	1977/78	897	568
1958/59	1715	1694	1978/79	1855	1886
1959/60	2574	2876	1979/80	1466	1351
1960/61	1880	1921	–	-	–
1961/62	2015	2107	mean	1876	1915

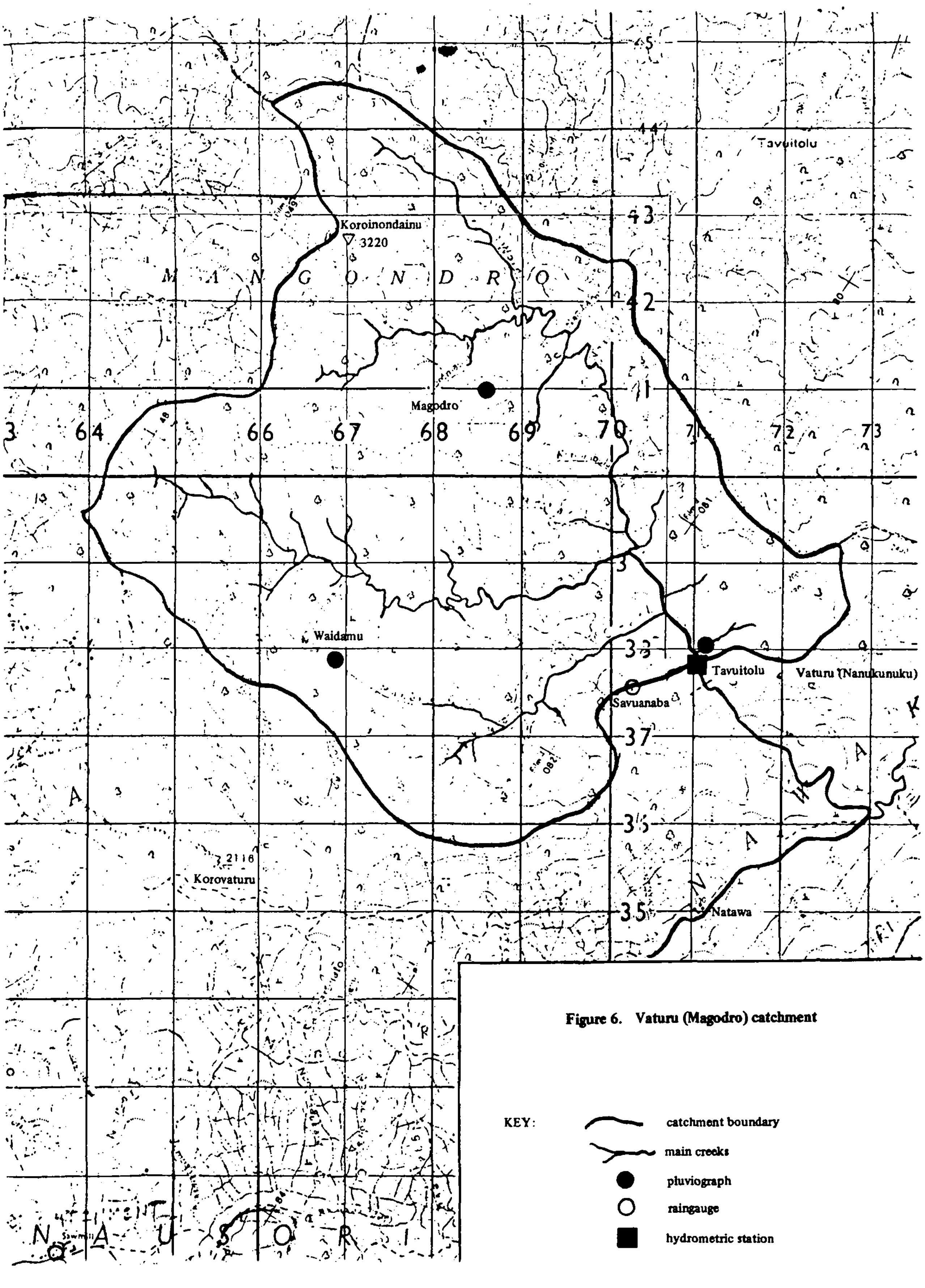


Figure 6. Vaturu (Magodro) catchment

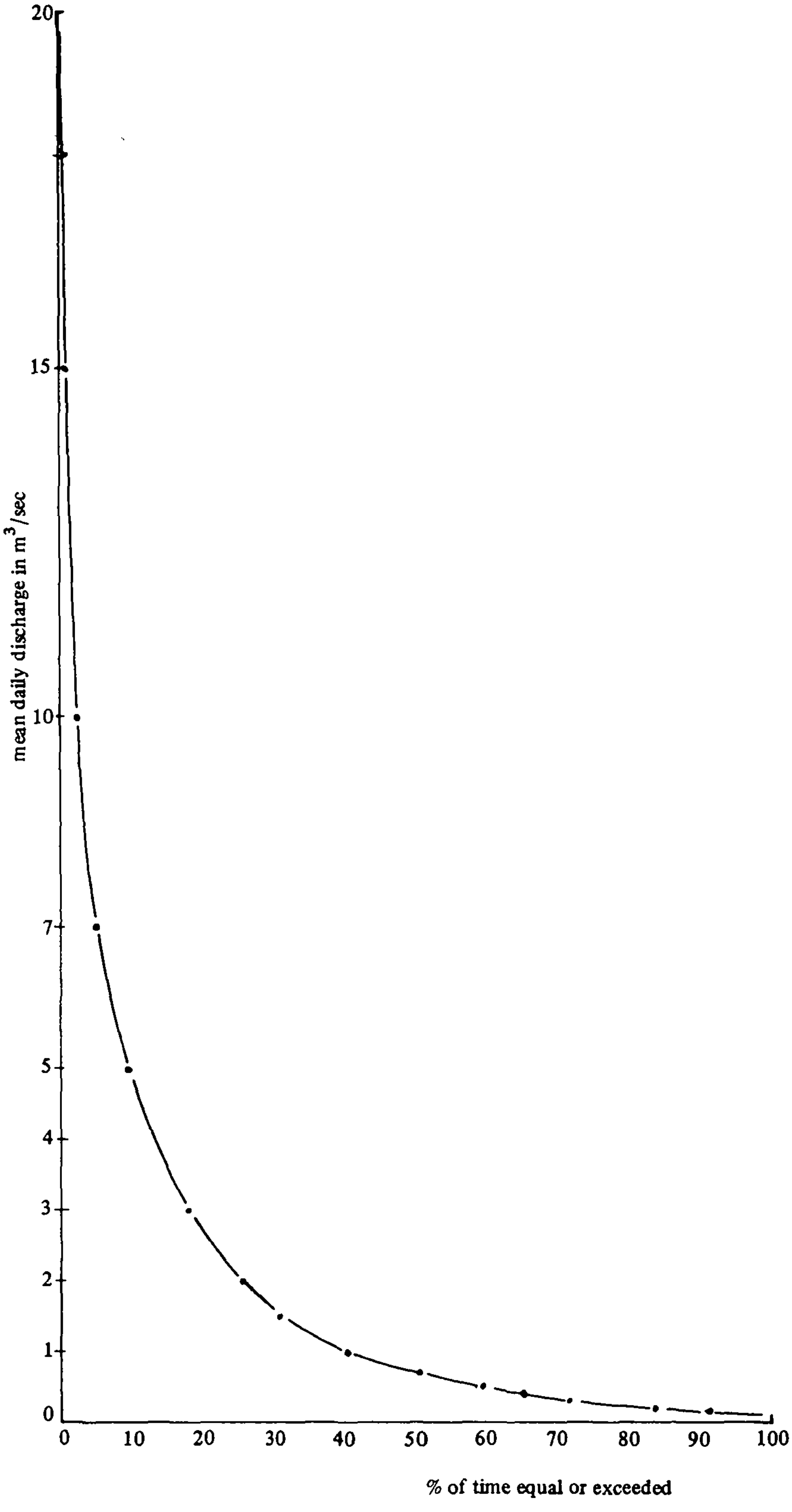


Figure 7. Flow duration curve, Nadi river at Nanukunuku, Sept. 1976 – Aug. 1980

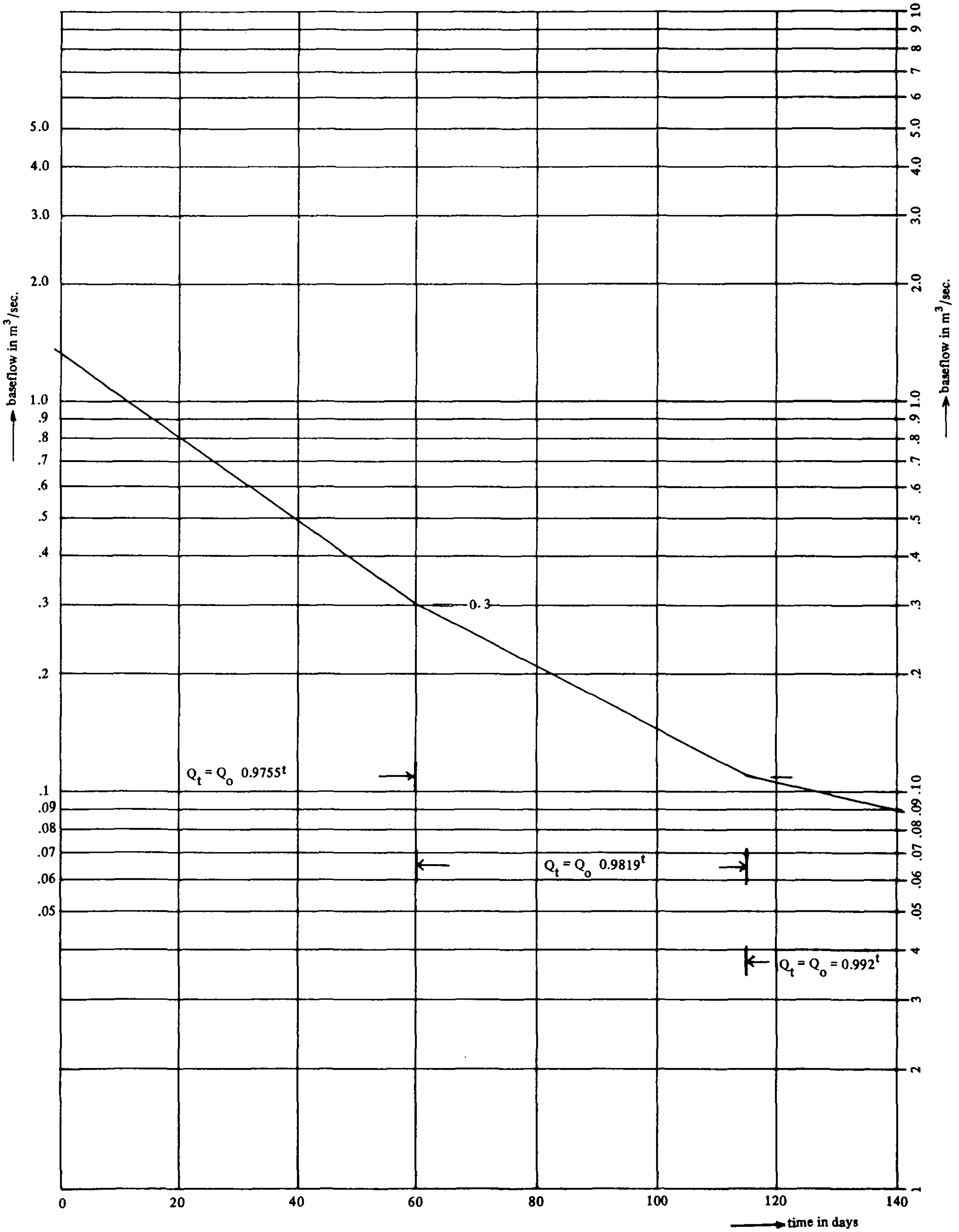


Figure 8. Baseflow recession curve, Nadi river at Nanukunuku

IV. INVESTIGATIONS EMPLOYED FOR DETERMINING YIELD OF THE GROUNDWATER RESOURCES OF TARAWA ATOLL, KIRIBATI

INTRODUCTION

Four main groups of islands form the Republic of Kiribati in the Pacific Ocean, with a population of over 58,000 people.

Tarawa atoll located at 1° 30'N, 173° 00'E, has the largest population of any of the islands with 17,920 in urban South Tarawa and 2,230 in North Tarawa (Harrison, 1980). The atoll consists of over 24 islands with a total area of 30.6 km^2 as shown in Figure 9.

Mean annual rainfall at Tarawa, recorded at the Betio meteorological station for the period 1947-1980 is 1976 mm. The land areas are flat and low-lying, with a maximum height above mean sea level of approximately 4 metres. Tarawa is a typical coral atoll formed on top of an old volcano which rises sharply from the ocean floor some 4,000 metres deep. A series of islands have formed around its rim, although on the western side they are entirely submerged. The lagoon coincides with the original crater and is rarely more than 20 metres deep. From the drilling programme carried out as part of the water resource investigations (C.I.R.L., 1981; Jacobson and Taylor, 1981) it was revealed that the geology of these islands is very uniform consisting of 10 to 18 metres of calcareous sands, gravels and sand-gravel mixtures which overlay an older limestone sequence.

The groundwater that exists on the islands occurs as a fresh water lens floating on the denser sea-water beneath the islands, with its size depending on recharge, width of island, permeability and abstractions. No rivers, lakes or surface reservoirs exist on the atoll and water supply comes from roof catchment areas, reticulated lens water, well water and tankers.

The urban Tarawa water supply is piped from galleries to communal tanks and other than rainwater is the only acceptable potable water supply. Supplies from the wells are relatively contaminated having high coliform counts due to the close proximity of septic tanks and cess pits (Department of Housing and Construction, 1981). It can be assumed that now a waterborne sewerage system is being provided an improvement in water quality will occur. The following discussion will outline the work undertaken to gain a thorough understanding of the groundwater resources of Tarawa to enable safe development of them.

By T.M. Daniell, UNESCO Consultant, Principal Engineer, Hydrology and Water Resources, Water Supply and Sewerage Division, Commonwealth Department of Transport and Construction, Canberra, Australia.

A. BASIC THEORY – THE GHYBEN HERZBERG RELATIONSHIP

The basic theory of fresh water lenses is well documented (Todd, 1959; Chow, 1964; Vacher, 1978a. b). The freshwater lens on an oceanic island floats on saltwater as shown in Figure 10, by virtue of the differences in densities of salt and fresh waters.

By assuming static conditions, a sharp saltwater/freshwater interface simple hydrostatic equilibrium gives –

$$Ps.hs.g = P_f.h_f.g + P_f.h_s.g$$

therefore
$$h_s = h_f \left(\frac{P_f}{P_s - P_f}\right)$$

Where h_s is the depth of the interface below mean sea level, g is gravitational constant, h_f is the height of the water table above sea level, P_s is the salt water density and P_f the fresh water density. The density of salt water is usually 1.025, therefore $h_s = 40 \ h_f$ and this is known as the Ghyben-Herzberg relationship after the original researchers who investigated the phenomenon in coastal aquifers (Ghyben 1889; Herzberg, 1901).

The sole source of recharge to the lens comes from rainfall. Losses occur as follows:

(a) Rainfall is evaporated directly from the ground surface,

(b) Water is transpired and evaporated from the soil zone,

(c) Water flows from the perimeter of the lens,

(d) Dispersion at base of lens.

Where the aquifer material is homogeneous and isotropic and the flow is 2-Dimensional the Ghyben-Herzberg lens has a lenticular shape with the upper and lower boundaries forming parabolas. This resulting characteristic shape is due to the flow of the fresh groundwater towards the island perimeter in response to the hydraulic gradient. The relationships described above assume the fresh and salt water are immiscible and separated by a sharp interface.

However nature's system is a dynamic one with water flowing in and out of the lens and a transition zone of

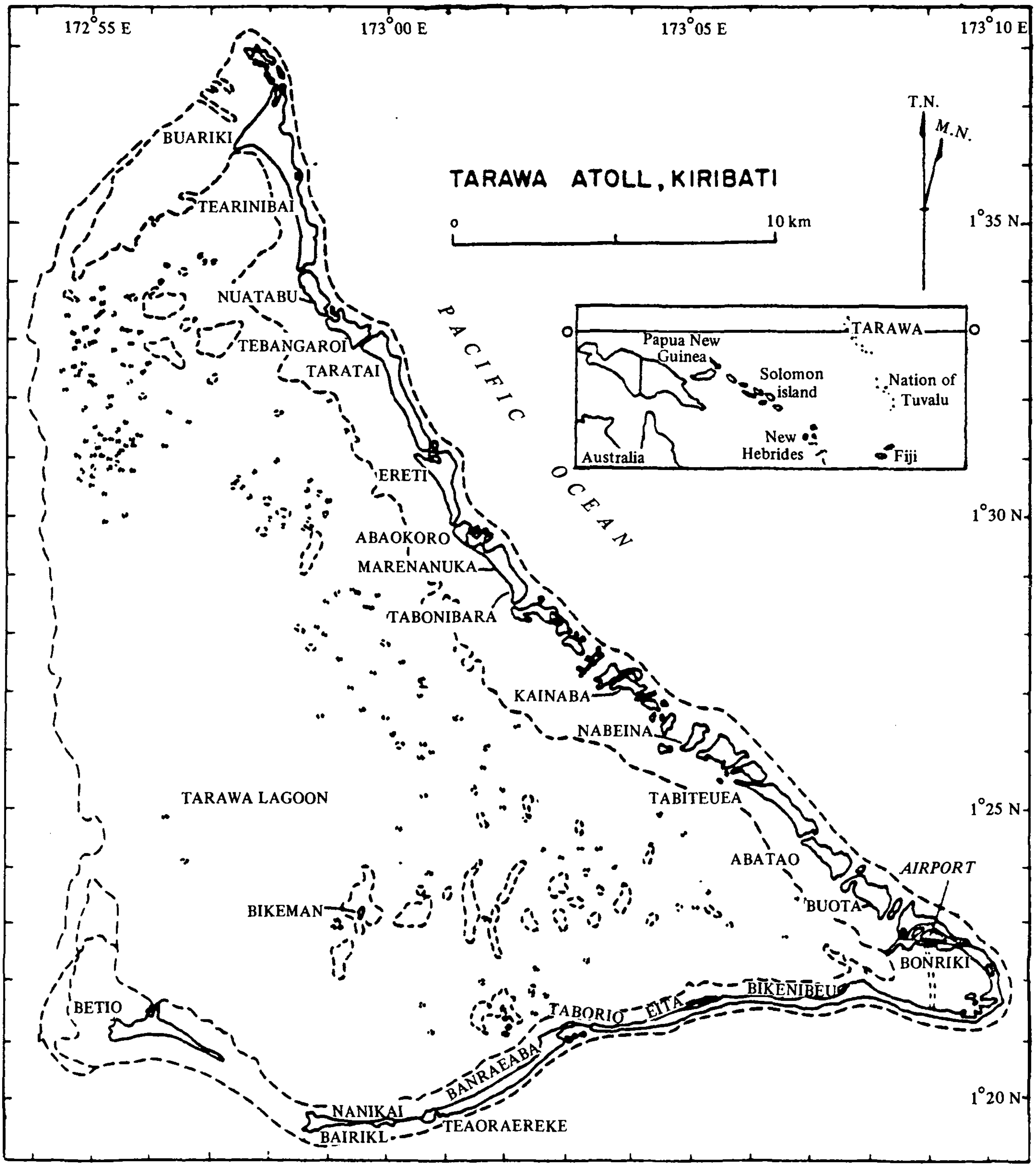


Figure 9. Map of location and islands of Tarawa, Kiribati

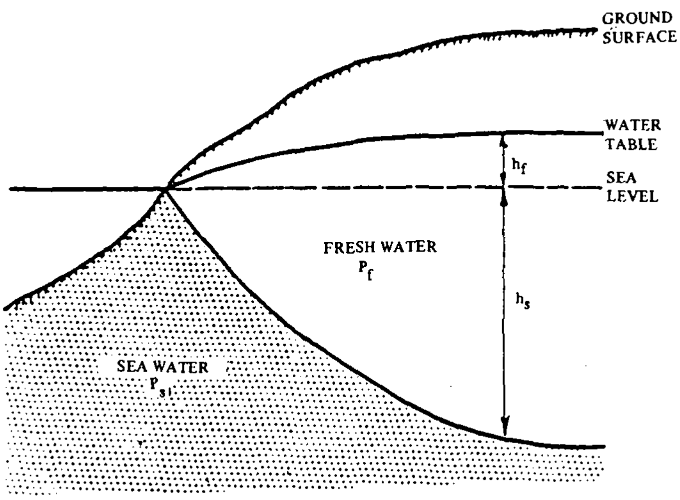


Figure 10. Hydrostatic balance in a Ghyben-Herzberg lens

some width being set up by movements of the ocean tides and fluctuations in recharge. It has been found that in reality that for usable freshwater the effective Ghyben-Herzberg value could be considered to be of the order of 20 to 30.

B. PREVIOUS INVESTIGATIONS

A number of investigations of the water resources in Tarawa and Christmas Islands in the Kiribati group of islands have been undertaken since 1960. Preliminary investigations by Kirk and Grundy (1961) revealed that poor bore and well location, overpumping and deep holes caused saline water to be drawn into the freshwater in Tarawa. Recommendations were made for surveys to be carried out and changes in the mode of operation of pumping from wells to preserve the freshwater lens.

Constantly rising populations on South Tarawa and hence the need for augmentation led to further studies of the ground water resources (Wilton and Bell, Dobbie and Ptrs, 1967; Mather, 1973). These studies culminated in the provision of a reticulated water supply (Dept of Works, 1973 and 1975) followed by further investigations (Wagner, 1977). However a cholera outbreak in 1977 indicated that the available water resources were under stress and in 1978 the Kiribati Authorities commissioned a feasibility study (Richards and Dumbleton International, 1978; Lloyd et al, 1980) of the water resources. From this study further investigatory work was recommended to ascertain more accurately the potential of the freshwater lenses on North and South Tarawa. This work was carried out under the auspices of the Australian Development Assistance Bureau (ADAB) by the Department of Housing and Construction (now Department of Transport and Construction) and resulted in a predesign report – (Department of Housing and Construction, 1981). In this report a scheme of upgrading the rainwater collection systems for larger domestic houses and incorporating rainwater collection from Government buildings into the reticulated system were investigated. It was concluded that while the domestic rainwater system realised a significant contribution the centralised rainwater system suffered from many problems in implementation.

C. ASSESSMENT OF GROUNDWATER LENSES

The parameters that affect the amount of fresh water that is stored in the lenses include recharge, permeability and porosity of the lens material, shape and size of island and abstractions. Water lenses are natural water storages having the advantage of large storage volumes compared to any manmade reservoir that could be contemplated on Tarawa. However there is the disadvantage that the lens leaks and loses fresh water to the sea at the island perimeter and dispersion with salt water at boundary. A delicate balance exists at the boundary of the fresh and salt water, the behaviour of which under various conditions such as tidal movement, high extraction rates and drought periods is not completely documented or understood. In the long term freshwater lenses exist in a situation of dynamic equilibrium with rainfall being balanced by evapotranspiration and losses to the sea. The rate at which water flows to the sea is a function of the depth of the lens, the permeability of the ground material and the shape of the island.

1. Recharge determination

A basic conceptual model is shown in figure 11 of the parameters that are needed to determine recharge and can be described by the following simple balance equation:

$$R = P - E_a - \Delta S_i$$

where R = Net recharge to water lens

E_a = total actual transpiration from unsaturated surface zone and direct transpiration from water lens.

ΔS_i = change in water content in surface zone.

Calculation of potential evaporation was completed by a three step development (Fleming, 1982) using all the available data which included 12 months of solar radiation data, 3 years of vapour pressure and sunshine hours data and 35 years of rainfall and temperature records. Firstly an

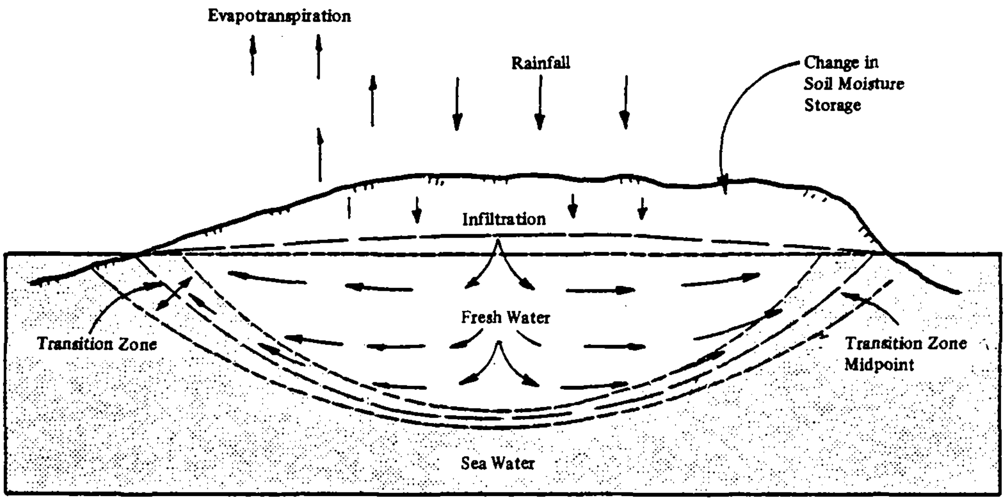


Figure 11. Conceptual model of recharge of Ghyben Herzberg lens

estimation of potential evaporation by the Penman (1956) formula was undertaken and a direct correlation was sought between solar radiation and E_t and sunshine hours and E_t. Secondly the evaporation series was extrapolated back using the full sunshine hours series. This was done through the direct correlation of sunshine hours and E_t. Thirdly the E_t series was extended to cover the full rainfall record. The available data for this period of record included maximum and minimum temperature and rainfall. The range of both temperature parameters was slight and poorly correlated, which left the rainfall record as the parameter for correlation. Figure 12 establishes a relationship between rainfall and E_t using the above information. It must be emphasized that in an oceanic location a strong negative correlation exists between high radiation levels and low rainfall.

The following empirical relationship was established

$$E_t = 115 \text{ for } P > 300 \text{ mm}$$

$$E_t = 115 + \frac{(300 - P)^2}{1286} \text{ for } P \leqslant 300 \text{ mm}$$

To determine the actual transpiration vegetation was divided into two groups firstly, the shallow rooting type and secondly the deep rooting vegetation reaching the water lens.

The relationship in figure 13 was used to determine the actual transpiration as a percentage of E_t for various water contents in the unsaturated zone in which roots are situated. As can be seen from the relationship the maximum transpiration rate only occurs when the unsaturated soil allows it. Deep rooting vegetation was assumed to have 75 per cent of their roots reaching the capillary zone immediately above the water lens so with the existence of a lens then 75 per cent of the vegetation requirements were met, irrespective of the water content in the soil zone. The remaining 25 per cent of the root system located above the capillary zone is dependent on the actual water content of this zone. A maximum transpiration rate of $.8E_t$ was selected for all deep rooted vegetation based on a study of date palms (Borrenbos and Pruitt, 1977). A water balance calculation was then carried out determining the amount of water entering the unsaturated zone through precipitation and being removed by evapotranspiration. When actual water content exceeds 130 mm then the water passes through the upper soil zone and recharge of the lens system occurs.

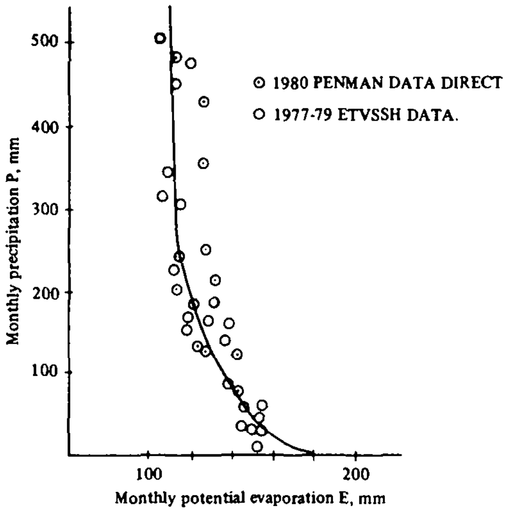
Transpiration through deep rooting vegetation is taken from the lens as negative recharge. A monthly analysis of recharge for the period 1947 to 1980 was done and the annual values of rainfall and actual evapotranspiration are presented in Figure 14.

The resultant 34 year averages were precipitation 1976 mm, actual evapotranspiration E_a 1312 mm and net recharge to the lens of 664 mm.

Methods of estimating average recharge include:

(a) Preliminary estimates using Penman and Thornthwaite type water budgetting techniques (Vacher, 1974; Plummer et al., 1976). It has been later stated that estimates using these techniques are low (Vacher and Ayers, 1980).

(b) Attempts to analyse water-table hydrographs in terms of recharge events (Vacher, 1974, 1978b).



RELATIONSHIP USED
$E = 115$ for $P > 300$ mm
$E = 115 + \frac{(300-P)^2}{1286}$ for $P < 300$ mm

Figure 12. Relationship of monthly potential evaporation and monthly precipitation (adopted from Fleming, 1982)

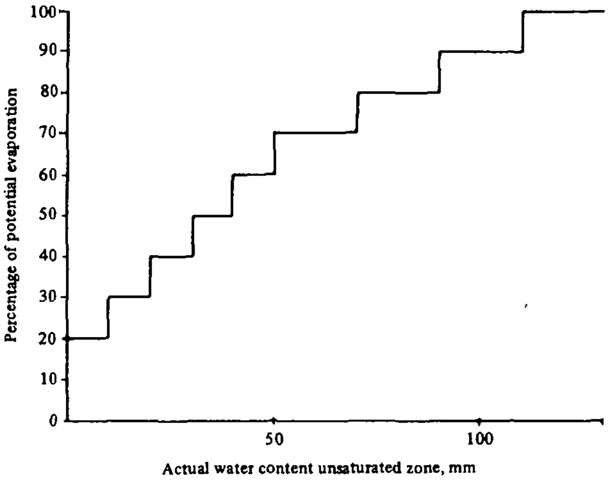


Figure 13. Relationship for determining actual transpiration as per cent of potential evaporation for actual water content in unsaturated zone.

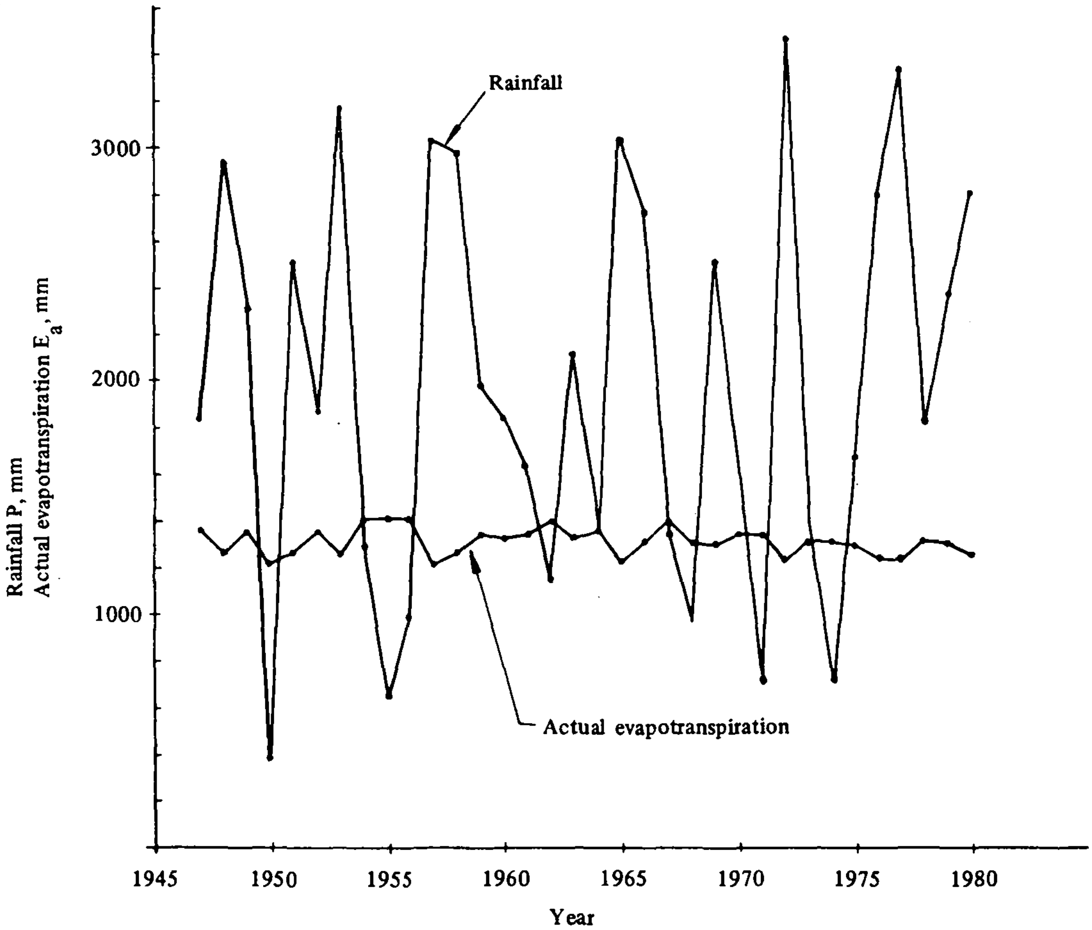


Figure 14. Annual values of Rainfall and Actual Evapotranspiration

(c) Interpretation of the size and configuration of the freshwater lenses and the behaviour of the water table.

(d) Interpretation of the configuration of the water table in the vicinity of extraction sites.

(e) Computer simulation of the water table configuration using estimates of recharge and permeability from (c) and (d) (Hunt, 1979; Vacher, 1974).

(f) Using the chloride concentration of rainfall and fresh groundwater (Vacher and Ayers, 1980).

In the hydrological studies of recharge for Bermuda the recharge has been calculated using (a) – (f) as 25 per cent of the precipitation. For the ground water analysis of Tonga (Hunt, 1979) recharge was estimated at between 25-30 per cent of the average rainfall.

Using a daily model for assessment of recharge on Kwajalein Island in the Marshall Islands group values as high as 50 per cent of the annual rainfall were obtained where as using monthly analysis a figure of 40 per cent was determined (Hunt and Peterson, 1980). During this same period of time 1979/80, the rainfall on Tarawa was above average and recharge was much higher than average.

Mather (1973) assumed an average annual recharge of 254 mm for Tarawa, only 13 per cent of the average rainfall but this was based on estimated transporation rates of coconut trees.

Method (f) is the simplest technique. This independent technique involves the ratio of the Cl^- ion in rainfall to the Cl^- concentration in the freshest part of the Ghyben-Herzberg lenses. For samples of groundwater collected in October 1980 at three different locations (in Tarawa) the following recharge chloride concentrations (Cl^-re) were obtained.

Teaoraereke (No 3 Gallery)	14 mg/l
Bonriki (No 3 Gallery)	13 mg/l
Abatao well	16 mg/l

Rainwater collected at Tanaea had a chloride concentration (Cl_{ra}) of 6 mg/l. Thus

$$\frac{Cl_{ra}}{Cl_{re}} = \frac{6}{14.3} = 0.42 = \frac{\text{Recharge}}{\text{Precipitation}}$$

The average annual precipitation for Tarawa is 1976 mm therefore average recharge = 0.42 x 1976 mm = 830 mm, which appears to be very high. However the range of chloride concentration in rainwater samples collected at other oceanic islands including Bermuda, Norfolk Island, Tokelau and Christmas Island is 1 mg/l to 11.5 mg/l (Dale, 1981).

A number of careful controls need to be undertaken when collecting samples of waters for estimation of recharge by this chloride ion technique.

Rainwater samples should be representative of the water that has been collected from trees or roofs and hence has picked up the accumulated salt particles that is representative of the island surface. Groundwater samples should be taken from the lens at as many locations as possible in the upper fresh water areas. The lowest values of Cl^-ions should only be used in the recharge calculations.

It must be stressed that this method should be used with caution and only as a first approximation.

2. Drilling investigation

In the report (C.I.R.L., 1981) a full description of the drilling undertaken in the study of Tarawa water resources is given.

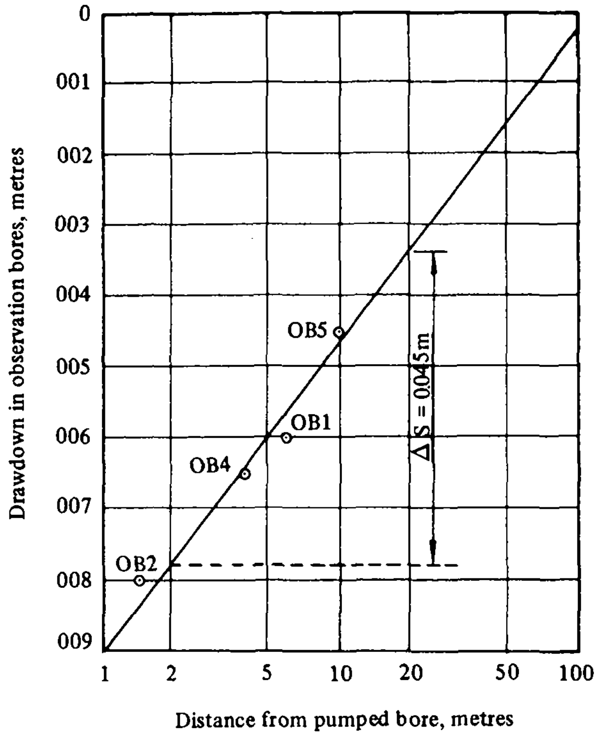
Permeability and Porosity

Little information was known about the variation of permeability with depth and lateral extent so an attempt was made to gain as much information as possible about this parameter. The fact that lenses of significant size exist under the small islands of Tarawa could be attributed to the relatively fine sands and gravels with their relatively low permeability trapping the fresh rainwater and reducing its rate of flow to the sea.

The three methods used to measure permeability were borehole pumping, insitu falling head tests and laboratory testing of collected samples.

Pumping tests on a completed bore in Buariki indicated a relatively high permeability of 200 m/day as shown in Figure 15, but because of the high electrical conductivity of this pumped water, it was concluded that the high flow occurred through fractured limestone at the base of the lens.

Insitu falling head tests were performed at 3 metre depth intervals on 6 of the bores drilled on Bonriki. Results indicated that typical values for the sands and gravels range from 5 to 50 m/day while much greater values, in excess of 54 m/day which was the maximum measurable, were found in the limestone zones. These results were confirmed by laboratory measurement of collected samples (C.I.R.L, 1981). No insitu test for the determination of porosity exists but laboratory analysis showed a typical value would be 40 per cent.



$T = \dfrac{2.3\,Q}{2\pi \Delta s}$ $Q = 630\ m^3/d$ $\Delta S = 0.045m$

$= 5120\ m^2/d$

Where Q is pump discharge, m^3/d,
Δ S is drawdown, m per log cycle;
T is transmissivity

Frigure 15. Buariki pump test, bore 4

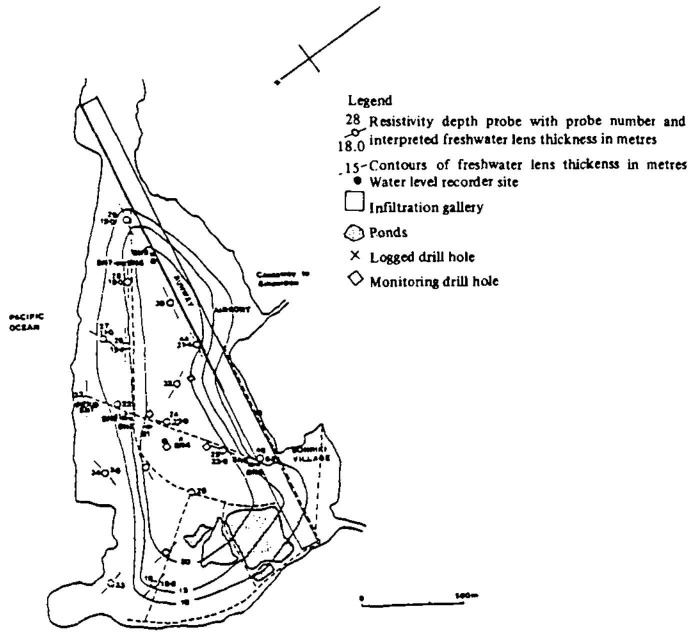


Figure 16. Bonriki resistivity depth contours, recorder sites drill holes and water level

3. Lens configuration

Definition of the boundaries of the fresh water lenses was done by surface resistivity methods and subsequently confirmed by taking water conductivity readings in the boreholes and comparing these results with the results of surface resistivity methods. Resistivity depth probes were carried out using Wenner electrode configuration with an Atlas Copco SAS300 Terrameter. Details of the results and methods of interpretation are described elsewhere (Jacobson and Taylor, 1981). The general model which can be used on these islands ranges from 1–2 metres of dry coral sands and gravel overlying 5–20 metres of sediments saturated with fresh water then merging into saline waters below.

The comparison of resistivity and conductivity measurements also provided a correlation between bulk resistivity of different layers with the water conductivity of samples taken from those zones. Figures 16 and 17 show depth contours of the lens boundary of fresh and saline water.

Figures 18 and 19 show two cross sections across Bonriki giving the variation in electrical conductivity with depth. The electrical conductivity profiles can be easily related to chloride concentrations. The W.H.O. highest desirable level of salinity in potable water is set at 200 ppm (WHO, 1971) which correlates with a conductivity of approximately 1300 µs/cm and the WHO maximum permissible is 600 ppm which corresponds to a conductivity of approximately 3000 µs/cm.

The asymmetric nature of the lens at Bonriki, with the deepest part of the lens located towards the lagoon could be attributed to any or all of the following:

(a) Higher permeability on the ocean side due to the fractured limestone sequence being closer to the surface thus allowing the lens to drain more rapidly to the sea in this area (Vacher, 1978a).

(b) Increased recharge in this area due to the clearing of coconut trees thus virtually eliminating direct evapotranspiration from the lens.

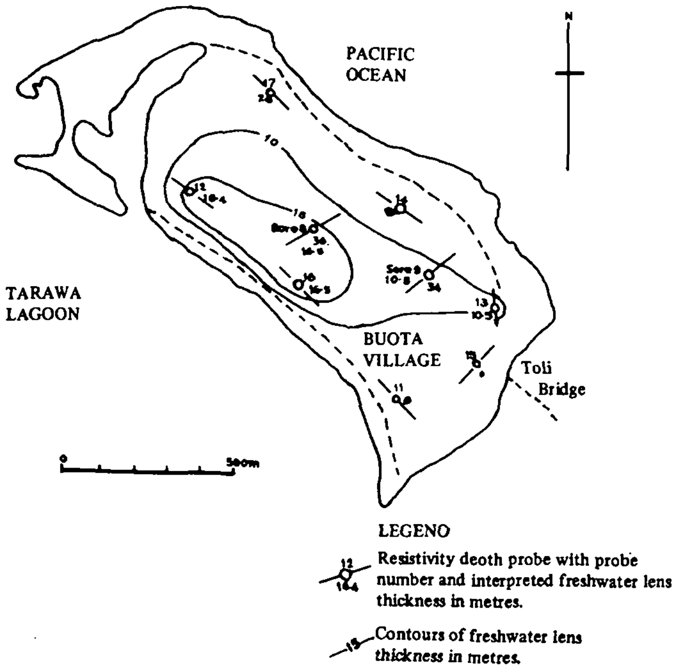


Figure 17. Buota – Resistivity Depth Contours

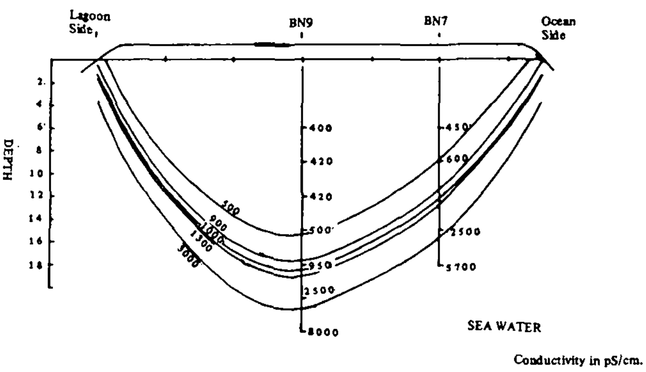


Figure 18. Bonriki – cross section through Bores BN7 to BN9 and electrical conductivity profiles

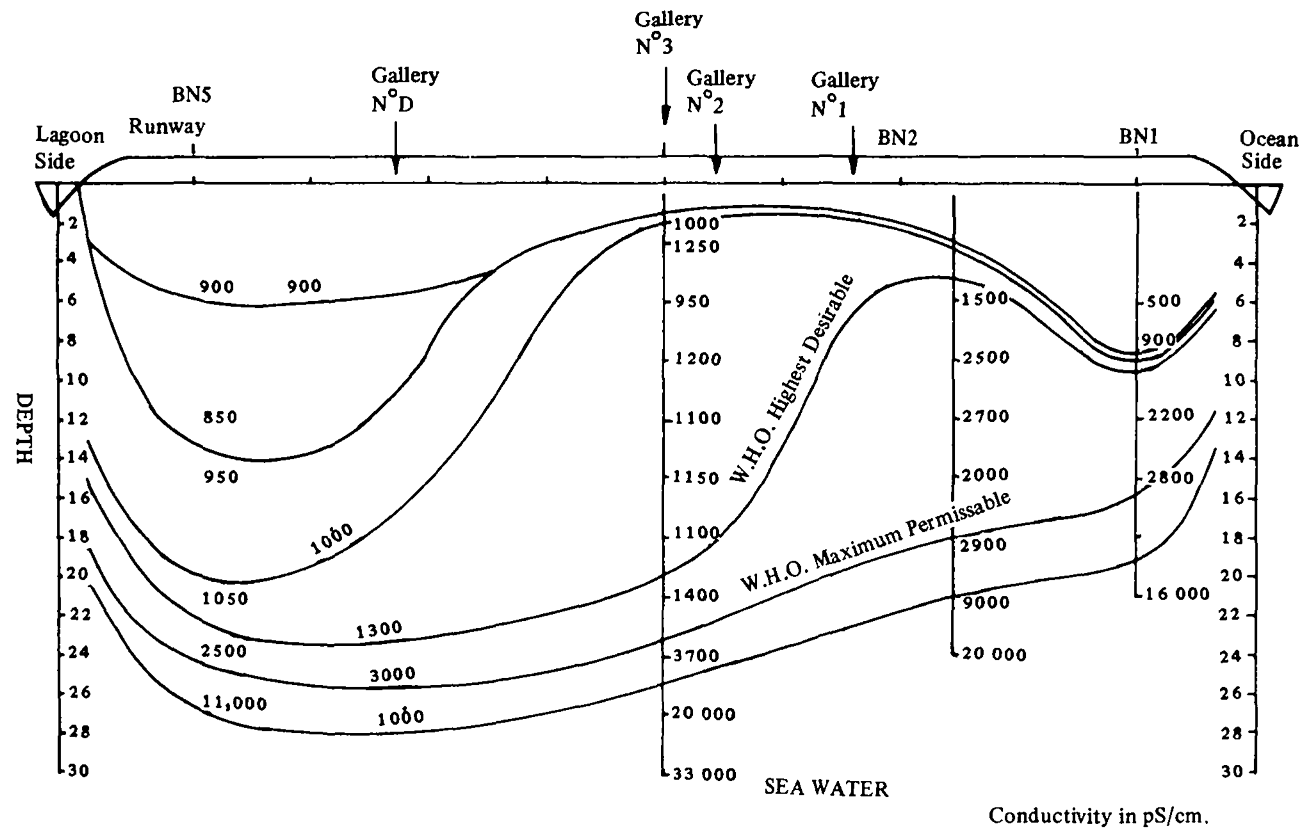


Figure 19. Bonriki – cross section through bores BN1 to BN6 and electrical conductivity profiles

(c) Majority of extraction from lens occurring on ocean side.

(d) Different amplitude of tides from ocean to lagoon causing groundwater to move to the lagoon side (Urish, 1980) but this however does not appear to be the reason at Bonriki.

4. Estimation of safe extraction rates

It can be seen from the lens configuration shown above that procedures of extraction of the available groundwater should be developed to avoid severe intermixing of lens and seawater. Intuitively it has been felt that long-term yield of the lenses should be matched to the long-term recharge. Mather (1973) even inferred that abstraction was negative recharge, which it would be if there were an infinite number of infiltration galleries. In Tarawa, where there is a relatively high recharge value the transition zone between fresh and saline water is narrow compared to that at Christmas Island where recharge is much lower. Extraction methods should therefore be such as to attempt to evenly withdraw water from the whole of the top of the lens in an attempt to avoid upsetting the balance that exists between the fresh and the more dense salt water beneath. A minor case of operating inadequate extraction methods appears to have occurred on Bonriki where the transition zone of higher salinity water has widened under the areas of extraction. Mathematical modelling of the lens was used to enable a quantitative assessment of how the lens was used to enable a quantitative assessment of how the lens would behave under extraction. The use of mathematical models to describe lens behaviour is not new.

Hantush (1968), Collins (1976), Fetter (1972), and Anderson (1976) have considered the lens problem and developed analytical and numerical model solutions. The latter two models were used to predict the response of water levels to recharge patterns on the South Fork of Long Island. A model was developed for analysis of lenses on Grand Cayman Island in the Carribean (Chidley and Lloyd, 1977). A computer programme was written based on this model to solve the unsteady flow in the fresh water lenses on the islands in Tarawa.

5. Modelling Assumptions

A few basic simplifying assumptions of the lens configuration needed to be made to enable modelling of the lens.

(a) A sharp interface occurs between the fresh and salt water boundary at the base of the lens.

(b) The sea is tideless and not affected by barometric pressure variation or alternatively the freshwater lens simply floats on the sea moving with its motion with no affect on the internal hydraulics.

(c) The permeability of the material in which the lens floats has a similar permeability in all directions but the permeability can change from point to point (i.e. nonhomogeneous but isotropic).

(d) Pressure distribution in the lens is hydrostatic.

(e) All natural flow from the freshwater lens to the salt water surrounding it occurs at the perimeter.

(f) A Ghyben-Herzberg type of relationship holds in that the elevation of the surface of the lens above the sea level datum is a fixed proportion of the depth of the lens below this datum. (A constant value of 30 was used in the subsequent analyses).

6. Analysis of lens

The following parameter values were used in the lens analysis.

(a) A value of 13 m/day was used for the permeability. This value was typical of the values determined from the various methods used to measure this in the field. Thus the selection of this value tends to be confirmed by the fact that the model predicts a depth of lens in 1980 very close to the depth actually measured during the drilling programme.

(b) Recharge was determined as discussed in Section 1.

(c) A value of .3 was used for the specific yield based upon 75 per cent of porosity.

(d) Generally the grid size for analysis was taken as 100 m x 100 m. Because second order terms are ignored in the derivation of the response equation, this leads to some errors in the depth of the lens adjacent to the perimeter.

After initial calibration, the lens was again modelled for the 34 years of record starting with the known depth of lens as measured in 1980 and with a total extraction rate of 750 m^3/day applied to the nodes as shown on Figure 20. The predicted response of the Bonriki lens to this extraction rate is shown on Figure 21 which is compared to the response that would have occurred if no extraction had taken place. It is seen that the depth of the lens drops

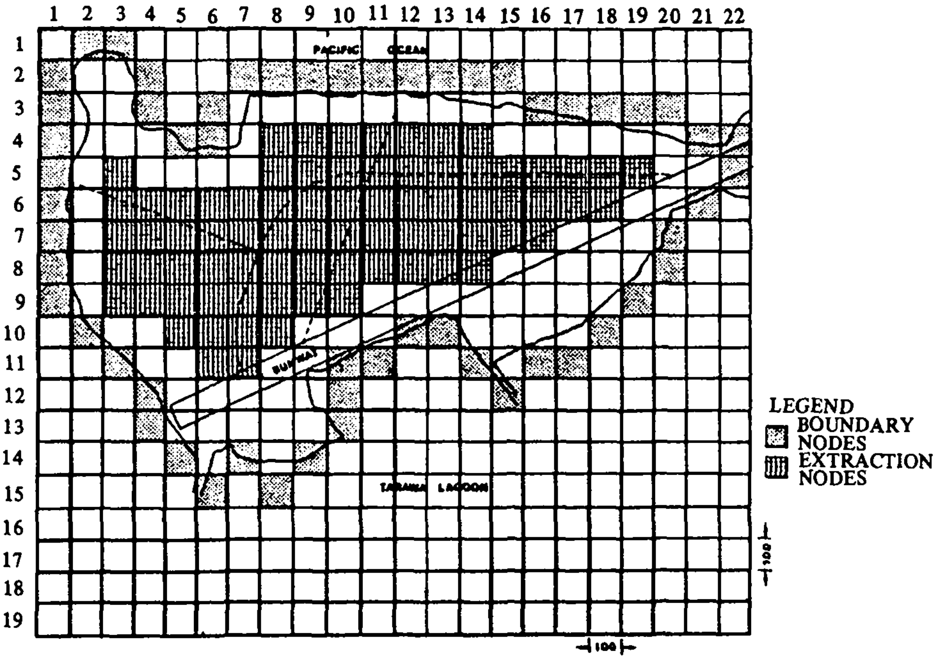


Figure 20. Bonriki – nodal layout and extraction points

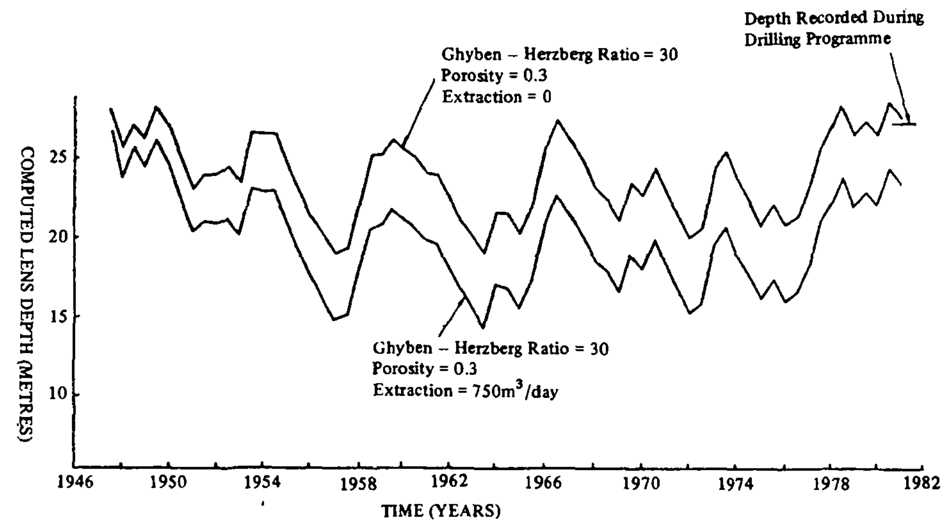


Figure 21. Bonriki – computed depth of freshwater lens assuming sharp interface

rapidly after extraction commences but tends to move to a new equilibrium position around which it fluctuates in response to rainfall variation. From this analysis extraction rates of this magnitude would appear to be easily managed.

7. Predicted long term yield of lenses

Predicted long term safe yields of the lenses examined in Tarawa are shown below, although higher rates could be extracted for short periods.

Bonriki	750 m^3/day	8.7 l/sec
Buota	250 m^3/day	2.9 l/sec
Teaoraereke	150 m^3/day	1.7 l/sec
Abatao	200 m^3/day	2.3 l/sec
Tabiteuea	150 m^3/day	1.7 l/sec
Total	1 500 m^3/day	17.3 l/sec

The analysis performed possibly overestimated safe yield as it ignores the effect of widening of the transition zone during extraction. By assuming that a Ghyben Herzberg relationship holds then it is in fact assuming that the transition zone narrows.

D. FUTURE MONITORING AND MODELLING

1. Monitoring

Monitoring of the response of the fresh water lens to extraction and fluctuation in recharge patterns is an essential requirement in a ground water resources study of this type in which safeguarding the supply and maximizing withdrawals has to be balanced. Salinity of the galleries are to be measured weekly and recorded in pumping logs. Salinity in the drilled bore holes which have had tubes inserted in them to enable sampling at various depths of the lens are to be measured at least at 6 monthly intervals to enable assessment of behaviour of the lens. These results are then to be used for recalibration of the mathematical model.

2. Modelling

The precise behaviour of the transition zone should be modelled to assess what influence the rate of natural dispersion of the salt water into the freshwater, tidal fluctuations and the flushing mechanism at the perimeter have on the overall assessment of yield from the lens.

E. PROPOSED METHOD OF EXTRACTION

With the proposed increased extractions from the Bonriki lens (DHC, 1981) and if the present extraction system and operation practice were continued then severe disruption to the lens could occur. Figure 22 shows a typical arrangement of infiltration galleries that would

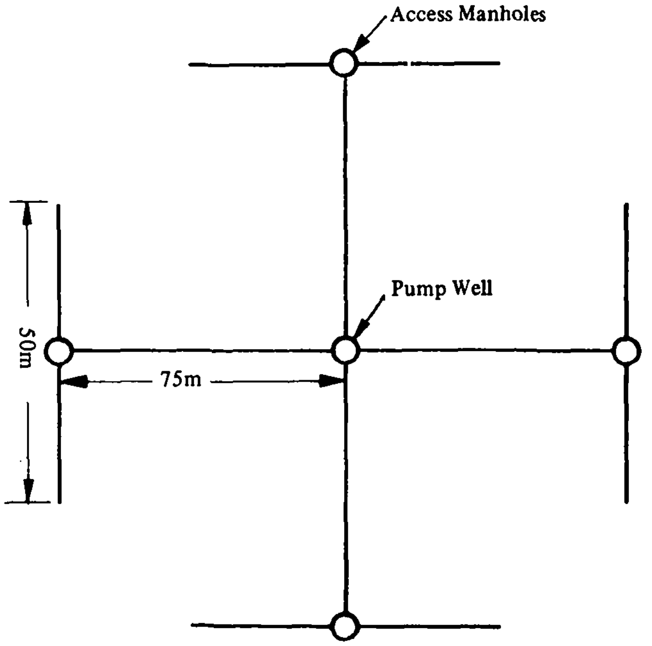


Figure 22. Plan of typical arrangement for infiltration galleries

enable higher yields from the lens with less chance of disrupting it. The extent of the infiltration galleries has been increased so that the drawdown due to pump extraction is greatly reduced from that which presently occurs in the existing galleries. It is envisaged that with expansion of the collection facilities at Bonriki, Buota and Teaoraereke provision of 1150 m^3/day could be achieved compared with the present scheme which supplies approximately 150 m^3/day of potable water and about 300 m^3/day of highly polluted groundwater.

CONCLUSIONS

It has been shown that to define the water resources of oceanic islands and propose methods of safe use of them it is desirable that a number of different investigatory techniques need to be employed. This paper has outlined how the present lens geometry in some of the islands in Tarawa Atoll was defined employing both resistivity and drilling methods. All available meteorological information was used in estimating recharge and then using a computer model the behaviour of the lens system was simulated. The drilling programme yielded information on the parameters such as permeability and porosity which affect the flow and storage of water in the lens as well as enabling sampling whereby the hydrochemistry of the lens water at various locations could be defined. Safe extraction rates and the need for methods of extraction to minimise the effect on the lense equilibrium resulted from the computer model analysis. It was found that the lens systems investigated were capable of yielding significant quantities of water by employing expanded infiltration gallery systems to reduce drawdown and disturbance to the lenses.

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V. INFORMATION AND INVESTIGATIONS REQUIRED FOR ASSESSING WATER RESOURCES FOR WATER SUPPLY ON ISLANDS

INTRODUCTION

Water resource investigations generally follow a number of steps once there is a designated need for a water supply to be constructed (e.g. a population centre, agricultural or commercial activities).

The following steps are usually performed depending on the availability of funding and identified need of the users:

1. Preliminary investigations and report including
   a. Data collection
   b. Reconnaissance
   c. Review of reconnaissance results
   d. Preparation of preliminary report
   e. Review of preliminary report results and recommendations
2. Confirmation of water resources and recommendations
   a. Continuation of data collection
   b. Water resource confirmation – surface water
   c. Water resource confirmation – ground water
   d. Formulation of water resource development programme
   e. Report on usable sources and preliminary schemes with economics of projects
3. Detailed design and construction of recommended schemes

   Within the preliminary reconnaissance there can be an implementation proposal for an improvement of an existing water supply. This can prove to be extremely beneficial for a community that is in urgent need of water but temporary measures should only be considered if they are inexpensive and unlikely to break down.

By T.M. Daniell, UNESCO Consultant, Principal Engineer, Department of Transport and Construction, Australia; and A. Falkland, Senior Engineer, Department of Transport and Construction, Australia.

A. PRELIMINARY INVESTIGATIONS AND REPORT

1. Data collection

a. Introduction

Data collection entails obtaining previous reports on water resources investigations from the various Government Departments, private bodies and educational institutions that use and investigate the water resources and locating the various Department that collect the information of concern. Before any field work is undertaken, every effort should be made to collect all relevant information and review it.

b. Data to be collected

(1) Maps of existing water system, if any, showing locations of facilities

(a) Extraction systems

Wells
Bores
Springs
Infiltration galleries
River or lake intakes

(b) Storage and supply systems

Treatment plants
Pumping stations
Reservoirs
Transmission mains and distribution system
Distribution system

(2) Information on existing water supply system

(a) Types and description of all extraction systems galleries, bores, wells, intakes

(b) Bore and well data

- Size or diameter
- Depth
- Logs, lithologic, electric
- Pump settings
- Water quality and hydrochemistry
- Water table fluctuations
- Drawdown and pump tests

(c) Pump capacities and operating heads

(d) Water quality at various stages in the storage and supply system

(e) Description of water storage and supply including systems: treatment plants, reservoirs, pipelines, etc.

(3) Climate data

(a) Precipitation records including pluviometer records if possible

(b) Temperature of the air and earth's surface

(c) Humidity and evaporation

(d) Wind velocities and direction

(e) Sunshine hours, solar radiation

(f) Barometric pressure

(4) Hydrological data

Hydrologic network
River flows
Tidal fluctuations
River and storage levels
Sediment flows
Analyses of above if available

(5) Present water demand – quantity from existing records by consumer category

Residential
Industrial
Agricultural
Business

(6) Boundaries of supply area

(7) Population concentration maps and demographic projections

(8) Geologic maps

(9) Water level contour maps

c. Review data collected

(1) Establish appropriate area water requirement from population and demand figures

(2) Establish data that is needed to supplement existing data

d. Reconnaissance to verify data and obtain unavailable information

(1) Determine local agencies where additional data may be located and cost of obtaining

(2) Identify local geologic features to be defined from maps and verified in field

Topography
Rock types
Drainage patterns
Geologic history
Geomorphology, physiography

(3) Identify vegetation types as vegetation influences evapotranspiration

(4) Identify existing water supply sources to be visited

(5) Identify areas with potential water sources to be investigated

Streams, rivers, lakes

Springs – seepages

Areas for ground water abstraction: wells, bore fields, infiltration galleries

2. Conducting reconnaissance

a. Examine existing water supply sources

(1) Determine seasonal yields from all ground water extraction systems (e.g. bores, wells, infiltration galleries)

(2) Determine seasonal yields from all surface water sources (e.g. rivers, springs, lakes)

(3) Measure as needed to verify information

(4) Check pump nameplate data

(5) Examine existing operating procedures

(6) Talk to local officials about seasonal variations of demand and obtain data if possible

b. Examine other potential water sources:

(1) Determine seasonal yields – from springs, lakes, rivers, availability as new sources

(2) Investigate other existing bores and extraction systems that could be used as a source to satisfy demands. Examine seasonal yields, logs, levels, depths, sizes and availability as new source.

c. Determine if simple inexpensive measures are possible to improve the existing and/or develop potential water sources. Such measures could be included in an immediate improvement programme

d. Examine local geologic conditions and conduct preliminary geologic mapping. Determine and/or verify

(1) Existing formations and rock types

(2) Potential aquifers present

(3) Geologic history related to potential aquifers

(4) Regional physiographic features

(5) Area structural features (e.g. faults, dykes, fractures)

(6) Areas and conditions of potential aquifer recharge

e. Collect and evaluate additional data required to confirm new surface water resources

(1) Velocities and flow rates (measure if necessary)

(2) Water quality and sediment samples

(3) Stream bed or spring features

Depth
Width
Flood levels
Potential erosion

(4) General feasibility of the potential sources

(5) Users of the source e.g. town water supply, irrigation, power station cooling, hydroelectricity

f. Collect and evaluate additional preliminary basic hydrogeologic data to clarify relationships of geologic features with ground water occurrence, movement, and quality

(1) Water levels in representative local bores and/or wells

(2) Field discussion with well and bore owners or operators and local officials to determine apparent regional water level fluctuations

(3) Flow rates and specific capacity characteristics of one or more of the wells, bores, infiltration galleries

(4) Water quality samples of bores and wells

(5) Geologic features and conditions pertaining to regional and local ground water occurrence and movement

(6) General feasibility of potential sources

(7) Geophysical surveys (e.g. electrical resistivity, seismic refraction) in areas of potential ground water

3. Reviewing reconnaissance results and preparing preliminary water resources report

a. *Introduction*

The preliminary water resources report should identify the sources for further investigation, eliminating those sources that are considered to be unsuitable. Recommendations should be included on the kind of data collection systems needed and where these measuring stations should be located and the reasons. The investigation procedures for ground water schemes are usually more expensive than for surface water schemes.

b. Review data and results of observations, mapping, and measurements for report

(1) Surface water resources

Determine available surface sources which may be investigated further for possible development, and those which are unsuitable for consideration for development

(a) Select for investigation

(i) Sources without obvious feasibility limitations of distance, accessibility or other physical conditions

(ii) Sources with reliable year round flows and/or suitable dam/weir sites

(iii) Sources with suitable water quality including physical, chemical and bacteriological parameters

(iv) Socially acceptable and legally available sources

(v) Sources feasible within reasonable budget limitations

(b) Eliminate from further investigation

(i) Sources too distant or too small to be economically developed

(ii) Sources having unreliable or insufficient seasonal flows

(iii) Sources having excessive variations in water quality through time

(iv) Sources with water rights problems

(2) Groundwater sources

Determine which ground water sources may be investigated further and considered for future development, and those which should be eliminated from further consideration

(a) Select for investigation

(i) Sources within reasonable distances and physical access for transmission to demand area

(ii) Sources with aquifers of suitable capacity

(iii) Sources having reliable seasonal storage and recharge

(iv) Sources with suitable water quality (physical, chemical, bacteriological) for uses intended

(v) Construction with procurable equip-- ment and materials

(vi) Sources free of social or legal constraints

(vii) Feasible within reasonable budget limitations

(b) Eliminate from consideration

(i) Sources too distant or with poor physical accessibility for transmission to area of use

(ii) Sources potentially low in capacity or seasonal reliability

(iii) Sources with poor or potentially hazardous water quality characteristics

(iv) Sources with difficult water rights problems

(v) Sources unfeasible with available equipment and materials

(vi) Sources which are uneconomical or unfeasible within financial capabilities

(3) Evaluate possibility of combination surface water ground water sources

(a) Combined use of surface water source with groundwater supplement

(b) Combined use of groundwater source with surface water supplement

(c) Geographically split surface-ground water systems

(4) Recommend further investigations required to confirm suitability of feasible surface water sources for supply purposes such as:

(a) Hydrometric network programme including

(i) Identification of gauging station locations

(ii) Types of construction required for recording flows e.g. weirs, float-wells, etc.

(iii) Extra meteorological stations for measurement of parameters such as rainfall, evaporation, etc.

(b) Relationship between streamflow and rainfall

(c) River (or stream) channel characteristics

(d) Erosion potential and likely downstream effects of transported sediment

(e) Water quality monitoring

(f) Existing and future plans for demands on surface waters and prior rights e.g. irrigation, electricity etc.

(g) Social and legal factors

(5) Recommend further investigations required to confirm suitability of feasible ground water sources, such as:

(a) Precipitation and recharge relationships

(b) Water level monitoring of selected existing bores and infiltration

(c) Water quality monitoring of selected wells

(d) Test drilling programme if necessary

(i) Select sites and number of bores to be drilled

(ii) Recommend depth, type and diameter of casing for bores

(e) Test pump existing bores and wells if possible

(6) Recommend further investigation to be carried out if existing is inadequate for assessment of transmission mains and water resources .

4. Review water resources report on preliminary investigations

This review is generally carried out to ensure that the different stages of the preliminary investigations have been thoroughly carried out. The review mechanism allows any investigatory work that has been overlooked to be included in the next stage. It also allows different interpretations to be placed on the data collected.

C. CONFIRMATION OF WATER RESOURCES AND RECOMMENDATIONS

1. Continuation of data collection

The data collection programme should be intensified at this stage acting upon the recommendations from the preliminary report. The activities that can be included here are shown in Section A.1.b. It is necessary to obtain the most current information possible. The confirmation of the selected supply sources depends on detailed data collection.

If suitable results are to be obtained from the data collection programme, documentation for performance and schedules of operating procedures need to be supplied to allow the various facets of the data collection programme to be performed. These should be in the form of check lists with accurate and concise operating instructions.

2. Water resources confirmation programme – surface water

a. Set up streamflow and rainfall measurement programme

(1) Prepare specifications and plans for hydrometerological stations

(2) Construct temporary and/or permanent stream gauging facilities

(3) Prepare gauging forms and schedules of measurements and operations and maintenance procedures

b. Set up water quality monitoring programme

(1) Organize sampling programme according to a designated schedule

(2) Identify and contact suitable laboratory to perform analyses of samples. Confirm that sampling programme is within their capabilities. If not, consider temporary laboratory facilities with possible reduction in water quality parameters.

(3) Prepare format for performing tests and reporting test results

c. Establish firm right to use supply source

Meet with appropriate authorities or people (village chiefs etc.) or others to obtain volumes of water allocated on a seasonal basis and the legislated or historical rights to this water

d. Purchase, lease or borrow necessary equipment to enable the programmes of measurement and monitoring to be carried out. This could include the following

(1) Current meter, wading rods, tapes and spares

(2) Weir plates, staff gauges

(3) Water quality test kit

(4) Conductivity meter

(5) Recorders for stream level measurement, and associated consumables (charts, inks etc.)

(6) rain gauge, evaporation pan and other meterological equipment as considered necessary

(7) tool kit for maintenance of equipment

(8) boat

(9) safety equipment

e. Provide resident supervision for programme

(1) Select personnel to perform supervision

(2) Train above personnel as required

(3) Train indigenous people as required

3. Water resources confirmation programme – ground water

a. Prepare plans and specifications for bore drilling programme. Include pumping observation bores and the following details

Diameter
Depth
Type of casing and screen
Well development methods
Test pumping required
Time to perform work

b. Advertise for tenders and awared contract(s) for performing drilling and test pumping

c. Prepare specifications and purchase test equipment if necessary

(1) Pump and motordriver

(2) Borehole logger (actual equipment dependent on expected geological conditions but should include electrical logging capability)

(3) Conductivity meter

(4) Other chemical testing equipment

d. Supervise drilling operations and long bore lithologic, water quality parameters (pH, conductivity, t.d.s. specifications)

e. Design well (locate screen in bore)

f. Conduct well and aquifer testing

(1) Step drawdown curves and recovery curves

(2) Determine permeability and/or transmissivity

b. Take water quality samples for laboratory analysis

(1) Determine a schedule for the no. of samples and at what depths

(2) Determine parameters that samples are to be analysed for

(3) Determine form for reporting results

4. Formulation of final water resources development programme

a. Evaluate confirmation programme – surface water resources

Define usable source and state

(1) Location, yield and security of supply (i.e. design drought)

(2) Water quality expected

(3) Facilities necessary to be constructed to utilize source

(4) Treatment facilities required

(5) Detailed programme for implementing source development to satisfy projected demands, including options of different levels of supply

(6) Cost estimates

b. Evaluate confirmation programme – ground water sources

Define usable bore fields; wells or infiltration galleries

Location
Number and capacity of installations possible
Spacing and diameter of installations
Depths
Size, capacity, heads, and type of drive for pumps
Expected drawdown
Expected water quality
Necessary treatment facilities required
Detailed programme for implementation
Cost estimates

c. Write final report on water resources programme covering all usable sources and an outline of the schemes. Recommendations within this report should cover the further collection of data to allow detailed design of the recommended schemes to occur without undue delay, such as:

(i) Survey information for treatment plant sites, transmission mains, weir etc.

(ii) Hydrometerological data and/or ground water monitoring to enable operating procedures of water supply system to be adopted

(iii) Water quality data to enable treatment plant design and land use policies and legislations to be passed

(iv) Further hydrological studies such as flood studies and sedimentation studies to facilitate locating and design of intake structures or bore fields

C. DETAILED DESIGN AND CONSTRUCTION OF RECOMMENDED SCHEMES

Discussion of this phase of the water resources development will be very limited as the design and construction procedures adopted are dependent on the schemes and countries which they are to be developed. It cannot be overstressed that the monitoring schemes developed during the investigation phase of the project should be continued to allow modifications and development of operation of the final schemes. A review of the extent of what monitoring and measurements are needed to be carried out once the water resources has been developed should be incorporated into the operations manual of the system. The programme of monitoring of both quality and quantity of water would possible be reduced compared to that performed when confirming the water sources.

CONCLUSIONS

A format and check list of operations in performing a comprehensive water resource investigation for water supply has been presented.

The framework indicated in this paper will enable a thorough investigation of the water resources to be undertaken albeit depending on the available funds.

The assessment of the various options available for different levels of supply to satisfy different demands should be performed from supplying water only for drinking or supply of water for both drinking and sanitation.

The need for collecting water resources data has been identified to enable correct decision to be made on augmenting a water supply system and operating it.

The major thread running through the various steps of the indicated investigations and reports is the continuing water resources data collection programme.

VI. SOME ASPECTS OF WATER RESOURCES PLANNING AND MANAGEMENT IN SMALLER ISLANDS

INTRODUCTION

Island countries have special problem as a result of their physical features, among them isolation, high population density, scarcity of resources such as land, water, mineral and energy, and exposure to natural disasters such as volcanic eruptions, hurricanes and tidal waves.

Prior to independence or self-government, many of these island countries had their entire economy depending upon the export of limited amounts of tropical cash crops and limited amounts of tourism. Following political independence, the need was recognized for these countries to upgrade their level of economic self-reliance, especially in food production and the development of local resources.

In its resolution 3338 (XXIX) on Developing Island Countries, the General Assembly during its 23rd plenary meeting (17 December 1974) called upon the Secretary-General "to take effective measures towards meeting the needs of the developing island countries in accordance with the Programme of Action of a New International Economic Order".

The United Nations Secretariat and especially the services in charge of technical co-operation activities, have assisted developing island countries to improve their social and economic conditions. The water resources sector has received particular attention as shown by the activities of the United Nations in this field (Topic I).

The remarks which follow have been drawn from the experience of the Water Resources Branch of the Natural Resources and Energy Division through such activities.

A. WATER RESCOURSES AVAILABILITY

The availability of fresh water in small islands is dependent upon the abundance and time distribution of rainfall and also upon the storage potential above or below ground. Storage capacity is dependent upon the presence of specific geological and topographical features.

The presence of perennial rivers, or large springs, is the result of exceptionally favourable geological and topographic conditions and is not a frequent occurrence. In Dominica (Caribbean), some 300 watersheds have been identified which result in steep topography, moderately pervious rocks and frequent heavy rains; in the Pacific a similar situation is found on the major islands of Fiji and Samoa and also on Ponape in Micronesia.

The building of storage dams to impound substantial quantities of water is dependent upon favourable topographic conditions, which are not met in low-lying islands nor in volcanic islands made of very pervious rocks.

By R. Dijon, Interregional Adviser, United Nations Department of Technical Co-operation for Development.

Significant groundwater storage is available in islands made of porous, but not too permeable, rock material such as sandstone, and porous non-karstic limestone (Malta, Barbados).

The least favourable storage conditions are encountered in low-lying limestone formation islands, especially the coralline atolls. Raised atolls (Niue, some islands of the Tuvalu group) and vast low-lying limestone islands such as the Bahamas, the Turks and Caicos, the Caymans, have better potential, but also greater water requirements.

Due to limited storage possibilities, the relationship between rainfall and water resources availability is much closer in small islands than in other island situation. On the basis of rainfall abundance and distribution, water resources problems in island environments may be classified:

1. Minimal, if rainfall is abundant, as in the case of the tropical-equatorial humid climate of the equatorial type with several rainy periods throughout the year (Ponape, Truk);
2. Moderate, with periods of crisis if the climate is of the tropical type with one main rainfall season and a relatively long "dry season" (Bahamas);
3. Serious, if the climate is of the subtropical (arid) type, as in the case of the Cape Verde Islands at the latitude of the Sahelian sub-saharan zone.

B. WATER RESOURCE NEEDS

In most island countries characterized by dense populations and high birth rates, the accession to independence or internal self-government has generated great hopes among the population for the improvement of living conditions. Water demand has increased significantly in all sectors of the economy, following the drive of these countries towards economic self-sufficiency. Competition has developed for the limited water resources available between urban communities, rural communities, tourism (one of the major sources of income in tropical islands), newly established rural repair industries, on processing or chemical agro-industries (sugar, oils, copra) and subsistence agriculture.

While such a situation is not uncommon in many areas of the world it has reached crisis proportion in a number of islands, as a result of the fact that need far exceeds available water resources. Decisions should be made for the allocation of water to the various sectors, at least over the medium-term with periodic adjustments envisaged. Some island countries such as Barbados and Singapore, have developed sophisticated water plans. All island countries are in great need to develop detailed plans for the supply and use of water. The implementation of such plans will require that:

1. An assessment of water resource potential be made;
2. Safeguards for the conservation of water resources be established;
3. Appropriate technologies for the supply and handling of water resources be selected;
4. A reasonably accurate evaluation of the costs and benefits of water supply be made; and
5. An appropriate institutional framework be established.

In a small island context the attainment of these intermediate objectives faces a number of difficulties.

C. ASSESSING WATER RESOURCES POTENTIAL

1. Groundwater

The proximity of the sea has considerable impact on island water resources through the movement of the tide and sea water intrusion through ionic diffusion into coastal aquifers.

Recently, hydrogeologists have developed new models to study the fresh water/saline water equilibrium in coastal areas,[1] with a view to optimizing the exploitation of the fresh water lens. While such models are a useful contribution, their reliability cannot be assessed fully as a result of the difficulties encountered in data collection. The "interface" concept should not be taken too literally. Its basic interest lies in expressing the condition that there are areas of fresh water and salt water with brackish water in between. However, the image of a regular, moderately thick, continuous transition zone would be misleading. In atolls and other low-lying limestone islands, the "fresh water" lens is pellicular, and not necessarily continuous while the transition zone, with increased salt concentration down to salt water, is quite thick. Any significant extraction of fresh, or brackish, water from the system may complicate considerably the pattern of distribution of fresh and brackish water, both horizontally and vertically. Such is the case in karstic islands where insulated

[1] Wheatcraft, Stephen W. and Buddenmeier, Robert W., 1981, "Atoll Island Hydrology" in *Ground Water*, May-June 1981 and Yusuke Kishi and others in the *Journal of Hydrology*, 58, 1982, Elsevier Scientific Publishing Company.

pockets of fresh water floating upon a variably saline environment may be found inland. Moreover, it may happen that the "interface" situation is disrupted to the point that the aquifers include bodies of fresh water of various dimension between transition zones of various concentrations, the situation changing rapidly according to levels of groundwater extraction and rapid recharge following periods of rainfall.

The difficulties encountered in the observation of the interface are even greater – in high-rise islands. Due to adverse topographic conditions, it is not possible to drill observation wells which would allow the observation and the monitoring of the interface at some distance from the coastal area. The movements of the tide complicate further the observation of the "interface". It is likely that for a long period of time coastal aquifers will be a controversial subject in hydrological studies.

2. Surface water

Surface water is available only in high-rise islands of significant extent. In many cases the fragmentation of the run-off patterns into a great number of small hydrographic basins (300 in Dominica – many of them having an area of only a few square miles) does not allow for easy and economic assessment of surface water resources.

By and large, water resources studies in islands are hampered by the lack of meteorological data and the considerable variations of the rainfall distribution over space and time, which does not allow for extrapolation of results; each island represents of single complex hydrological system of its own.

It, therefore, appears that hydrological and hydrogeological studies in small islands will be difficult and costly if reasonably accurate and reliable results are to be achieved. In many cases, island countries do not have the necessary resources at their disposal to carry out such studies.

D. ESTABLISHING SAFEGUARDS FOR THE CONSERVATION OF WATER RESOURCES

Traditionally, in island environments coconut water, ground water, rainwater and spring and river water are the liquids utilized for drinking and cooking.

1. Groundwater

In the fragile environment of small islands, ground water resources are particularly threatened by contaminants, especially in atolls.

Shallow wells in porous limestone, or sandy formations, are quite vulnerable to pollution. As far as organic pollutants are concerned, the widespread use of "banjo" toilets with direct outlet on the sea, and the fact that pigs, chickens, and other animals are caged, tied to trees or kept behind walls in outer areas, have contributed greatly to limiting the risks of organic pollution. On the other hand, the use of fertilizers and pesticides represents a major and serious threat.

Sea water intrusion is also a danger. During periods of drought, important quantities of fresh ground water are lost through evapotranspiration and little or no recharge occurs. The hydrological equilibrium is re-established by salt water replacing fresh water in the aquifers.

Sea water intrusion may also occur if excessive extraction of ground water takes place by means of extended drains, trenches, and motorized pumps.

2. Rainwater

The storage of substantial quantities of rainwater is probably the most efficient and economical way to satisfy drinking and domestic water needs in small island countries. However, the storage of fresh water in cisterns for appreciable periods of time may generate environmental and health risks which have to be kept under control.

The determination of the characteristics of rain collectors and of storage tanks to secure a limited supply during drought periods should be made on the basis of the minimal needs to be satisfied, based on the study of daily, seasonal and yearly rainfall distribution over a period of several years.

3. Spring and river water

The protection of spring and small river catchments against pollution is a difficult if not an impossible task in the generally crowded environment of small islands, particularly if the springs and rivers are public property and are utilized for community water supply. Political difficulties may arise if rules and regulations are enforced which may prevent settlements in catchment areas.

Conversely, river and spring water may be subject to inalienable rights of ownership which do not allow for their rational utilization in the interests of the community.

It has to be recognized that the conservation of water resources cannot be secured without considering the social and cultural values and habits of the people. In tropical islands some population groups have no traditional attitudes for the storage and conservation of water. They have been accustomed to utilizing water in its natural condition and to allow it to flow freely from a gutter, a tank, spring, or creek. It is therefore necessary that the concept of water conservation be assimilated by the populations together with basic concepts of health and hygiene.

E. SELECTING APPROPRIATE TECHNOLOGIES FOR THE PRODUCTION AND HANDLING OF WATER RESOURCES

1. Ground water

In low-lying limestone islands the "skimming" of the pellicular fresh water lens has been traditionally made by means of shallow holes or wells. Recently, systems of drains and trenches have been developed in the Caribbean and the Pacific, and also well-points systems (Bahamas).

Pumping devices must be selected with due consideration given to the economic, social and cultural backgrounds of the communities which they are intended to serve. Due to the frequent isolation of such communities, they should be sturdy and easy to operate and to repair. They should be reasonably resistant to salt corrosion, which is commonly a serious phenomenon in coastal areas.

A wrong choice may result in a quick failure. Water installations may be unused, because people are unaccustomed to seeking water in a new location, or high energy costs may discourage pump use. Vandalism may occur or the installation may fall into a state of disrepair because of mishandling, lack of maintenance, or the impossibility of obtaining spare parts.. A great number of examples may be given of such failures, and also of successes, but no general rule can be established.

In high rise islands, especially volcanic islands, the search for ground water is difficult due to complex geological conditions, the great depth of the water table, the high costs and the complexity of appropriate drilling equipment, the difficulties encountered in field geophysical surveys and in the interpretation of their results. Difficulties are also encountered in drilling in very porous volcanic formations, due to loss of water and air circulation characteristics.

By and large, with the exception of unusually favourable hydro-geological conditions (Barbados), or in larger islands (Fiji, Samoa) ground water resources are not available in important quantities and cannot provide the bulk of the supply. In atolls, ground water should be utilized mainly where conditions of scarcity or emergency prevail.

2. Rain water

In addition to traditional ways of collecting rainwater, modern technologies have recently been developed which use a variety of devices and materials. An in-depth review of most of the technologies now available was made at the International Conference on Rain-Water Cistern Systems which was held from 15-18 June 1982 in Honolulu (Hawaii) on the initiative of the Water Resources Research Center of the University of Hawaii.

The state of the art today is described in the proceedings of the Conference which dealt *inter alia* with the following aspects:

1. Description of past and present systems in various parts of the world
b. Rainfall analysis
c. Catchment areas (development, operation and maintenance)
d. Diversion systems (gutters, filters: type, construction, materials)
e. Storage cisterns (capacity, materials, construction, operation and maintenance)

3. Spring water and surface water

In most high-rise islands, community water supply needs are met by spring water fed through gravity systems. Small storage dams have been built to regulate gravity water flow.

This approach to supplying water for a long time has been considered the most appropriate. It has, however, to be re-examined in the light of the energy situation in the developing island countries, taking into account that gravity water has the potential to be hydropower. As a matter of fact, a competition has developed in some projects between water supply and power generation. Gravity water is commonly put at the disposal of populations at low cost, or free of charge (through standpipes) due to social or political considerations. As a result it can be largely wasted. A better handling of this most valuable resource may provide opportunities for hydropower development and a corresponding reduction in energy imports. There is a definite need to look at the water and energy sectors as a whole. This can be achieved through the merging of power and water agencies into a single utility corporation and the development of combined schemes for hydropower production and water distribution.

F. EVALUATING COSTS AND BENEFITS

In a small island environment, evaluating the costs and benefits of water resources development is a risky exercise which cannot be left solely to a water utility or an engineering firm to determine. A number of factors have to be considered beyond cost/benefit considerations. It may well be necessary for social and/or political reasons to provide water at high cost and to give it free to the poor. Such problems will draw heavily on the national income. Conversely, costly (e.g., desalination) projects may be developed to serve the needs of the water users who can pay the relatively high price, such as luxury hotels, residential areas and industries, while relatively inexpensive but limited water resources may be developed for the urban poor, rural areas, and subsistence agriculture.

It this case, the production of expensive water while drawing also on the country's wealth will allow the development of activities attracting foreign investments and generating income.

Protection of water catchments which in the short and mid-term may appear a costly policy, may prove in the long term to be the most economical solution if it avoids costly treatment processes or accords development of alternative costlier sources of water.

The water sector cannot be considered sectorally in island countries. In self-contained, tight, interrelated, small island environments, the development of water resources must be considered within the overall framework of development/conservation aspects and in relation to economic and social policy.

This relates to all aspects of the problem: (i) delivery systems; (ii) water-use policy (including water demand analysis, risk analysis); and (iii) water quality treatment.

As in the case of groundwater development, the technologies to be selected for rain catchments, should take into account socio-cultural and economic conditions. Such conditions vary greatly from one island country to another, and also from one island to another within the same island country. Be that as it may, rainwater collection systems, traditional or modern, are, and will remain, the major source of water supply in most low-lying islands or small area's extent.

G. ESTABLISHING AN APPROPRIATE INSTITUTIONAL FRAMEWORK

Taking into account that, in an island of modest dimensions, water problems are commonly very serious from the point of view of the quantities of water which can be secured, their vulnerability to various contaminants, water costs, and the competition for water between various users, it is essential that a single organization be involved in the planning and development of water resources. A water utility may be the best alternative or when applicable a water power utility as mentioned above. However, the primary goal of such a utility, to provide safe drinking water at a price which should cover water producing costs to the extent possible, should be mitigated with other considerations such as:

a. Providing low cost or free water to the poor

b. Securing a minimum of water to allow for the survival or the development of agriculture

c. Controlling water development as a whole, including, for example, independent, privately owned, water systems for tourist installations

To allow for the expansion of current activities of a public utility into such a framework, the guidance of a Water Resources Board with representation by Planning, Health, Public Works and other government departments would be necessary.

In countries where individuals commonly provide their own supplies through roof catchments and water tanks, small wells with handpumps and other devices, one may conceive of a system of state support for community investments, and community or individual control of operation and maintenance, while water quality would be under the supervision of the water agency or utility.

CONCLUSIONS

Most developing island countries have a modest or small territorial extent and a major water problem.

The problems go beyond the enigmas and uncertainties arising from particularly difficult hydrological conditions such as: capricious rainfall, extremely porous rocks of a volcanic origin or karstified limestone) or impervious rocks without significant storage potential, or topographical features not allowing for impoundment of surface water storage.

The water problems result from the fact that since independence of these island countries, the socio-economic context has dramatically changed in two directions: first, an aspiration towards better living standards and second, the need to achieve a reasonable level of self-sufficiency – within an environment which tends to be overcrowded and deficient in natural resources. It stems also from the fact that the countries are isolated with some parts of their territory – outer smaller islands – difficult to reach.

Accordingly, existing water policies have to be reassessed (or non-existent water policies have to be defined) in line with new development guidelines and priorities.

In particular water resources which are scarce and/or not fully reliable have to be allocated to the various sectors of the economy and also strong environmental safeguards have to be established. In addition, there must be conservation of water resources.

This complex situation is further aggravated by the lack of human and financial resources, both qualified personnel and adequate financing.

In some countries, the water situation has been dealt with in an efficient and economical fashion. In others, some water development projects have been successful, yet some others have not reached their goals, mainly because the technologies used were not fully adequate from the point of view of their design, the materials used, the cultural habits of the populations, or because of excessive operation and maintenance costs.

A first approach has been developed by the United Nations Department of Technical Co-operation for Development in the Caribbean to study water problems in smaller islands on a subregional basis, in the form of a modest project. In addition, it would be worthwhile to embark on a world-wide study of water problems in small islands aimed *inter alia* at:

a. A study (including rainfall analysis) of the most common hydrological conditions and the most efficient and economical way to analyse them so as to determine where, how, and how much water resources can be developed safely;

b. A study of existing water policies: their achievements and the difficulties they have been experiencing;

c. A study of the attitudes of the islanders towards fresh water; including customary rights, cultural habits, and others;

d. A study of existing technologies, to determine their advantages and defects;

e. A study of the institutional framework for water (water utilities), government services, etc.;

f. A study of the role of water sector within the National Development Plan.

Such a study could involve several agencies of the United Nations system, various bilateral organizations and funding institutions. It would be of vital interest to a number of countries, not only the smaller island countries, but also major countries, such as the Philippines and Indonesia, which include a number of small islands within their territory.

VII. TRAINING OF WATER SUPPLY PERSONNEL IN THE SOUTH PACIFIC

A. IDENTIFICATION OF THE PROBLEM

From what I have heard from the participants and read in the country reports one of the major problems is the "inadequate manpower". The identification of "inadequate manpower" as a major problem was rather easy, since it was obvious and widespread. Now the difficult part is how to solve the problem. Eventhough, we cannot solve the problem here and now, we can put our heads together to formulate some proposals, to suggest some plan of action which would hopefully, when implemented, begin to reduce and in the long run eliminate the problem.

Before we start to find out solution to your problems, let me take some time to inform you what World Health Organization (WHO) does to assist the countries in the South Pacific to solve their problems.

By O.V. Natarajan, Project Co-ordinator, Development of Water Supply and Sanitation Manpower, World Health Organization, Fiji.

B. WHO ACTIVITIES TO SOLVE THE PROBLEM

1. Financial assistance

Every two years WHO allocates some funds to each of the countries. For exmaple for 82-83 WHO's contribution to Fiji is US$ 850,000.

For the Trust Territory of the Pacific Islands it is $ 600,000. With the approval of WHO the countries plan specific activities such as consultants training courses, fellowship etc at their national level. A major portion goes into fellowship wherein national staff are sent to educational and training institutions, near and far.

It is true that the health department personnel gets the lion's share of these funds; however provision of safe drinking water and adequate sanitation are the key elements in any countries' health situation. Therefore all personnel involved in water supply and sanitation are eligible to receive such fellowships and they do receive some.

2. Intercountry projects

There are projects which are regional in nature and covers many countries. Seminars, workshops and training courses are implemented under these projects and WHO invites and pays for the national participants in such courses.

In addition, WHO has two sanitary engineers stationed in Fiji, who provide advice in all basic aspects on water supply and sanitation to any country in South Pacific which requests such advice. Many times they do conduct planned training courses and *ad hoc* on-the-job training.

Further, we have a specific unit, the center for Promotion of Environmental Planning and Applied Studies (acronym PEPAS) at Kuala Lumpur serving the entire Pacific area including the South Pacific. It provides assistance through expert advice, training courses etc. on more technical aspects of water supply and sanitation such as water quality, pollution control, environmental impact etc.

3. Special projects

Sometimes WHO obtain funds from other agencies such as UNDP, Japan Shipbuilding Association etc and helps the countries in their water supply programmes. Assistance to Samoa and Solomon Islands are examples of this type.

One such specially funded, intercountry project, called "Training of Water Supply and Sewerage Manpower in the South Pacific" is coordinated by me. This project is funded by UNDP and covers thirteen English speaking island countries. The activities include:

a. Strengthening of training institutions
b. Training of national trainers
c. Development of training modules
d. Conducting pilot national training course and
e. The propagation of ferrocement technology

We have strengthened the Fiji Institute of Technology by provision of equipments, training materials, and books; worked with their staff to improve their ability to teach subjects on water supply. We have trained 26 trainers from eleven countries. We have published already one training module and two others are very near completion. Several others are at various stages of preparation. We have assisted in conducting national level training courses involving 107 people from seven countries. Ferrocement technology was propagated to four countries. This project ends in June this year.

With this brief background information on WHO activities in manpower development in water supply and sanitation let us focus our joint efforts to develop some strategies to solve the inadequate manpower situation in your respective countries.

C. ANALYSIS OF THE PROBLEM AND STRATEGIES FOR ITS SOLUTION

Let us analyse the problem of the "inadequate manpower". Breakdown the problem into smaller components.

Would you please take a long sheet of paper and list the most significant (not more than 10) problems that affect your day to day operational performance.

Examples of practical problems are:

(a) Inadequate record system
(b) Unable to retain staff

Do not say the problems in very general nature such as 'unreliable water supply'. List the bottlenecks in the water supply system such as:

(c) The quantity at source is not sufficient
(d) Leaky distribution system
(e) Unreliable power supply for pumps, etc.

Some of the questions you may ask which would help to analyse the problems are:

Do you have enough men to do the required job?

Are your people qualified to do the assigned job?

Are you utilizing your staff to the best of their ability?

Is there a system to reward the staff who perform very well and produce more than that expected of him?

Do unqualified people get the posts by "back-door" and "underground" methods?

Do you have an organizational set up which reflects the actual activities and shows the real burden each class of staff is shouldering?

Are there reasonable chances for regular promotion of the staff?

Are your staff reasonably happy and content in doing their duties?

Do you keep your boss informed regularly about your organization's activities, the problems you are facing and possible solutions for them?

Does the consumer and the general public know about the difficulties you are facing?

You may come with a list similar to that shown in the following example:

a. Shortage of plant and equipment;
b. Craftsmen unable to repair plant and equipment;
c. Managers and supervisors doing their work that subordinates should be doing;
d. Unable to recruit the right kind of staff;
e. Unable to retain staff;
f. Inadequate record systems;
g. Lack of understanding of training concepts and their training responsibility by management and supervising staff;
h. Lack of clearly defined responsibilities by employees at any level.

When you carefully look at these broken down elements of the day to day problems, you will realize all these problems cannot be solved by training alone; many problems can't be solved even by having an effective manpower development programme in which training is only one element.

You will realize that to solve some of the elements it would take quite a long time and more funds; some of them may require legislation and some have to wait for change of attitudes of the community.

You have to resign to the fact that some of them cannot be solved in your lifetime and you have to learn to live with that.

D. MANPOWER FORECASTING

Let us take one common often heard element that "they don't have enough people". Suppose the finance ministry gives enough funds and you get the necessary authority to fill the needed post would your problems be solved? You may not get properly qualified people or even if you do you may have problems again when your needs increase or when someone resigns. So you should forecast your manpower needs and recruitment rates for a period of 10 years in general terms and for a period of 3-5 years in a more specific manner.

How does one forecast the manpower needs?

It is a mathematical exercise with some relevant value judgements.

WHO came out with a guideline for the development of a national manpower and training plan for a country of 2 million population. Eventhough it may not be completely suitable for your countries, that guideline would indicate the general methodology.

There are many factors which would affect the mathematical forecasting. Some of them are external to the country and some of them are internal to the country. Even if the factor is internal to the country it may be outside the realms of the water supply organization.

Some of them are:

a. *Migration*

Examples – Cook Islands: nurses
Fiji: various categories

The migration rate itself changes constantly so the allowance for this factor also will change and to be adjusted accordingly.

b. *Foreign aid*

Sometimes the foreign aid comes with strings such as in the form of personnel. This affects the forecasting.

Generally, expatriates come and work in a developing country with a counterpart whom he is supposed to train. In some countries there is no counterpart assigned. In some other places one local person will be counterparts for quite a few of the expatriates.

Even after a counterpart really achieves the technical level of the expatriate, the counterparts salary would be lower than the expatriate because of the national salary structure. This gives the counterpart a temptation to migrate to green pastures.

This would affect the manpower forecast.

c. *General economic condition*

Blockage of sewer pipe – not only because people do not know the proper usage but also because people can't afford to buy toilet papers.

d. *Education level*

e. *Government policy on parity among different section of the community*

f. *Opportunities outside the sector*

Hotel pays water treatment technicians more than Public Works Department

g. *Non continuity of the programme*

h. *Small population base*

From what we have seen so far it is obvious that training alone cannot solve all the manpower problem. So it is better to approach with a broader perspective which is sometimes referred as human resources development.

E. HUMAN RESOURCES DEVELOPMENT

The term human resources development means more than the education and training of people. It includes their employment, supervision, continuing education and training and occupational welfare.

Recently, WHO published a "Basic strategy document of human resources development". The basic strategy document recognizes the need for a strong yet flexible approach in national human resources development planning, to accomodate the wide variety of national circumstances. It proposes a framework to identify elements affecting the development of national strategies. Human resources development is widely defined to include the supervision and skill development of any level of paid and unpaid staff serving the water supply and sanitation sector.

Government must plan for their long-term sectoral manpower needs, but must also take immediate steps to meet current priorities, including allocation of funds for more staff and better training.

Better coordination needs to be achieved between education and training schemes, and agencies implementing water supply and sanitation programmes.

Both formal and non-formal training is encouraged. Resources will be needed for more university, technical and vocational training places, as well as for teacher training, and training materials for use in institutions, local communities and on the job.

Special effort needs to be made to identify and train women in technical and managerial skills in drinking water and sanitation project development and health education programmes. Women's participation is crucial to the improvement of drinking water and sanitation given their roles as water carriers, managers, users and family educators, and their potential as motivators and change agents.

Because of the wide range of agencies and programmes involved, most countries need to designate an appropriate focal institution to co-ordinate nation Decade human resources development activities. Governments are encouraged to explore optional ways to ensure adequate funding for their human resources development plans within the context of regular national planning mechanisms.

VIII. TECHNOLOGY INTERCHANGE AND TRAINING WMO HYDROLOGICAL OPERATIONAL MULTIPURPOSE SUBPROGRAMME

INTRODUCTION

1. Concept and aims of HOMS

In its decision on the implementation of Hydrological Operational Multipurpose Subprogramme (HOMS) (Resolution 30 (Cg-VIII)), WMO Congress approved the concept of HOMS in the following terms:

"HOMS is a subprogramme implemented within the OHP, and consists of the organized transfer of hydrological technology operationally used in network design, observations, collection, processing and storage of data and hydrological modelling, and includes instrument catalogues, software packages, and general guidance and detailed manuals on the use of this technology under different conditions. HOMS is aimed not only at users who seek a high level of sophisticated technology, but also at users in need of simple technology appropriate to their conditions. It applies the systems approach in integrating components already available to WMO with others to be contributed by Members."

The hydrological technology available in HOMS is presented and transferred in the form of components. These consist of manuals of procedures and general guidance, descriptions of equipment, and computer software.

The components relate to the sequence of activities normally carried out by a hydrological service, viz: network design; instrumentation and data collection, data transmission; data storage and retrieval; data processing; catchment modelling, etc.

By A.J. Hall, WMO Consultant, Hydrologist, Bureau of Meteorology, Melbourne, Victoria, Australia.

The aims of HOMS therefore are:

a. To provide an efficient means of technology transfer;

b. To aid in the application of and training in appropriate technology, especially in developing countries;

c. To assist field projects of Members;

d. To improve the quantity and quality of hydrological data available for use by decision-makers;

e. To provide an international systematic framework for the integration of the many techniques and procedures in the collection and processing of hydrological data for use in water-resource systems.

2. Fields of interest

HOMS is aimed specifically at the needs of basin-wide national, regional and international agencies engaged in or using operational hydrology. Research and educational institutes may also find it of value. The fields of activity covered by the subprogramme are based on those of the Operational Hydrology Programme (OHP) of WMO and therefore include, for example, hydrological data collection, transmission, storage and retrieval, flood forecasting, and data processing for the planning, design and operation of water-resource projects.

The design of systems for data collection and processing is not a purely technical matter because important economic factors, amongst others, must be taken into account. Furthermore, the processing of data for use in the design and operation of water-resource systems cannot be undertaken in isolation from other vital inputs to decision-making in water resources, such as those of an economic, social and legal nature. The types of inputs required for decisions by water-resource managers is illustrated by Figure 23. Therefore, although economic, legal or similar components are not included in HOMS itself, the subprogramme is designed to facilitate interfacing with such inputs so that it is capable of playing its full role in supplying the hydrological inputs which are fundamental as a basis for rational water management decisions.

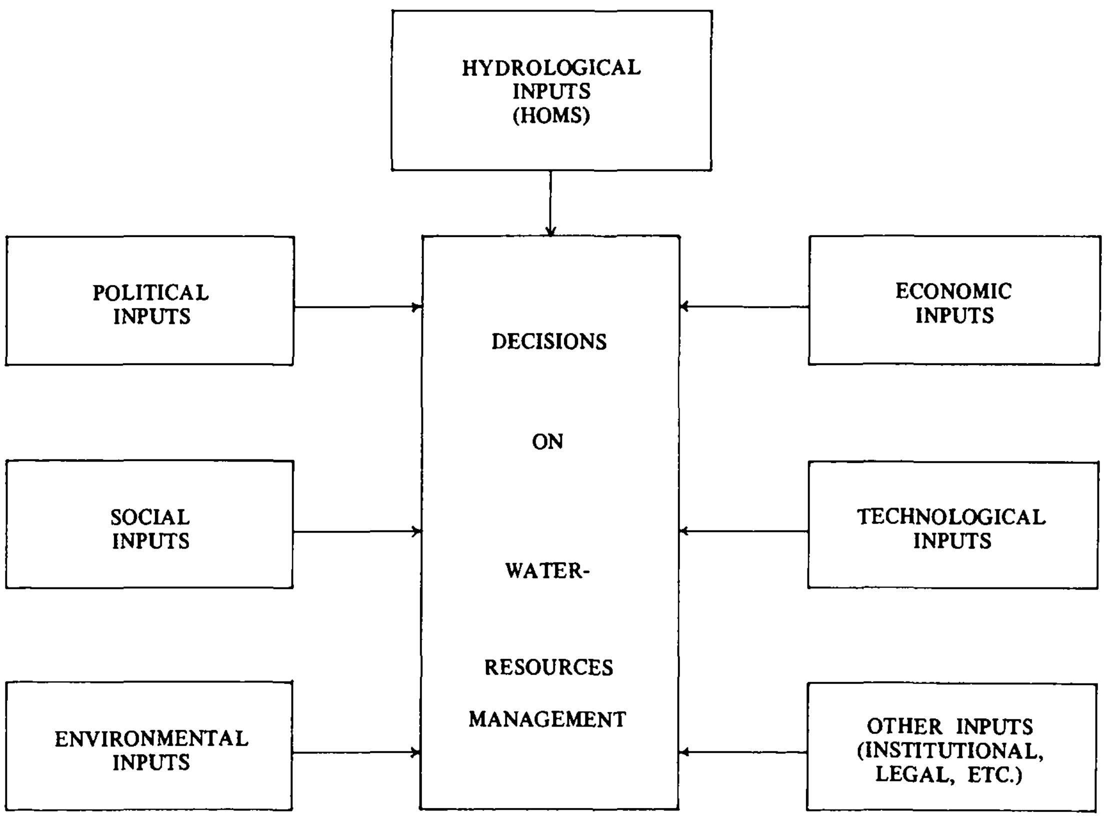

Figure 23. Inputs to decisions on water-resource management

A. ADMINISTRATION

1. Need for co-ordination

WMO Congress, in its Resolution 30 (Cg-VIII), considered that there was a general need for an international framework which could provide assistance in the planning and implementation of HOMS, and stated that WMO, with its responsibilities in operational hydrology, was the appropriate international organization to implement such a subprogramme within its Operational Hydrology Programme.

The various activities involved, not only in the development of HOMS, but also in maintaining the effectiveness of the system, require careful management and co-ordination. These activities fall into two groups. Those which can be undertaken at a national level and those requiring international action. Congress therefore decided that HOMS should be implemented as a joint effort of WMO Members with the direct co-operation of their national services and institutions. Congress further decided that the organization of activities involved in this co-operation should take place at both the national and international level.

2. Co-ordination at national level

Congress decided that

"At the national level, the following activities will need to be undertaken for the purpose of the project.

- Establishment of an inventory of components which are currently available and operationally used in the country and which are considered appropriate to be proposed for inclusion in the HOMS projects.
- Collection of these components, their adaptation as necessary and transmission of their description to WMO for inclusion in the HOMS Reference Manual.
- At the request of other countries or of WMO, transmission of these components, either bilaterally or through WMO, for use and application in other countries.
- Receipt and storage of components requested and received from other countries, either directly or through WMO.
- Calling the attention of potential users in the country to the availability of HOMS components.
- Assistance in the use and application of the HOMS components, as appropriate."

Accordingly, Eighth Congress invited Members to participate in the implementation of HOMS, taking into consideration existing national structures and practices (Resolutions 30 (Cg-VIII)). In extending this invitation, Congress assumed that the above activities could be performed at the national level by the service or institution in charge of operational hydrology (presumably the national hydrometeorological or hydrological service). Depending on the internal structure and organization of hydrological and water-resource management activities in different countries and in particular where these activities are carried out by several national institutions, it felt that it may be necessary to establish or designate an identifiable focal point within the Member countries to carry out, at national level, the functions described above. It was proposed that such focal points be called HOMS National Reference Centres (HNRCs). It should be emphasized, however, that the decision on the establishment, arrangements and specific internal functions of such a centre rests entirely within the competence of each Member. Permanent Representatives of Members are requested to inform the Secretary-General of decisions taken in this regard.

The information received by the Secretary-General concerning the arrangements made by Members for the co-ordination of HOMS activities at the national level is summarized in Annex A to this Manual. This annex is published for the information of all wishing to use HOMS components, as their first points of contact are expected to be at national level. It also facilitates direct contacts between those involved in HOMS in different Member countries and provides essential information for use in the international co-ordination of the subprogramme. Annex A is updated as required by the issuing the supplements to the Manual.

3. Co-ordination at international level

WMO Congress also stated that the co-ordinating functions to be carried out at the international level by WMO in the development and implementation of the HOMS project will consist, in particular, in:

- Ascertaining the needs of Members in the overall orientation of the project.
- Elaborating and distributing to Members general and specific guidance on the substance and form of HOMS components to be prepared at the national level.
- Preparing, maintaining and updating the HOMS Reference Manual and periodically distributing it to Members.
- Assisting in the technology transfer among Members, within the framework of the project.

"As a project within the OHP, technical guidance and review of the whole project will be the responsibility of the Commission for Hydrology. Its Advisory Working Group, meeting as the Steering Committee for HOMS, will advise on the implementation of the Commission's resolutions and recommendations. The Commission and the Steering Committee will call upon the support of the various rapporteurs and working groups of CHy, who will prepare more detailed guidance on the specific HOMS components related to their specific terms of reference. The regional association Rapporteurs and Working Groups on Hydrology will co-operate in the development of the HOMS project with respect to its application to the particular needs of their Regions."

B. OPERATIONAL ACTIVITIES

1. Availability and use of HOMS components

HOMS components are available to all Members, their national services and agencies, and to all international agencies for use in water-resource management projects requiring operational hydrology. A potential user can obtain information on HOMS from or through the HOMS National Reference Centre or focal point in the user's country. International agencies and users in countries not listed in Annex A may contact the WMO Secretariat directly by writing to.

The Secretary-General,
World Meteorological Organization,
Case postale No. 5,
CH-1211 Geneva 20,
SWITZERLAND.

The components of HOMS, the technical substance of the project, are for use by Members, either individually or in regional or international projects. WMO is primarily concerned with the planning and co-ordination of the project. The WMO Secretariat, itself does not use the HOMS components for operational purposes and therefore handles no operational data. However, one of the major tasks of the Secretariat, as specified under A.3 above, is to ensure that Members have ready access to the components. Some components are available directly from the HOMS National Reference Centres and focal points listed in Annex A. Others are available from or through the WMO Secretariat or, on a bilateral basis, from their originators. Specific conditions are also attached to the supply of certain components. Detailed information concerning the source and availability of the components, and any conditions attached to their use, is included in the summary descriptions contained in Annex C.

2. Technical co-operation

The availability of components does not eliminate the need for assistance to developing countries by individual experts. Needs arise for technical co-operation and external assistance in the use of HOMS and its components. However, HOMS provides a clear definition of the needs in each particular case, thus making such co-operation and assistance far more efficient and less costly.

Requests for technical expertise and equipment in the use of HOMS are handled through the normal well-established channels of WMO or other international organizations, as well as through bilateral technical co-operation agencies. Information concerning these can be obtained from WMO.

3. Training

Quite apart from their operational application, many HOMS components can be used to great advantage in training in operational hydrology. Such use is to be encouraged. However, the principal role of training in relation to HOMS is training in the use of the various components themselves. The availability of a HOMS component is no substitute for hydrological expertise in the application of that component. Although every effort is made to ensure that users' manuals for components are as self-explanatory as possible, few components can be used to their fullest potential by personnel who are totally unfamiliar with them.

For the above reason, training, including in-service training, in the use of various components is undertaken at both the national and co-ordinated with the overall development and implementation of HOMS. They are organized through the normal channels of WMO, information on which can be obtained from the Permanent Representatives of Members with WMO or directly from the Organization's Secretariat.

Part Five

INFORMATION PAPERS PRESENTED BY FIJI GOVERNMENT

I. ASPECTS OF THE RAINFALL AND EVAPORATION CLIMATE IN FIJI

INTRODUCTION

Previous relevant Meteorological Service publications are listed in the references. These include mean rainfall data and estimate of potential evapotranspiration (PE). Figure 24 illustrates the relationship between mean monthly values of rainfall and PE.

A. VARIABILITY OF MONTHLY SEASONAL AND ANNUAL RAINFALL

Table 19 shows the wide range of variation of monthly rainfall and gives coefficient of variation and Gamma parameters for monthly and annual values. Rainfall totals have been found to fit the Gamma distribution in many places. The value of Gamma can probably be interpolated from a relatively small number of sample estimates, for selected places and time intervals. Then, given an estimate of the mean (from the monthly mean data), one can make an estimate of a "quantile" for any place or time interval. Gamma has high values (15+) when the distribution is near normal, or rainfall is reliable. Gamma has low values when the distribution is skewed, e.g., monthly rainfall, especially in dry regimes where rainfall is unreliable. (e.g. Nandi Airport, annual rainfall, gamma = 17; July rainfall gamma = 0.9.)

B. RAINFALL CORRELATIONS

Much of Fiji's rainfall comes from large-scale weather systems which bring rain to all or a large part of the group. At other times rainfall is sporadic and localised, but still tends to favour certain areas. The extent to which rainfall is spatially coherent on various time scales is revealed in correlograms showing the decrease in correlation with distance from a reference station of for example monthly and annual totals. The regression relationship derived at the same time is also useful for estimating missing data in a rainfall series.

Table 20 gives some preliminary results with Nandi Airport as reference. Areas with 'R' greater than 0.8 can be considered similar in respect to the element concerned. Other factors need to be considered as well before climatic "regions" could be defined.

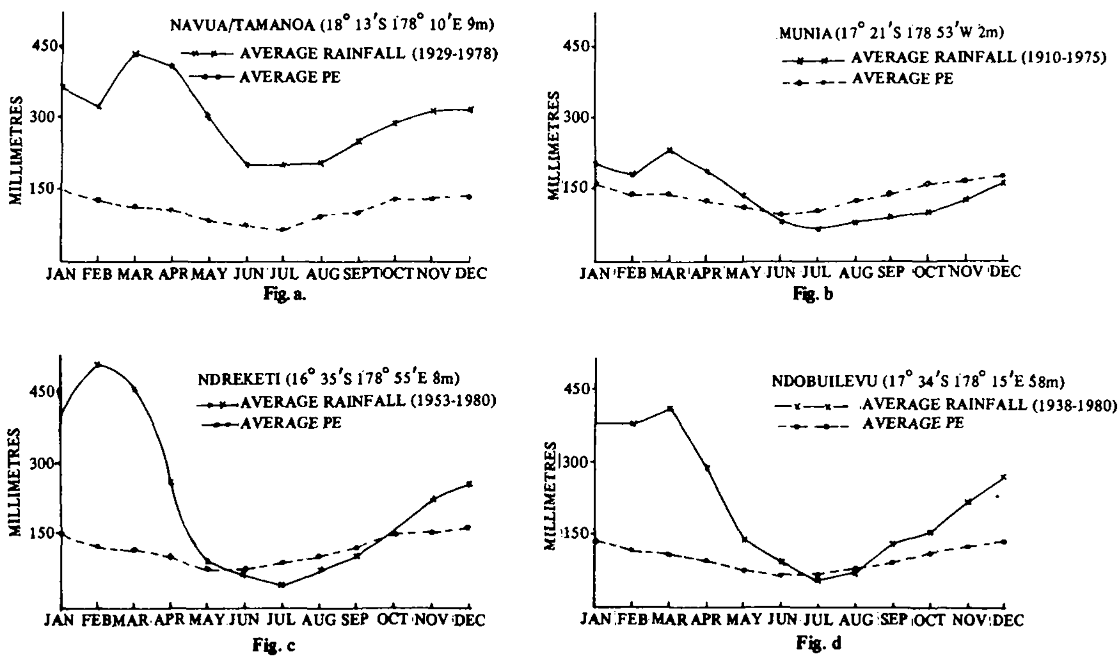

Figure 24. Average monthly rainfall and potential evapotranspiration of Navua/Tamanoa, Munia, Ndreketi and Ndobuilevu

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By J.D. Coulter, S. Kishore and P. Kumar of the Fiji Meteorological Service.

Penman potential evapotranspiration for Nandi Airport – millimetres 1972-1979

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jly*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year*
Mean	153	131	125	110	97	83	99	110	132	157	154	171	1522
Max	171	146	137	121	101	91	113	122	144	183	177	191	1634
Min	133	121	116	95	90	76	87	96	120	143	130	141	1436
SD	15	8	9	8	4	5	9	9	9	16	18	18	71
CV (%)	10	6	7	7	4	6	9	8	7	10	12	11	5

C. EVAPORATION

Tank evaporation data from Fiji station have been critically examined and unreliable readings excluded. Table 21 summarizes the results. It can be seen that tank evaporation shows appreciable differences from place to place and with season, but the inter-year variability of monthly totals is much less than for rainfall.

A test has been made of a Penman type calculation of tank evaporation, and daily values were found to agree closely after a seasonal corrections factor was applied (Kishore, in press). Estimates of open water evaporation (EO) can be made from the measured tank data by application of an empirical factor – of uncertain validity – or they can be calculated by the Penman formula from solar radiation or sunshine, temperature, humidity and wind data.

Penman PE or EO can be calculated for about 14 places in Fiji. Though well tested elsewhere no independent testing of these estimates is possible in Fiji. Monthly, PE does not vary greatly from year to year, as illustrated in the above table.

D. WATER BALANCE

By means of a simple water balance budget calculation the water input by rainfall can be assessed in relation to the water needs of crops or to evaporation from open water surfaces. Because of day to day rainfall variability it is necessary to use daily rainfall data. To get a climatologically valid sample about 20 year's data are needed. Computer analyses have been made for four Fiji stations; sample results are given in Tables 22 and 23 for Nandi Airport, in the dry sugar growing area of western Viti Levu, Ndreketi River, in the somewhat wetter rice area of Northern Vanua Levu, and Vunilangi in the plantation area of southern Vanua Levu, an area of rather low average rainfall.

We define "deficit" (D) as PE-AE where AE becomes zero when calculated soil moisture withdrawal (DS) reaches a limiting value S, and is equal to PE if water available from the day's rain or the soil moisture reserve is sufficient. Each day's rainfall is apportioned first to evapotranspiration (AE), then to restore soil moisture, and then any surplus is defined as "runoff" (RO). We tabulate soil moisture status DS and monthly accumulated totals of RO and D and the number of days with runoff, and deficit – the latter (ND) is often used as a measure of duration of "agricultural drought.

Nandi Airport has the most clear cut seasonality. Average rainfall (R) – PE shows an annual surplus of 270 mm, but monthly deficits occur from May to December.

Using monthly average Penman PE and an assumed soil moisture capacity of 75 mm, the daily water balance shows for example annual accumulated deficit totals ranging from 101 mm in 1974 to 820 mm in 1979 with an average of 465 mm in 1960-1979. Annual surplus (believed to be a fair index of water available for streams flow or ground water recharge) in the "water year" September to August ranged from 48 mm in 1977-1978 to 1401 mm in 1973-1974, and averaged 700 mm with coefficient of variation (SD/Mean) 0.46. This shows that water yield must be expected to be considerably more variable than rainfall (Mean = 1827, CV = 0.24 over the same period). A very clear seasonality is shown, with frequent deficits in months from July to December, even when "S" is increased to 150 mm.

Results for Vunilangi and Ndreketi (Tables 22 and 23) illustrate the same general relationships. The sample includes very dry years from 1965 to 1970, though overall the rainfall was not far from the long term average.

At Vunilangi average annual rainfall (2000 mm) is about 500 mm above PE. On average the sum of monthly deficits is only 30 mm. From the daily water balance with S = 75 mm the average annual deficit, 1962-1972, was 219 mm, (CV 0.73); ranging from 518 mm (1966) to 11 mm. (1971). Water year surpluses (RO) averaged 776 mm (CV 0.41), ranging from 308 mm (1969-1970) to

1427 mm (1964-1965) in the years 1962-1963 to 1971-1972. RO values were greatest in March (average 147 mm) and least in July (7 mm) and occurred in all years in March and in 3 out of 11 in July and August. Note that some years have both RO and D in the same month.

A value for S of 75 mm is appropriate for shallow rooted crops or shallow soils. For some circumstances a different value for S is more appropriate. Results are available for S = 125 or S = 150. A larger soil moisture reserve delays and reduces both deficits and surpluses, but in a prolonged wet or dry period the difference becomes slight. For example, at Vunalangi for S = 125 the accumulated deficit in 1966 was 419 mm and the surplus in 1964-1965 was 1048 mm. The average deficit was 138 mm and average surplus 731 mm (cf., 518, 1427, 219 and 776 mm respectively for S = 75).

The differences in detail in surplus and deficit values from year to year are striking. One perhaps unexpected observation is the relatively high frequency of deficits extending well into the "wet" season, i.e. December – January.

Conclusion

Computer data archives are in process of being built up. Shortly, and in the light of these preliminary results, it will be possible to undertake systematic analyses of these and other aspects of the rainfall climate in Fiji.

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Table 19. Rainfall deciles for consecutive months, mean, maximum and minimum rainfall, standard deviation in millimetres, coefficient of variation, Gamma and number of observations for selected Fiji stations

Month	*Min*	*Deciles* 1	2	3	4	5	6	7	8	9	*Max*	*Mean*	*SD*	*CV*	*Gamma*	*No. of year*
	V60101		UNDU POINT			16°08'S			179°59'W		62 m			1951-1980		30
Jan	91	107	186	266	291	339	367	379	446	462	991	332	173	52	4.0	30
Jul	61	36	51	69	73	83	89	107	155	206	-326	103	71	69	2.4	30
	V68591		NDREKETI			16°35'S			178°55'S		5 m			1953-1982		
Jan	71	142	256	304	328	407	423	433	577	640	696	390	159	41	5.0	28
Jul	0	1	11	21	33	43	53	59	67	123	172	49	43	89	0.7	30
	V68971		NAMBOUWALU			16°59'S			178°42'S			34 m		1951-1980		
Jan	37	86	222	256	291	332	414	460	489	533	631	344	163	47	3.0	30
Jul	18	27	86	50	71	85	99	116	145	158	355	94	69	74	2.2	30
	V68671		NDELAINASAU			16°40'S		178°43'S		22 m				1941-1970		
Jan	73	104	229	318	358	407	454	492	534	687	843	402	204	51	3.1	30
Jul	0	0	7	18	23	27	39	52	73	104	213	44	48	110	0.6	30
	V69353		NDAKU			16°22'S		179°33'E		8 m				1960-1982		
Jan	46	66	160	278	329	366	438	518	641	724	972	403	240	59	2.2	23
Jul	0	15	20	25	37	40	45	64	89	136	221	57	52	91	1.1	22
	V69433		WAILEVU			16°26'S		179°2		42 m				1951-1980		
Jan	43	101	186	233	295	346	393	416	551	627	712	351	177	50	3.2	29
Jul	0	3	7	14	32	40	47	66	83	116	232	51	51	100	0.8	29
	V69541		VUNIMOLI			16°41'S		179°24'E		14 m				1951-1980		
Jan	68	152	296	327	375	424	502	594	616	817	1061	465	237	51	3.2	30
Jul	0	9	11	20	26	34	46	66	80	94	203	47	43	91	1.1	30
	V69671		VUNILANGI			16°45'S		179°38'E		3 m				1958-1979		
Jan	58	69	121	164	223	248	299	327	346	404	453	247	118	48	3.5	21
Jul	7	24	34	39	54	65	104	120	125	155	188	81	53	65	2.0	20
	V69831		SAVUSAVU AIRPORT			16°48'S		179°21'E		16 m						
Jan	68	152	296	327	375	424	502	594	616	817	1061	465	237	51	3.2	30
Jul	0	9	11	20	26	34	46	66	80	94	203	47	43	91	1.1	30
	V77491		YANGGARA			17°26'S		177°59'E		24 m				1951-1980		
Jan	2	51	96	155	187	276	369	467	503	589	851	315	231	73	1.2	30
Jul	0	0	5	9	15	20	31	41	52	88	99	31	29	94	0.7	29

Table 19. *(Continued)*

Month	*Min*	*Deciles 1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Max*	*Mean*	*SD*	*CV*	*Gamma*	*No. of year*
	V77551		NDRASA		17°35'S		177°32'E		35 m						1951-1980	
Jan	31	93	176	242	260	320	406	424	448	557	805	331	178	54	2.7	30
Jul	0	2	9	12	21	27	41	53	66	120	147	43	42	98	0.7	30
	V77575		RARAWAI MILL			17°30'S		177°42'E		5 m					1910-1980	
Jan	35	85	139	202	238	317	351	413	515	571	999	328	199	61	2.4	71
Jul	0	2	7	10	26	32	45	60	78	96	166	44	41	94	1.0	70
	V77581		VATUKOULA			17°30'S		177°51'E		61 m					1951-1980	
Jan	45	77	157	221	288	350	474	534	685	948	1125	422	297	70	1.9	29
Jul	0	5	12	15	24	33	43	51	80	109	179	44	41	93	1.0	28
	V77591		NANDARIVATU			17°34'S			177°57'E		835 m				1951-1980	
Jan	85	133	261	376	496	636	686	788	879	1024	1371	596	320	54	2.7	29
Jul	6	14	26	29	38	43	66	81	101	175	304	70	66	90	1.5	27
	V77641			LAUTOKA MILL			17°36'S		177°27'E		26 m				1951-1980	
Jan	18	127	163	211	271	327	392	436	454	559	568	322	160	50	2.7	30
Jul	0	2	11	19	27	38	49	61	84	124	207	51	50	98	0.7	30
	V77744			NANDI AIRPORT			17°45'S		177°25'E		16 m				1942-1979	
Jan	41	66	145	195	236	277	308	399	473	549	598	298	163	55	2.6	37
Jul	0	1	6	11	19	34	43	58	94	137	190	48	50	104	0.9	38
	V78311			PENANG MILL			17°22'S		178°10'E		3 m				1951-1980	
Jan	18	92	143	225	281	340	450	480	566	626	754	353	198	56	2.2	29
Jul	4	7	12	28	30	38	49	57	83	93	148	45	36	80	1.5	29
	V78521			NDOMBUILEVU			17°34'S		178°15'E		58 m				1951-1980	
Jan	44	165	236	294	336	398	462	483	531	578	673	384	165	0.43	3.7	30
Jul	0	13	17	34	36	53	67	82	118	135	239	65	54	0.83	1.1	30
	V78831			VUNIDAWA			17°49'S		178°20'E		27 m				1913-1948	
Jan	70	147	248	264	306	392	436	474	555	648	926	395	197	50	3.8	30
Jul	7	32	47	68	80	104	123	152	174	215	232	111	66	60	2.2	30
	V87031			LOMAWAI			18°02'S		177°19'E						1951-1980	
Jan	6	74	171	187	211	272	367	394	426	633	823	314	202	64	1.7	30
Jul	0	4	9	24	32	39	44	69	144	169	235	63	65	103	0.7	30

Table 19. *(Continued)*

Month	*Min*	*Deciles* 1	2	3	4	5	6	7	8	9	*Max*	*Mean*	*SD*	*CV*	*Gamma*	*No. of year*
	V87141			THUVU			18°08'S		177°26'E		3 m				1951-1980	
Jan	7	61	111	129	225	253	287	315	416	518	705	264	176	67	1.8	30
Jul	4	21	37	42	58	62	78	93	112	168	285	82	63	77	1.8	30
	V8715D			SINGATOKA			18°07'S		177°30'E		61 m				1953-1980	
Jan	21	97	127	190	232	301	347	426	460	555	629	303	169	56	2.5	30
Jul	12	22	38	44	52	63	72	82	116	176	232	79	58	73	2.2	30
	V88053			KORONIVIA RESEARCH					18°03'S		178°32'E		15 m		1951-1980	
Jan	104	223	235	269	309	375	421	449	481	519	681	366	137	37	6.6	30
Jul	38	49	78	91	111	138	145	164	273	371	447	166	117	70	2.3	30
	V88141			SUVA/GOVT.HOUSE					18°09'S		178°26'E		23 m		1884-1980	
Jan	29	547	444	375	341	295	236	199	145	120	803	308	166	54	3.1	93
Jul	7	297	225	176	146	119	111	93	71	53	543	155	109	70	2.2	70
	V88143			LAUCALA BAY					18°09'S		178°27'E		6 m		1942-1973	
Jan	43	140	179	209	266	311	350	377	413	518	578	308	136	44	4.3	32
Jul	38	68	75	87	103	114	136	176	230	321	408	153	98	64	3.0	
	V88212			NAVUA/TAMANOA					18°13'S		178°10'E		9 m		1951-1980	
Jan	114	200	228	263	324	361	404	484	523	620	811	388	169	44	5.4	30
Jul	52	85	104	121	136	193	214	257	305	374	572	208	125	60	3.1	30
	W66000			YASAWA-I-RA					16°42'S		177°35'E		49 m		1951-1980	
Jan	25	46	115	146	204	254	283	315	366	430	666	246	150	61	2.1	30
Jul	0	8	11	24	29	34	37	56	79	93	147	44	35	80	1.2	30
	W66507			SONGGULU					16°05'S		179°59'E		30 m		1951-1980	
Jan	23	103	186	285	326	383	459	527	581	759	1168	412	248	60	2.3	28
Jul	22	27	35	47	60	62	66	120	126	224	334	92	77	84	2.0	25
	W67610			MANGO IS					17°26'S		179°08'W		12 m		1951-1980	
Jan	129	147	193	219	248	257	267	292	345	387	546	268	93	35	8.8	30
Jul	6	39	47	56	69	74	79	101	110	153	295	90	64	71	2.5	30
	W67800			LEVUKA		17°41'S		178°50'E		2 m					1951-1980	
Jan	46	127	170	198	222	282	332	353	423	472	507	286	129	45	4.2	30
Jul	27	39	56	73	84	109	117	150	166	204	319	117	70	60	2.9	30

Table 19. *(Continued)*

Month	*Min*	*Deciles* 1	2	3	4	5	6	7	8	9	*Max*	*Mean*	*SD*	*CV*	*Gamma*	*No. of year*
	W69100			LAKEMBA		$18^{o}14$'S		$178^{o}48$'W		2 m					1951-1980	
Jan	59	131	153	180	227	252	279	339	411	462	503	272	125	46	4.5	30
Jul	24	32	37	45	53	63	77	109	132	153	173	80	47	59	3.1	30
	W69300			VUNISEA-KANDAVU			$19^{o}03$'S		$178^{o}10$'E			31 m			1951-1980	
Jan	39	87	115	192	243	273	281	299	398	449	635	265	137	52	3.2	29
Jul	26	55	84	90	95	108	141	156	177	210	287	127	59	46	4.5	29
	W69700			MATUKU		$19^{o}08$'S		$179^{o}44$'S		3 m					1951-1980	
Jan	45	109	159	173	197	224	268	303	347	419	629	253	134	53	3.5	30
Jul	11	33	41	64	81	89	116	129	159	209	266	106	67	63	2.3	30
	W69900			ONO-I-LAU		$20^{o}40$'S		$178^{o}43$'W		27 m					1951-1980	
Jan	16	59	108	162	193	208	223	246	269	330	381	200	95	48	2.9	30
Jul	26	34	43	56	68	70	114	122	138	161	176	90	48	53	3.4	30

Zero values of rainfall were replaced by 0.1 in order to calculate gamma.

Table 20. Correlation analysis, Nandi airport and selected stations

	Nandi	*Wangandra*	*Navo*	*Lautoka*	*Singatoka*	*Penang*	*Dombuilevu*	*Navua*	*Lauthala Bay*	*Nambouwalu*	*Ndelainasau*	*Lambasa*	*Undu Point*	*Ono-i-Lau*
JANUARY														
M	310	297	275	322	303	345	384	388	329	344	372	403	332	200
SD	166	171	154	160	169	205	165	169	140	163	179	197	173	95
SD/M	0.54	0.58	0.56	0.50	0.56	0.59	0.42	0.44	0.42	0.47	0.48	0.47	0.52	0.48
R		0.93	0.89	0.88	0.63	0.73	0.83	0.42	0.54	0.72	0.63	0.58	0.31	0.55
A		0	22	61	104	67	129	256	187	126	162	188	232	102
B		0.96	0.82	0.84	0.64	0.89	0.82	0.43	0.46	0.70	0.68	0.69	0.32	0.32
$\bar{X}$/M		1.04	1.13	0.96	1.02	0.90	0.81	0.80	0.94	0.90	0.83	0.77	0.93	1.55
JULY														
M	51	54	58	51	79	45	64	208	155	94	44	49	103	90
SD	51	55	59	50	58	35	54	125	105	69	35	46	71	48
SD/M	1.01	1.03	1.02	0.98	0.74	0.77	0.84	0.60	0.68	0.73	0.79	0.95	0.69	0.53
R		0.99	0.94	0.85	0.82	0.52	0.46	0.21	0.17	0.20	0.17	0.34	0.24	0.43
A		0	3	9	32	27	32	183	137	81	38	33	86	70
B		1.06	1.08	0.83	0.93	0.35	0.48	0.50	0.35	0.27	0.11	0.30	0.34	0.40
$\bar{X}$/M		0.95	0.88	1.00	0.65	1.12	0.79	0.25	0.33	0.54	1.15	1.05	0.50	0.57
ANNUAL														
M	1094	1889	1844	1971	1937	2378	2646	3513	3118	2535	2313	2394	2574	1763
SD	456	455	491	570	479	617	491	621	548	561	681	602	506	419
SD/M	0.24	0.24	0.27	0.29	0.25	0.26	0.19	0.18	0.18	0.22	0.29	0.25	0.20	0.24
R		0.93	0.92	0.86	0.86	0.70	0.54	0.31	0.29	0.74	0.58	0.76	0.41	0.71
A		131	−37	−82	220	573	1536	2712	2462	809	669	497	1714	528
B		0.92	0.99	1.08	0.90	0.95	0.58	0.42	0.34	0.91	0.86	1.00	0.45	0.65
$\bar{X}$/M		1.00	1.03	0.97	0.98	0.80	0.72	0.54	0.61	0.75	0.82	0.79	0.74	1.08

X and Y are monthly or annual rainfall totals
X = Nandi Airport
Y = comparison station
M = mean
SD = standard deviation
R = correlation coefficient
Regression equation : $Y = A + B . X$
Period 1951 - 1980

Table 21. Average tank evaporation (ET), standard deviation (SD), coefficient of variation (CV), number of years data used (N) and estimated open water evaporation (EO)

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jly*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year*
V77641				Lautoka Mill 17°36'S 177°27'E WF476533 26 m									1972-1978
ET(mm/day)	5.9	5.8	5.5	5.0	4.3	3.9	4.3	4.6	5.5	5.7	5.9	6.4	5.2
SD(mm/day)	0.69	0.72	0.85	0.69	0.73	0.43	0.70	0.30	0.47	0.35	0.67	0.41	0.31
CV(%)	12	13	16	14	17	11	16	7	9	6	11	6	6
N(Yrs)	7	7	7	7	7	7	7	7	8	7	8	8	7
ET(mm)	183	162	171	150	133	117	133	143	165	171	177	198	1903
EO(mm)	126	112	118	104	92	81	92	99	114	118	122	137	1315
V77744				Nandi Airport 17°45'S 177°27'E WF482371 16 m									1972-1980
ET(mm/day)	6.2	6.2	5.4	5.4	4.9	4.2	4.8	5.2	6.1	6.6	6.6	7.1	5.7
SD(mm/day)	0.90	0.64	0.58	0.37	0.45	0.30	0.39	0.35	0.57	0.81	0.80	1.06	0.28
CV(%)	15	12	15	15	16	17	8	15	16	9	12	11	6
N (Yrs)	9	9	9	8	9	9	9	9	9	9	9	9	8
ET(mm)	193	174	168	161	153	126	150	161	183	206	199	219	2093
EO(mm)	133	120	116	111	106	87	104	111	126	142	137	151	1444
V77794				Nandrau 17°43'S 177°57'E XF014415 777m									1978-1982
ET(mm/day)	3.8	3.9	3.1	3.0	2.6	2.5	2.6	2.6	3.6	3.8	4.0	4.5	3.3
SD(mm/day)	0.14	0.49	0.40	0.32	0.22	0.30	0.23	0.18	0.54	0.37	0.35	0.53	0.20
CV(%)	4	13	13	11	9	12	9	7	15	10	9	12	6
N(Yrs)	4	5	5	5	5	5	5	6	6	6	6	4	5
ET(mm)	118	109	96	90	81	75	81	81	108	118	120	140	1217
EO(mm)	81	75	66	62	56	52	56	56	75	81	83	97	840
V88053				Koronivia Agricultural Research 18°03'S 178°2'E XF622040 15 m									1970-1978
ET (mm/day)	4.8	4.5	4.0	3.4	3.1	2.8	2.7	3.1	3.6	4.2	4.3	4.5	3.8
SD(mm/day)	0.26	0.37	0.49	0.37	0.24	0.43	0.34	0.34	0.43	0.38	0.67	0.72	0.14
CV(%)	5	8	12	11	8	16	13	11	12	9	16	16	4
N(Yrs)	8	9	8	9	9	9	9	8	8	8	7	7	7
ET(mm)	149	126	124	102	96	84	84	96	108	130	129	140	1368
EO(mm)	103	87	86	70	66	58	58	66	75	90	89	97	945
V88143				Suva/Lauthala Bay 18°09'S 178°27'E XE542931 6 m									1968-1972
ET(mm/day)	4.8	4.0	3.6	3.4	3.1	2.8	2.4	3.4	3.9	3.8	4.2	4.9	3.7
SD(mm/day)	1.06	0.35	0.43	0.17	0.35	0.89	0.70	0.63	0.92	0.26	0.88	0.49	0.02
CV(%)	21	9	12	5	11	7	29	19	23	7	21	55	1
N(Yrs)	3	3	4	4	4	5	4	5	4	5	3	3	3
ET(mm)	149	112	112	102	96	69	74	105	117	118	126	152	1332
EO(mm)	103	77	77	70	66	48	51	72	81	81	87	105	918
V88212				Navua/Tamanoa 18°13'S 178°10'E XE231850 9 m									1969-1980
ET(mm/day)	4.7	4.3	4.0	3.3	2.7	2.3	2.5	2.9	3.5	3.8	4.4	4.6	3.6
SD(mm/day)	0.45	0.31	0.32	0.48	0.50	0.37	0.39	0.35	0.53	0.54	0.40	0.80	0.16
CV(%)	9	7	8	15	18	16	15	12	15	14	9	18	0.04
N(Yrs)	8	7	6	8	10	10	9	9	9	8	7	7	5
ET(mm)	146	120	124	99	84	69	78	90	105	118	132	143	1308
EO(mm)	101	83	86	68	58	48	54	62	72	81	91	99	903

Table 22. Water balance, Vunilangi station

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
	A	S = 75 mm										
	1962											
RO	140	126	15	278	3	69	0	0	0	0	62	2
D/ND	0	0	0	0	0	0	0	100/31	79/24	9/2	20/6	29/7
	1963											
RO	48	0	294	50	149	4	0	0	0	27	243	86
D/ND	0	7/2	0	0	0	0	0	0	25/8	0	23/6	0
	1964											
RO	0	129	407	81	5	0	0	50	150	31	214	112
D/ND	60/18	2/1	0	0	0	14/6	53/19	0	0	0	0	0
	1965											
RO	138	383	191	108	100	0	0	0	0	0	178	–
D/ND	0	0	0	0	0	35/14	40/16	22/8	68/21	79/20	13/3	97/22
	1966											
RO	166	0	35	87	14	0	0	0	0	0	0	2
D/ND	39/9	3/1	4/2	0	0	53/21	55/20	82/26	98/28	48/12	76/19	48/13
	1967											
R0	283	120	94	104	0	0	0	0	2	66	103	0
D/ND	0	0	0	0	0	26/12	62/24	78/26	23/8	0	6/2	87/20
	1968											
RO	51	129	142	54	0	47	22	0	10	12	162	38
D/ND	17/4	0	0	0	50/18	0	0	6/2	7/4	76/19	0	26/6
	1969											
RO	0	78	202	116	0	0	0	0	0	9	102	0
D/ND	0	0	0	0	8/3	71/28	29/12	98/30	83/23	55/14	0	30/9
	1970											
RO	0	45	6	0	41	75	0	0	0	19	0	7
D/ND	8/2	0	8/2	0	0	38/15	14/5	98/31	69/21	2/1	3/1	5/3
	1971											
RO	92	181	162	30	7	201	52	74	0	67	113	368
D/ND	0	0	0	0	0	0	0	0	0	11/3	0	0
	1972											
RO	317	43	68	7	187	7	8	61	115	224	22	0
D/ND	0	0	0	0	0	0	19/7	0	0	0	0	0
(RO)												
Mean	112	112	147	83	46	37	7	11	27	41	109	56
Percent	73	82	100	91	73	55	27	27	36	73	82	64
(D)												
Mean	11	1	1	0	5	22	25	44	41	25	13	29
Percent	36	27	18	0	18	55	64	64	73	64	55	64

Monthly Surplus (RO), Evapotranspiration Deficit (D), in mm, Days of Deficit (ND). Based on daily rainfall, average Penman PE, for limiting soil moisture storage "S"

Table 23. Water balance summary

Year	*DEF*	*ND*	*RR*	*Water Year*	*RO*	*NR*	*RR*
V77744	Nandi airport						
1960	359	94	2533	1960-61	632	23	1880
1961	269	76	2041	1961-62	709	36	2015
1962	399	101	1758	1962-63	637	23	1977
1963	224	52	2040	1963-64	1126	26	2203
1964	547	146	2115	1964-65	936	21	2059
1965	607	145	1893	1965-66	409	26	1281
1966	723	184	1412	1966-67	737	38	1636
1967	542	144	1653	1967-68	456	17	1646
1968	508	130	1676	1968-69	190	10	1001
1969	820	211	863	1969-70	575	12	1669
1970	287	75	2053	1970-71	875	37	2129
1971	273	83	2164	1971-72	646	31	1909
1972	496	135	1830	1972-73	940	25	2082
1973	378	95	2077	1973-74	1401	49	2792
1974	101	32	2984	1974-75	537	33	1817
1975	418	114	1989	1975-76	904	51	2118
1976	483	128	1601	1976-77	1082	35	2158
1977	771	195	1802	1977-78	48	5	895
1978	506	132	1169	1978-79	702	23	1810
1979	586	145	1742	1979-80	463	35	1466
Mean	465	121	1870		700	28	1827
C.V.	0.40	0.38	0.24		0.46	0.43	0.24
V69761	Vunilangi						
1962	273	70	1832	1962-63	608	28	
1963	55	16	2212	1963-64	1028	36	
1964	129	44	2482	1964-65	1427	52	
1965	354	104	2088	1965-66	480	25	
1966	518	151	1273	1966-67	603	37	
1967	282	92	1813	1967-68	616	41	
1968	182	53	1925	1968-69	618	29	
1969	374	116	1517	1969-70	308	29	
1970	245	81	1399	1970-71	825	52	
1971	11	3	2753	1971-72	1246	57	
1972	19	7	2602				
Mean	219	67	1991		776	39	
C.V.	0.73	0.71	0.25		0.41	0.30	
V68591	Dreketi River						
1954	120	34	2688	1954-55	1943	85	
1955	105	35	3745	1955-56	3024	88	
1956	372	97	3626	1956-57	1690	52	
1957	335	92	2872	1957-58	616	24	
1958	461	148	1316	1958-59	865	39	
1959	281	82	2207	1959-60	1537	53	
1960	189	52	3196	1960-61	1395	61	
1961	112	28	2995	1961-62	1752	85	
1962	354	94	1360	1962-63	959	53	
1963	216	56	2234	1963-64	1636	47	
1964	120	36	3424	1964-65	3037	87	
1965	485	121	3545	1965-66	1045	37	
1966	668	173	1934	1966-67	1169	48	
1967	312	88	2268	1967-68	1192	46	
1968	352	86	2450	1968-69	796	27	
1969	481	138	2016	1969-70	1310	68	
1970	280	81	2575				
Mean	308	85	2614		1498	56	
C.V.	0.51	0.50	0.29		0.47	0.37	

Annual Deficit (DEF), Surplus (RO), Number of days of deficit and surplus (ND,NR) annual rainfall (RR), Coefficient of Variation (CV = Std. Dev./Mean). Soil Constant S = 75 mm: Average Penman PE: Deficit for calendar year, surplus for Sept.–Aug. "water" year. (millimetres)

II. THE WATER BALANCE MODEL AND ITS APPLICATION TO FIJI

INTRODUCTION

In any evaluation of agricultural water use it is essential to estimate the various components in the water balance equation. This is especially so in the island environment of the South Pacific such as Fiji where the availability of water particularly in the dry zone is often limited for agricultural purposes.

Until the present, research on the agricultural hydrology of various crops in Fiji has received little attention. However, in the future, as the demand on water increases with agricultural expansion, the efficiency of crop water use will become a crucial consideration in water resources development. In this context, the water balance equation will serve as a useful framework to evaluate the different factors responsible for the disposal of water.

In view of the importance of this equation, this paper sets out to briefly examine the water balance model, and to analyse its applications to Fiji.

A. THE WATER BALANCE MODEL

A generalized water balance equation may be stated as follows (Tanner, 1967):

$$ET = P - (V_r + V_i + DV_w + DV_s)/A \qquad \text{-----}(1)$$

Where

ET	=	Evapotranspiration	cm, cm/time
P	=	Precipitation	cm, cm/time
V_r	=	Volume of surface and sub-surface runoff from the catchment	cm^3
V_i	=	Volume of intercepted water	cm^3
DV_w	=	Volume change in ground water storage	cm^3
DV_s	=	Volume change in water storage above the water table	cm^3
A	=	Area (catchment)	

The term evapotranspiration refers to the combined evaporation from all surfaces and the transpiration of plants. The concept of potential evapotranspiration was defined by Penman (1956) as:

> The amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water.

This definition has received general acceptance by hydrologists, although its limitations have been discussed by Chang (1968).

There are at least six different methods for estimating potential evapotranspiration: (1) direct measurements by lysimeters, (2) empirical formulae based on climatic factors, (3) the aerodynamic approach, based on the physics of the atmosphere, (4) the energy budget approach, (5) the use of evaporimeters such as pan evaporimeters and (6) the water balance method.

Methods such as the lysimeter, the aerodynamic and the energy budget may be regarded as primarily for research purposes. A distinguishing feature of the methods mentioned above is that they are process oriented, and as such they provide a deeper understanding of the physics of the evapotranspiration process.

In Fiji, the estimation of potential evapotranspiration using either the lysimeter or the aerodynamic method has not been made primarily because of the high cost of the installation and the operation of the instruments used in these techniques. The energy budget method has been used for stations where the appropriate data were available such as Nadi Airport. The most common instrument for estimating potential evaporation is the United States Weather Bureau Class A Pan. The water balance technique has also been used by Ward (1965) to determine actual evapotranspiration based on the Thornthwaite (1949) method.

The estimates of potential evapotranspiration and water balance have been used to study applied agricultural problems. While the scope of water balance technique has not been explored fully in Fiji it appears that it can be used to investigate the following problems: (1) evaluation of water resources of a region; (2) determination of crop water use and irrigation needs; (3) formulation of agro-climatic models and (4) prediction of crop yield. In this paper, the irrigation requirement of sugar cane based on the water balance model is analysed.

B. APPLICATION OF THE WATER BALANCE MODEL

One of the most important functions of the water balance model is to determine the irrigation requirements

By Prem C, Prasad, Head of Geography, School of Social and Economic Development, The University of the South Pacific.

of crops. In Fiji, a feasibility study was carried out to determine the water requirements of sugar cane based on climatological factors (Prasad, 1981). A detailed study was carried out for the Lautoka district. Other sugarcane growing areas were also included in a separate study as reported below.

1. Estimates of irrigation needs of sugarcane in the Lautoka district

In absence of detailed information on the canopy development of sugarcane in Fiji, which is vital for monitoring the consumptive water use of the crop, observations of rainfall and unadjusted pan evaporation were used to obtain a simple water balance model for Lautoka on a monthly basis. Measurement of rainfall and pan evaporation taken at Lautoka Mill were assumed to be representative of Lautoka district. The results are summarized in Table 24 from which it is clear that in the district there is a distinct dry season from May to November. For the remaining months, water surplus condition prevails.

The water balance models given in Table 24 provide information on the status of water on a monthly basis. In particular, they indicate the onset, the severity and the length of the drought season. This type of information is vital in assessing the impact of water resources on agricultural production.

While these computations give an idea of the relative amount of the water required by sugarcane, the following limitations in the interpretation of the data should be taken into account: (1) the evaporation from pan may be equated to the water use by sugarcane only over a period such as a month, but the relationship is not valid for shorter intervals as demonstrated by Ewart (1967), (2) the relationship between pan evaporation and the consumptive water use pattern changes significantly as the canopy develops (Chang, 1961), and (3) the role of soil moisture storage is not taken into account. In spite of these limitations the rainfall minus potential evapotranspiration index has been used to monitor irrigation requirements of sugarcane in India by Mallik and Pimpalwadkar (1963).

Monthly potential evaporation rates for Lautoka were calculated using the Thornthwaite (1948), Linacre (1977) and Penman (1956) methods. Water deficiency based on these methods amounted to 335 mm; 264 mm; 242 mm; and 450 mm. The range in the estimates amounted to 208 mm. The differences in the estimates cannot be resolved until precise measurements of potential evapotranspiration rates are made.

The amount and the frequency of irrigation will depend upon the stage of the crop growth. For this reason it is important to consider the growth cycle of sugarcane in relation to the monthly distribution of water balance. There is, therefore, a pressing need to commence measurement of the canopy development of sugarcane, particularly from the point of view of leaf area index, crop geometry and height. Such variables can be incorporated in the water balance model to arrive at a more realistic estimate of crop water use.

Table 24. Estimates of water deficiency for Lautoka Mill

	Water balance method	*Period*	*Water deficiency (mm)*	*Duration of water deficiency*
1.	Rainfall minus pan evaporation	1958-1967	335	May to November
2.	Rainfall minus pan evaporation	1961	158	March. May-July, Sept.-October
3.	Rainfall minus pan evaporation	1963	51	October
4.	Rainfall minus potential evaporation (Thornthwaite, 1948) a	Mean 20 years	264	May to mid-November
5.	Rainfall minus potential evaporation (Linacre, 1977)	1961-1970	450	About April to mid-November
6.	Rainfall minus potential evaporation (Penman) a	1957-1980	242	June to November

[a] Fiji Meteorological Service, Information Bulletin.

2. Estimates of irrigation requirements of sugarcane in selected sugarcane growing districts

Simple water balance calculations using the rainfall minus potential evapotranspiration were made for Labasa Mill, Sigatoka Research Station, Nadi Airport, Seagaga Agricultural Station and Rarawai Mill. The results are summarized in Table 25.

For Labasa Mill, calculations based on Penman (1956) and Thornthwaite (1948) methods yielded close results: the seasonal water deficiency was 210 mm and 221 mm respectively; and the seasonal water surplus was 845 mm and 903 mm respectively. The months during which deficiency and surplus occurred were the same in both cases.

Thornthwaite's method gave water deficiency of 38 mm for Sigatoka Research Station while Priestly-Taylor's method gave the deficiency of 102 mm. For this station, the result is consistent with that found in Hawaii, where Thornthwaite's method under-estimated the potential evapotranspiration (Chang, 1968). However, the calculated values for water surplus were closer, but the months during which surplus occurred were shown to be different in the two calculations (Table 25).

For Seagaga Agricultural Station, water deficiency of 201 mm was identified during May to October, and a surplus of 953 mm during January to April, and during November and December.

Thornthwaite's method was also used to calculate water deficiency and surplus at Rarawai Mill. Deficiency of 180 mm occurred during May to November while surplus of 838 occurred during January to April and in December.

Rainfall minus pan evaporation was calculated for Labasa Mill for 1965-72. The season of water deficiency is well defined for this station extending from May to September. The month with most severe water deficiency was August.

Calculations presented in Table 25 cannot be verified, as no measurements of potential evapotranspiration are available for Fiji conditions. At this stage, the quantitative values of deficiency should be regarded as an approximate guide to irrigation needs.

CONCLUSION

Estimates of potential evapotranspiration, water balance and irrigation needs of sugarcane reported in the paper vary considerably from one another. This variation reflects the empirical nature of the climatological formulae used in the estimates.

The accurate determination of agricultural water use is likely to assume greater importance in Fiji in the future as agricultural expansion occurs particularly in the dry zone where the occurrence of droughts often decrease crop production. The application of the water balance model can yield solutions to practical problems in agricultural hydrology.

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Table 25. Rainfall minus potential evapotranspiration for selected stations in sugarcane growing districts of Fiji

		Station	*Period*	*Water deficiency (mm)*	*Duration of water deficiency*	*Water surplus (mm)*	*Duration of water surplus*
1.	Penman	Labasa Mill	1959-1980	210	June-October	845	January-May and November-December
2.	Thornthwaite	Labasa Mill	Mean 20 years	221	June-October	903	January-May; November-December
3.	Priestly-Taylor[a]	Sigatoka Research Station	1954-1980	102	August-November	446	January-July; and December
4.	Thornthwaite	Sigatoka Research Station	Mean 20 years	38	June-August; and October	484	January-May; September; November-December
5.	Penman	Nadi Airport	1949-1970	212	May-November	342	Jan-April; December
6.	Priestly-Taylor[a]	Seaqaqa Agricultural Station	1971-1979	201	May-October	953	Jan-April; November-December
7.	Thornthwaite	Rarawai Mill	Mean 43 years	180	May-November	838	Jan-April; December

[a] Fiji Meteorological Service.

III. LAND AND WATER RESOURCE DEVELOPMENTS AND THEIR ENVIRONMENTAL IMPLICATION

Water apart from being the essence of life and basis for the viability of natural ecosystems, for man it has become a vital resource for personal hygine, agriculture, industry, transport, power generation. Even though about 70 per cent of the earth's surface is covered with water, only about 1 per cent of this is freshwater and man has attempted to control and utilize its availability and movement by modifying almost every stage of natural hydrologic cycle. Attempts have been made to increase rainfall, increase or decrease runoff, reduce evaporation from water surfaces. Rivers and streams have been impounded in dams, reservoirs for potable water supply, generation of electricity and flood control. Flow of water in creeks and rivers has also been interrupted or diverted for agricultural, domestic and industrial purposes. Water is diverted from one basin to another. Ground water resources are utilized and recharged. Rivers lakes apart from being major sources of water they have been both purposefully as well as inadvertently used as disposal pathways for waste materials produced during man's activities.

Planning and utilization of these various aspects have been independent of each other and often oblivious of the environmental effects on the system. As noted by Bowman (1979) planning and management of resources have been "future-oriented and problem centred: concerned with avoiding future problems and ameliorating those already evident. This piecemeal approach which has partly been due to necessity and historical development has resulted in the consideration of specific resource management separately with little or no coordination of activities which affect the quality of water and environment."

As the terrestrial and aquatic ecosystems are interwoven with water providing the media of continuance and the interrelationship and interdependies between physical and biological processes in a system, man's activities in one affect the viability of the other, as illustrated in the following figure.

An ecosystem in its natural state is in a state of equilibrium and gradually shifts over the evolutionary time scale. Urban and other developments with their associated technological changes and demands changes these rates by order of magnitudes beyond the potential of environment to absorb and thus with far reaching effects on its quality.

Land and water resource developments affect both the quality and quantity of water available for various uses.

By Padma Narsey Lal, Fisheries Division, Ministry of Agriculture and Fishery, Suva, Fiji.

All the various developments are justifiable within their narrow parameters and have positive benefits to the society in the context of development and 'progress'. However, there are also over effects which if considered early in the project cycle could be minimised and benefits derived over a period of time. These other effects tend to have deleterious effects on the environment through series of chain reactions. All projects alter natural environment.

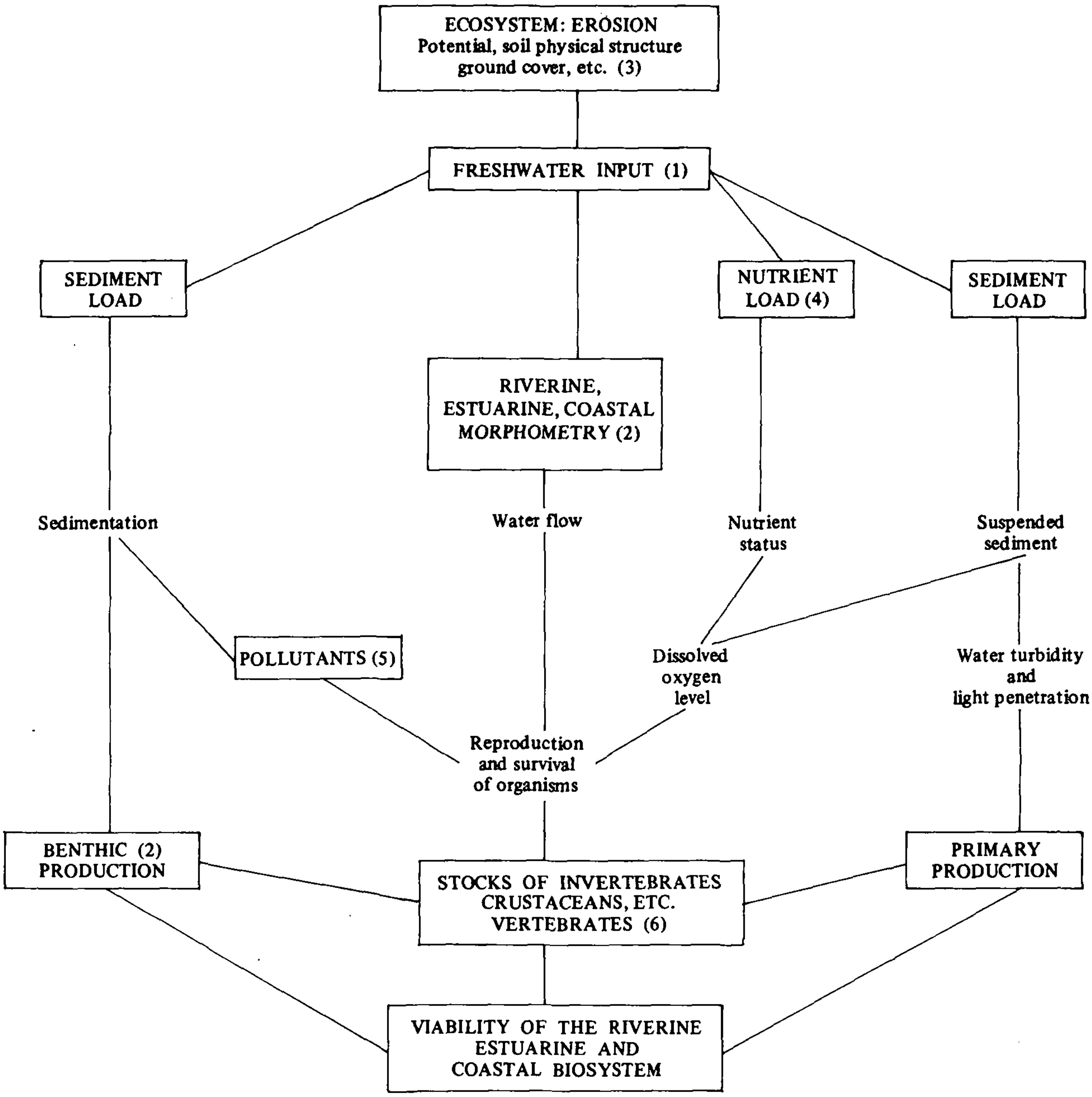
For example impoundment of water for various purposes such as hydroelectric schemes, reservoirs for water supply for domestic, industrial purposes, or irrigation uses, all drastically alter the terrestrial and riverine environment and superimpose a limnological system on them. This resultant system may be an unstable artificial lake with its characteristic limnological features.

The change in volume discharge, velocity of current, development of temperature regime causes modification to the tropic environment (Ackerman et al., 1973). With fluctuating water level, and the changing physical and chemical conditions of water (see Edmunson 1969 for details) and depending upon the morphometric structure of the impoundment thermocline develops which then determines oxygen levels and which subsequently affects the primary and secondary productivity of the system (Bayley and Williams 1973; Ackerman et al., 1973). One of the important effects of impounded water is the possible changes in fisheries resource. Depending on the rate of change of water level, and the morphometry of the lake, nest building and benthic species may get substituted by pelagic species. Other effects of dam construction are changes in water flow downstream, possible discharges of polluted water and their effect on fishery downstream. (Table 26).

Uncontrolled tapping of groundwater particularly in coastal areas can cause changes in water salinity with infiltration of seawater into the aquifer.

Dredging of estuarine or coastal areas, draining of coastal wetlands cause in some cases destruction of habitats, spawning and nursery grounds. Modification of stream courses and training of streams results in some cases in abnormal flow of water which may cause severe flushing and erosion of banks as well as changes in periodicity salinity particularly where large volumes are diverted.

Development activities have direct and indirect impact on water quality and aquatic environment in general. Urban development in general leads to an increase in rainfall-runoff (Starter and Boyd, 1972). This increased



Man's intervention:

(1) Dams, weirs, diversions, drains
(2) Dredging and infilling
(3) Agriculture, roadworks, housing, etc.
(4) Excessive nutrient load from sewage, rainfall and runoff
(5) Pollution load in excess of flushing capacity
(6) Overfishing, effects of pollution, reclamation of feeding and nursery grounds.

Figure 25. Interrelationships between physical and biological processes in and implication of man's activities

freshwater input leads to changes in riverflow, estuarine and coastal circulation and flushing patterns which may cause changes in salinity regime and associated sedimentation process (Warner et al., 1977). Changes in freshwater flow have resulted in certain areas decreased productivity of commercial fish, prawns (see Chapman 1966, Lindall 1973, Sutcliffe 1972, Kutkuhn 1966; Ruello 1973 to mention only few).

Urban development and associated industrial developments make demands on freshwater for domestic and industrial uses. This then necessitates impoundment of water. Usually these uses change the water quality during the utilization, and polluted water is discharged into rivers, lakes or coastal waters.

Agricultural practices make demands on water for irrigation which requires damming or pumping of water from rivers. Agricultural development itself are sources of pollutants. Poor land use management causes exposure of soil surface which leads to erosion. Subsequently through siltation and sedimentation estuarine and coastal habitats (Brown and Clark 1968; Hattersley et al., 1973) and coral reef (Endean 1978) are affected. Increased sedimentation leads to changes in estuarine circulation patterns, tidal flushing which alters the hydroperiodicity and salinity regimes with implications on the ecological balance (Carter et al. 1973).

With increased intensification of agricultural activities, such as increased use of fertilizer and pesticides, irrigation, the poor management has resulted in loss of fertilizer and pesticides into top soil, surface and ground water (Loehr 1979).

The effects of chemical pollutants and other kinds of contaminants are not very specific. Biological systems show a generalized response to stress of many kinds, such as nutrient enrichment, chemical and thermal pollutants. The response include increased overall productivity of the community (through productivity of some, often desirable stocks are reduced) (EPA 1976; Farrington 1976); reduction of average size and life span of the individuals of the community both by increased mortality and by changes in faunal physiology (Schubell and Maude 1976); build up of harmful chemicals such as herbicides and pesticides in food organism (Lincer 1976; SPCC 1979). The net result being that of some of the water bodies can no longer be used as a source of water, for recreation and/or fisheries.

While it is accepted that for development certain changes in environment are unavoidable but the conservation of an ecosystem is vital for its continued *multipurpose* usage and its stability. Usually development can be encouraged within the constraints of nature and with minimal effect on the aquatic life. Given the peculiarities of small island nations with their limited land and freshwater source, it is urgently necessary to develop a multipurpose policy for both land and water. With increasing demands for land and water, overall policy for use and management of them as a *system* is required. Also for other types of water resource management such as urban runoff, industrial and domestic effluents, irrigated water in general any source of polluted or contaminated water, pollution control measures are urgently required before our rivers, estuaries and coastal water become devoid of the aquatic life and quality deteriorates to the points where no other uses can be allowed.

Table 26. Possible negative effects and its possible solutions of water and land development

Development activity	*Possible negative effects*	*Possible solution*
1. Impoundment and/or diversion or abstraction of water	(a) Loss of the original stream fishery within the reservoir basin. Alteration of upstream fish fauna because of migrations of fish from the reservoir.	(i) Development of a fishery in the new reservoir (man-made lake).
		(ii) Efforts may also be made to change the composition of other faunal (or floral) assemblages such as plankton, benthic invertebrates, forage or predatory fishes. (Note that care must be exercised in selecting new (i.e., non-native) aquatic species for introduction into a reservoir or elsewhere throughout the basin because of possible adverse effects on upstream and downstream faunal relationships.)
		(iii) Other aids to development of fish populations include installation of spawning devices, improvement of shelter, vegetation control, and destratification. Fishing for food species using nets may be facilitated by clearance of trees and brush prior to impoundment. Provision of access roads and launching and landing facilities may be necessary for fishery development of the reservoir.
		(iv) Aside from the development of a fishery in the major reservoir which has been created, it may be possible to establish aquaculture in other areas (especially irrigated ones) using some of the water diverted from the stream.
	(b) Reduction of flow in normal stream channel below dam, with a consequent reduction of living space and spawning and nursery grounds, changes in food production zones, etc. Productivity in the main stream can also be lessened through diminished inflow of organic matter from the formerly inundated areas. Conversely, reduction of flow may be harmful in some streams by diminishing the normal pattern of flushing action which serves to keep channels clear for fish migration and prevents the encroachment of riparian vegetation which may diminish fish habitat and make (sport) fishing difficult.	Provision of adequate flows of water, especially at critical times of year or even day.
	(c) Fall in water level below a dam may uncover barriers to upstream movement and inhibit downstream migration of fish.	Removal of exposed barriers.
	(d) Changes in velocity of water with consequent effect on holding position of fish, their feeding, spawning, etc.	As above. Installation of devices to increase or decrease velocity.

Development activity	Possible negative effects	Possible solution
	(e) Change in water quality below dam (e.g., discharge of dissolved toxic gases or water with low oxygen) with consequent injury to fish.	(i) Regulation of time, place, and amount of discharge. (ii) Destratification of the reservoir by various means to improve water quality. (iii) Clearing of vegetation from reservoir. (iv) Re-aeration below dam.
	(f) Changes in water temperature which affect survival or spawning of particular species, food production, etc.	Selective water release from surface or lower levels of the reservoir, through installation of multiple outlets or changes in chronology of release.
	(g) Disappearance of shrimps, oysters and other estuarine species through changes in the seasonal salinity gradient or reduction of food supply as floods decline.	(i) Modification of the stream flow releases to accomodate various environmental requirements of the estuarine fauna. (ii) Relocation of the fishery. (iii) Substitution of aquaculture of various kinds.
	(h) Fluctuation of water level in reservoir above dam may strand fish, reduce living space, destroy vegetation, change or reduce food components, influence spawning adversely, produce changes in habits inimical to stocks, etc.	(i) Regulation of levels to provide "minimum pool", and/or more constant conditions at critical seasons. (ii) Construction of secondary impoundments.
3. Diversion or abstraction of water from streams or reservoirs	(a) Loss of fish which enter diversions (canals, penstocks, etc.). Physical damage to fish passing over dams.	(i) Installation of mechanical fish screens (stationary, rotary, belt-type, travelling, louver, etc.), or electrical deflectors or screens. (ii) Use of by-passes in diversions to enable fish to return to streams.
4. Drainage and dredging or land-filling of water and wetland areas (estuaries, lagoons, marshes, overflow areas, etc.). Removal of deposition of spoil, logging debris, etc.	Destruction of habitat, spawning areas, food-producing zones, etc. Creation of barriers or deterrents to fish migration.	(i) Prevent damaging drainage. (ii) Provision of adequate flows to maintain overflow areas. (iii) Ban on removal of gravel necessary for spawning. (iv) Removal of debris. (v) Removal of unnatural barriers. (vi) Installation of devices to permit migration (e.g., through road culverts).
5. Modification of stream courses (training)	Abnormal increase of flow of water can cause severe flushing and erosion	Preservation of natural features of streams, contours, or meanders rather than straight chutes.
6. Any activity resulting in water pollution. (Pollution with respect to fisheries includes all harmful changes in water quality, including excess heating, salinization and siltation as well as the introduction of toxic substances, pesticides, oxygen-consuming materials, radio-active wastes, etc. Thus agriculture road building, logging, irrigation return, and discharge from thermal plants may contribute to pollution.)	Degradation of aquatic habitat (as through silting, which destroys stream bed organisms, renders spawning gravels less permeable, etc.), destruction of food organisms, deterioration of fish stocks, changes in species composition, mass destruction, establishment of residues in fish flesh which are harmful or objectionable to consumers.	(i) Control of siltation through reforestation, cover cropping, terracing, contouring, better road location, soil stabilization, etc. (ii) Removal of silt from channels through various devices. (iii) Control of other forms of pollution by pre-treatment of effluents, timing of discharges, land disposal of pollutants, redesigning of processes to alter quality and quantity of effluents, better location of plants, re-use of wastes, etc. (iv) Ban on use of certain pollutants.
7. Any of the above which reduce fish stocks or habitat.	Reduction or change of habitat to such an extent that the natural wild stocks have declined to a point of almost no return.	Replacement or augmentation of fish stocks through: (i) artificial stocking; (ii) operation of artificial spawning areas. Such means may involve the construction and operation of new fishculture facilities for collection, holding, spawning, hatching, rearing, and transport. If study shows that the decline in natural stocks (due to the development project) will be severe, provision for some or all of the above measures should be an integral part of the project.

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IV. WATER RESOURCES FOR ELECTRICITY GENERATION IN FIJI

1. This paper begins with brief notes on Fiji and the organization, the Fiji Electricity Authority, which is developing the hydro resources to be found here. Reference is made to the climate and size of islands which both affect the level of resources, and to the demand, actual and potential which affects the scale and pattern of development. We then list the hydro resources available for electricity generation, and describe factors which have a bearing on their development. We describe the investigation and history of the Monasavu hydro station. Hydro potential in the smaller islands is considered as well as mini hydro.

2. Fiji consists of a group of over 100 islands in the South Pacific, lying between latitude 15° and 22° South and longitudes 174° West, with a total land area of some 18,400 sq. km. No more than 100 islands in the group are permanently inhabited. It has a population of about 650,000 of which approximately 90 per cent lives on the two main islands of Viti Levu and Vanua Levu. It has a typical tropical oceanic type of climate, modified by the mountainous ranges of the large islands which lie athwart the prevailing southeast trade winds. Temperatures range between 60° and 90° Farenheit (15.7° - 32.5° C). The two main islands have distinct wet and dry zones, with the northwest (dry) zones experiencing average annual rainfall of about 1,800 mm compared with the southeast (wet) zones which have an average annual rainfall of about 3,300 mm.

3. The Fiji Electricity Authority (FEA) was established by Act of Parliament in August 1966 as a statutory authority to promote and encourage the generation of electricity to aid the economic development of the country. It was also to advise the Government on all matters relating to the generation, transmission, distribution and use of energy and to establish and operate such electrical installations as the Authority might deem it expedient to establish. At the time of its establishment, the Authority's installations were limited to two Government-owned suppliers at Lautoka on the main island of Viti Levu, and Levuka on the island of Ovalau, and to the power supply at Nadi International Airport on Viti Levu. Total consumers numbered 2,500. Since then the FEA has taken over and expanded a number of electricity supplies, including the Suva City supply, run by the City Council. At the end of 1981, the Authority owned and operated a total of 11 power supplies with an installed capacity totalling 85 MW and a firm capacity of 61 MW. The total number of consumers at the end of 1981 was 42,244. During 1981, it sold 206 Gwh of electricity, with a maximum demand of about 40 MW. All the present generating sets are diesel powered of a considerable range of ages, efficiencies and sizes. These figures indicate growth and also the ability to take up much of the output of a medium sized hydro station.

4. Fiji has a useful amount of potential hydro power, mainly in the island of Viti Levu, where it is capable of supplying total electricity demand for many years. This hydro potential has long been recognized and there have been a number of more or less detailed investigations since the 1930's. The main ones were of a dam site on the Navua river by an English firm of consultants (abandoned because of foundation problems), a major study of potential schemes on the Nadrau plateau in Central Viti Levu by a New Zealand firm of consultants and the investigations leading up to the present development by Australian consultants. The islands of Fiji vary greatly in size, topography, climate and population, all of which have a considerable bearing on hydro generation resources, or on the demand for electricity. Nearly all resources and most of the demand are on Viti Levu, but there is some potential power available on the other islands.

5. There are several important factors to be considered in hydro development in Fiji. Power is of course, basically a product of stream flow and head. As noted earlier, the climate here has distinct wet and dry zones, and the rainfall pattern can vary quite quickly over a catchment. As well, there is a pronounced pattern of dry and wet seasons each lasting about half the year. There is also a great difference between wet and dry flows in most long term hydrographs. This is particularly so in the smaller streams in the mountains where much of the hydro potential is located. The result of all this is that large storage is needed to even out flows over the year.

6. Topography is another important factor. Many of the islands are of igneous and volcanic origin. In Viti Levu volcanic activity has resulted in a high central plateau ending in a vertical escarpment. Not only does this provide good head, for a reasonably sized flow, but the plateau is flat enough for a dam to provide adequate seasonal storage. On the other hand in Vanua Levu the mountain ranges are the steep razor backed type, so that usually when catchments have reached the size to carry useful flows, there is little head available. Another result of the geological origin is that there can be permeable strata in the formations, or stress or temperature cracking. Many of

By E.W. Heine and H.Y. Sue, Chief Engineer and Assistant Chief Engineer, Fiji Electricity Authority.

the rocks too, decompose or weather to red clays in the local climates. They are very sensitive to moisture, and difficult to work in any sort of wet conditions. It is the case too, that there is little fine material in sand sizes, causing problems in getting these materials at low costs, not only for dam construction but also in road and other construction. There is often no way of avoiding costly crushing and screening. Hydro stations are often located in isolated areas, with high access and transmission line costs.

7. There are economies of scale in hydro construction and in a place the size of the Fiji Islands, costs tend to be high. The rather small sizes of streams (but with large floods), the small or medium sized power stations and also the rather low demand, all help to raise costs, although there are plenty of developments here with quite acceptable costs. It is noted too that hydro stations are capital intensive with mainly fixed costs and low output-related costs. It can make a great difference to the economics of a scheme to be able to take up the rated output quickly. It also warrants careful study on how best to make up occasional "very dry year" deficiencies.

8. Before describing specific developments we list in Table 27 the resources proven or indicated that are available. The list is in several categories beginning with the Monasavu scheme now under construction. The category of 'proven' includes schemes which are additions to Monasavu or to the Nadi/Lautoka Water Supply dam at Vaturu. While they are small, their output and feasibility conditions are proven and they can each be implemented and built within 2-3 years. The next category is 'under investigation' where we have a fair understanding already of the run-offs and heads, where preliminary layouts have been drawn up, but where detailed survey, and also a comprehensive drilling programme is still required, before the scheme can be regarded as 'proven'. Lastly 'indicated' includes sites where a study of contour maps and inspection shows a combination of catchment area and head that is worth looking at, but not much more. The first step after identification is setting up a hydrological network to establish flows and flow patterns. Table 27 gives both average annual output and, 'firm' output. 'Firm' output is defined as that which can be sustained for 95 per cent of months over a long period (50 years or more).

9. The Monasavu Power Scheme, now under construction, is on Viti Levu, which has about 75 per cent of the total population, mainly in the Suva area in the East and the Nadi/Lautoka area in the West. It is located on the high central Nadrau plateau and represents the result of a number of investigations into several viable schemes. Originally the proposal was to begin with a smaller scheme, to meet load increases on the existing system, but when the world prices of oil increased rapidly it became economically attractive to build a much larger station to replace the existing diesels as well as to meet the load increases. The scheme as first planned was also extended by the diversion of a number of adjourning catchments into the reservoir, thereby more than doubling the inflow. The 3-stage scheme includes an 80 m high dam at the point where the Nanuku Creek falls over the Nadrau escarpment, backed by a lake with an area when full of some 500 hectares. This lake is fed directly by Nanuku Creek and, via a series of weirs and tunnels, by five intermediate creeks. The farthest catchment, the Wainisavulevu Creek is a sizeable one, with a flat stream gradient which will allow for more storage to be provided later.

10. Storage is an important part of this scheme. The main reservoir at the Monasavu dam has a specified range of 35 m, this giving a live volume of 117 million cubic metre (MCM), which is quite adequate to make good use of flows. For example at a demand between 'firm' and 'average' water spilt in routing a synthetic hydrograph of 68 years was 11 per cent, while shortfalls were 3 per cent. At the present time the diversion from the Wainisavulevu Creek is of run-of-river type. In a few years, a weir of around 10-15 m high will provide pondage (4-6 weeks average flow) so that better utilization of Wainisavulevu water will economically meet increasing demand. Later again, a storage dam (upto 20 months average flow) can be built upstream, but this would likely be used to provide storage for future schemes which have only limited storage.

11. As often seems to be the case with hydro developments, longer hydrological records for Monasavu would have been helpful. The dam is located near the edge of the escarpment referred to earlier, with the Nanuku Creek running directly back from it, and rainfall decreasing quite quickly with distance back. Rain gauges show a considerable variation over the catchment. Also while flow gaugings had been taken on the creek for some years, there were gaps in the record and doubts about some data. It was necessary therefore to begin an intensive programme of rainfall and stream flow recording. There was a long established rainfall recorder some distance away on the plateau, and a degree of correlation was found between this and the new gauges installed in the catchment. All this allowed a reasonable estimate of flow, but more results will be needed to get a better assessment of station output.

12. At the Monasavu scheme power will be generated by four 20 MW turbines at a station on the Wailoa river some 600 m below the reservoir. The bulk of the Viti Levu demand is at Suva on the East and at Nadi/Lautoka on the West of the island, with little in between. The Monasavu

scheme is in the middle, and a high voltage line to supply these loads is included in the scheme. It was necessary also to amalgamate the Suva City Council electricity supply with the Fiji Electricity Authority. The transmission line of course added to the cost of the scheme, but has introduced advantages into the operation of the two load centres even before hydro generation, by allowing the use of the most efficient engines on both sides of the island. The final design is for a 132 kV line 136 km long to the Cunningham Road Substation near Suva in the East and to the Vuda Substation near Nadi in the West. The scheme with its installed capacity of 80 MW is estimated to have a production of 'firm' energy of 361 Gwh/ann. and 'average' energy of 394 Gwh/ann., which can be compared with the demand figures in the 1981 annual report for Viti Levu of about 40 MW and an annual consumption of about 217 Gwh.

13. For investigating future schemes we have set up a sizeable hydrological network with the Ministry of Works. This will cover all stations likely to be needed to beyond the year 2000, the aim being ultimately to give 15 years or more of record at a station when intensive investigations are begun. Detailed investigations have begun on the North-Western part of the central plateau where two rivers, the Sigatoka and the Ba run parallel for some distance but with the Ba about 300 m below the Sigatoka. Various diversion layouts are possible. Storage is limited to months of long-term average flow (LTAF). There could be problems with permeable zones in one creek. About 100 Gwh and 40 MW should be available. Another scheme to be investigated is on the Navua river, this so far being limited to map studies and aerial inspection. It is a much bigger development good for perhaps 300 Gwh at 50 MW. It was at one stage linked to a possible mineral development, but with present levels of demand and growth it would take a long time to absorb its output. The scheme would have much of its head provided by the dam, limiting live storage. Low flows and also large flood and diversion flows will have to be coped with. Other schemes are similar to Navua (dam providing the head) or possibly diversion schemes. There could be another 600 Gwh available.

14. In planning and programming hydro developments in Viti Levu we must note that existing diesel stations have to be kept operational for many years for security of supply. This is partly to provide supplementary supply in very dry years, but mainly to provide a back up for the single power station and the long single transmission lines to East and West. This means that in meeting shortfalls in dry years as the load increases, the cost can be taken as a fuel cost only. In planning the expansion of the system we can thus compare the fuel cost to meet shortfalls with the savings in capital charges from deferring capital construction. Of course once we have duplication of transmission lines, and a number of separate stations, the position changes.

15. Vanua Levu, the other main island has not nearly the same resources. While climate is similar, the topography is one of steep ridges, and there is no high central plateau to provide head and storage sites. By the time most creeks have picked up useful flow, there is little head left. However a recent energy survey, and also previous work have identified a number of possible small hydro sites. The main problem is dry weather flow and also the fact that the load consists of two main centres separated so far that the distance and the small load hardly warrant interconnection. However, there is a sugar mill in Labasa, the main centre, which generates enough electricity to carry much of the local load. The off-season for the mill is in the wet season so it and hydro complement each other, to some extent. The Vanua Levu schemes are small, ranging between about 500 kw and 1000 kw.

16. There is scope for some mini hydro in Fiji, but detailed investigation is needed. The main objective would be to find sites close to a village, also to find sites with adequate flow and head. Other problems are low flows, and in the drier parts of the island these can be very low indeed. Estimates in various reports range from one $1/s/km^2$ upto less than 10. Figures of 2-3 $1/s/km^2$ seem not uncommon and this indicates the need for dry season gauging before building on a site. Floods, particularly if a station is fed from a tributary to a main stream, can mean rises in water level of the 10 m or more, ruining any hydro station caught by it. To begin with, a comprehensive study is needed, to set guidelines and standards for demands and for the various items that go to make up an installation. However, there are certainly promising sites. Care is needed too that engineering costs do not get out of proportion to the total costs. Capital costs of turbine generating sets for mini hydro are currently high, but efforts are apparently being made in various places to bring this down.

17. We can summarize the above by saying that Viti Levu has good hydro resources. The first stations will begin generating next year, and we are setting up a programme of investigations that should allow us to meet future load demands with hydro, until after 2000. There are useful small resources in other islands, but a problem is usually the low flow. However, these down to mini hydro size do bear investigation and costing, so that if the situation warrants it, they can be brought into use.

Table 27. Hydroelectric resources in Fiji

		Firm power 10^6 kWh	*Average annual generation 10^6 kWh*	*Installed capacity MW*	*Storage months – LTAF[c]*
	VITI LEVU				
1.	Under Construction–Monasavu Stages 1 – 3	361	396	80	11 Nanuku[a] Creek
					4– (Total inflow)
2.	Proven –				
	Wainisavulevu Pondage	18	20	–	4-6 weeks
	Wainikasou Power Scheme	16	20	6	4-6 weeks
	Vaturu Power Scheme	24	36	15	(Operated with PWD)
	Vaturu Trunk Main Power Scheme		3-14	1.6	
3.	Under Investigation-Upper Sigatoka/Ba	62	144	46	2-4 months
4.	Indicated Navua		340	50	
	Other		600-700	100	
	TOTAL – VITI LEVU (approx.)	1000	1500	300	
	VANUA LEVU				
1.	Partly investigated[b]		10^6 kWh	KW	
	Saquru		6.5	970	
	Lovo		4.7	710	
	Other (approx.)		10	1500	
	TOTAL – VANUA LEVU (approx.)		20	3000	

[a] Nanuku Creek feeds directly into the reservoir, forming Stage 1. Stages 2-3 are diversions into the reservoir by tunnel from other catchments. The largest creek diverted Wainisavulevu can have pondage (4-6 weeks) and storage (20 months) constructed on it, which will give a much more controlled flow into Monasavu.

[b] The schemes are from studies by several consultants. The results vary from fairly detailed surveys, with some years of hydrological records to assessments. The schemes will be fairly small (¼–1 MW) with small intakes, so only limited further work is probably adequate.

[c] Long-term average flow.

V. DEVELOPMENT OF AN ELECTRONIC DATA PROCESSING SYSTEM FOR HYDROLOGICAL DATA IN FIJI

INTRODUCTION

This paper describes the development of a hydrological computer system by Public Works Department (PWD) – Hydrology Section in Fiji. The discussion of such a subject is relevant at this Water Resources Conference because proper development of water resources is only possible if the collected information about these resources is processed. Other agencies dealing with the collection or use of information about water resources may consider processing of their information using a computer.

This account aims to emphasize the problems that may be faced when developing such systems in a small developing country. It also wants to brief local agencies (e.g. some data users) about hydrological data processing in Fiji.

The history of data processing in Fiji is reviewed briefly. Some advantages and disadvantages are listed and some major options affecting the system are included as well. In order to indicate the staffing requirements for the development of such a system, the development process and the Fiji system are described. Finally some Fiji experience is evaluated in more detail.

Some words need to be specified. Data processing (DP) includes all data operations after it has been collected (digitizing and preparation for computer input, storage, validation and retrieval of data, publication, analysis of data, etc.). Electronic data processing (EDP) indicates the use of a computer. A data base or data bank (DB) is a collection of files, in this case on a computer compatible medium.

A. BACKGROUND INFORMATION

Hydrological information in Fiji is collected by the Mineral Resources Department (groundwater), the Meteorological Service (rainfall and evapotranspiration) and the Water and Sewerage Section (water quality) and Hydrology Section (rainfall, runoff and evapotranspiration), both of the Public Works Department.

The rainfall network in Fiji consists of about 280 rainfall stations of which 110 are instrumented with a chart recorder. PWD–Hydrology Section rainfall network includes 98 of these chart recorders and 62 daily read manual raingauges.

By F. Helmich, FAO Hydrologist, Hydrology Section, Public Works Department, Fiji.

The streamflow network is completely operated by the PWD. It consists of 49 stations equipped with a chart recorder and 40 twice daily reading gauges.

The annual volume of data generated from this network includes about 0.1 million (M) daily data values and 1.3 M hourly data values. The backlog of historic data is much greater (say 10 M data values).

The PWD – Hydrology Section is structured in three divisional offices and two units dealing with data processing and instrumentation. The Senior Hydrologist co-ordinates the activities at national level between these five bodies.

B. JUSTIFICATION OF AN EDP SYSTEM IN FIJI

1. History of data processing in Fiji

Many hydrological data in Fiji have not yet or have only poorly been processed. Even the processing of current data in Fiji by manual means is becoming totally impracticable. Overall quality control of data has always been superficial. Thus a systematic feedback between data itself and the data collection has never been practised. This has resulted in a gradual deterioration in the reliability of data. In Fiji this has lead for instance to the rejection by consultants of most early Monasavu river data.

Data publication practices are also poorly developed. The usage of hydrological data in Fiji is seriously limited. Access to hydrological data is difficult, in some cases even almost impossible. Manual analysis of hydrological data have only been carried out in Fiji for a small number of priority projects. This illustrates the limited usage of hydrological information in Fiji once more.

Computer systems for hydrological data have only been introduced recently to Fiji. Some computer based processing of daily and 15 mins rainfall using locally developed software was carried out in 1975/76. The cooperation between EDP – Services and PWD continued in 1979. New systems were initiated then but, partly due to limitations in the allocations of EDP resources, serious delays have been faced since. Provisional systems for daily rainfall and hourly gauge heights became operational in early 1982. In July 1982, a joint EDP/PWD project started to implement PWD's basic requirements. The first phase (processing of hourly gauge heights) is scheduled to run live from April 1983.

The capture of data by EDP Services has not yet been scheduled resulting in serious punching delays and a growing punching backlog. Since 1979/80 about 400 years of PWD daily rainfall data and 1 200 months of hourly gauge heights were entered.

2. The advantages of an EDP system

As described in the previous paragraph, the processing of Fiji hydrological data in general is rather poor. History proves that manual processing is not adequate. Much data remains poorly processed and such a situation represents a misdirection of resources. At present investment decisions in new water resource projects must be taken on the basis of limited amounts of unvalidated data available to project designers. This introduces broad limits of uncertainty into the design, leading at best to over-investments, and at worst to operational failure of schemes.

An EDP system includes the following advantages:

a. Immediate processing of all data will be practised.

b. The level of processing will be high, it includes for instance data quality checks and publication of data.

c. Rapid access to information, easing the analysis of data.

d. More effective use of labour force and expertise, no duplication of work.

e. Standardization of activities related to data processing improves the quality of data, especially where data processing expertise is insufficient (for instance in Fiji's Northern Division).

f. It provides reliable storage of data.

g. It facilitates the transfer of technology.

3. The disadvantages of an EDP system

The disadvantages include:

a. Possible difficulties in maintaining machinery and equipment.

b. A high level of professional hydrological and computer expertise is required to establish and maintain the system.

c. It may reduce employment possibilities.

C. SOME OPTIONS WITHIN AN EDP SYSTEM

Major decisions will have to be taken at the start of the development of EDP system. Some options are listed below:

1. Selection of hardware
2. Centralized or distributed data bank
3. On or off line data processing
4. Level of data preparation and level of data punching (at national/regional/local level)
5. Automatic or manual chart digitizing
6. Digitizing at fixed or variable time intervals
7. Cycles and schedules for data processing
8. Standardization of procedures and routines
9. The complexity and the extent of the computer system
10. Co-operation with other agencies collecting similar data (compatibility requirements).

Other decisions to be taken concern the EDP system development strategy:

1. Local development of a simple system or the adaption of a system from elsewhere
2. Agency to be responsible for software development (for instance in Fiji EDP – Services and/ or PWD and/or outside agency)
3. Need for outside expertise during design and implementation.

There are also other alternatives related to the design of the computer system. These include:

1. Data storage medium (tape or disc.)
2. File organization (for water resources data normally sequential files)
3. Record size and format (fixed or irregular interval series).

D. THE PROCESS OF DEVELOPMENT OF A DATA PROCESSING SYSTEM

1. The development of a computer system

To give some insight in the complex process of the development of a computer system, this process has been classified in the following five stages. The sequence presented is meant as a logical description of the development process. In practice, however, some overlapping may occur.

a. Preliminary investigation

This stage should include the following activities.

- review existing data processing activities
- define future information requirements
- summarize available equipment
- describe preliminary input and output requirements
- investigate existing systems and methods.

b. Preliminary system design

At this stage of development a preliminary system design should be made. This design should be oriented towards recognition and description of subsystems. Each subsystem should be described in terms of:

- input and output specifications
- data processing activities of the subsystem
- internal flow of information
- routine processing and retrieval requirements
- communication paths between the subsystems.

c. Detailed design of the computer system

Once the user has specified his requirements a more detailed design has to be carried out taking into account the following considerations:

- data storage medium and structures
- data model structure (based upon relations between data types)
- record format and file design
- specific problems related to processing routines.

d. The implementation

If a general computer system cannot be made available from elsewhere, much effort will be needed to build a system locally. Such a system includes software for at least entry, edit, update (merge), conversion and output of data.

e. Operation and maintenance

After completion and extensive testing of the system the actual build-up of the data base can take place. It requires a continued input of expertise.

2. Development of data processing routines

DP includes all data operations after its collection. In Fiji the data are digitized and/or prepared manually on coding forms in divisional offices, this is near the source of data. Data punching and further processing is centralized. This implies data transmission. In order to co-ordinate the DP activities within the PWD, a National Data Unit has been established. The responsibilities of the Unit are to:

a. Set standards and procedures for data preparation and if necessary for data collection.

b. Formulate procedures of access to PWD computer data by users.

c. Train national and divisional personnel in data preparation and further processing.

d. Participate in the development of a computer system.

e. Co-ordinate and register routine data processing activities.

f. Carry out immediate correction of punching errors.

g. Supply data listings to users on request.

h. Develop software for basic analysis of data.

i. Store original data charts and sheets.

Number a to c require the production of a manual.

E. BRIEF DESCRIPTION OF THE DATA PROCESSING SYSTEM IN FIJI

PWD processes its hydrological data using Government's computing facilities in Suva. An ICL ME29 together with tape and disc drives, two printers and a number of terminals are the main components of the hardware installed in this centre.

Separate tapes are kept for daily rainfall, hourly rainfall, gauge height (hourly, half hourly, twice daily) and discharge data (daily values with monthly instantaneous extremes). In addition there are tapes with details of rainfall and stream flow stations. The streamflow station detail file includes rating parameters.

The main objectives are: (a) to establish a rather simple DP system and (b) to train local staff to maintain and expand the system.

The daily rainfall computer system, complete with a station information file, has partly been adopted from New Zealand Meteorological Service. This is a rather simple system, however, poorly documented. Punching errors are detected using a sum check (monthly total, i.e. the total within one record). The Fijian version of this system is rather basic and requires to be modified. PWD requires suitable data listings (to enable quality control) and data tabulation (to enable publication). The system as it exists is shared with Fiji MET Service, the files are separated.

PWD has been coding hourly rainfall for more than 4 years. Their requirements have been specified and the preliminary design of a combined system with Fiji MET Service is being finalized. The implementation is expected to be seriously delayed.

The gauge height and discharge system is being developed at present. As with daily rainfall the time intervals are fixed and the record is being identified by station number and date. One record comprises one day of data values. Special checks and correction procedures have been designed to ease and speed up the detection and correction of punching and systematic errors. The system includes data conversion into discharges, data tabulation for publication and the printing of discharge hydrograph and flow duration curves.

Coding forms are sent from the divisional offices to the National Data Unit in Suva. The Unit regulates and registers all movements of coding forms as well as computer printer reports between the PWD divisional offices and EDP-Services. It also carries out the checking of edit reports. The detection of systematic errors and minor punching errors in gauge heights is a divisional responsibility.

F. STAFFING REQUIREMENTS FOR SYSTEMS DEVELOPMENT AND MAINTENANCE IN FIJI

Generally speaking an EDP system can be easily specified for most computers. However, there are several reasons for being cautious with their applications, particularly if there is a lack of computing experience in the country concerned. The main reasons are:

a. Computer systems require a high level of technical skill to implement and maintain.

b. The task of converting to a new system, or modifying an old one, can be very substantial.

c. Computer systems are frequently too inflexible in their design.

The development of an EDP system is an evolutionary process. Expertise will have to be built up, the data base will expand not only in volume but also in data base contents, retrieval options and management level. The maintenance of a system does require continued expertise. In order to give an idea of the staffing resources that are needed when developing a computer system, the (estimated) staffing requirements are listed for Fiji. This is done according to the phasing given in Section D.

For the preliminary investigation approximately half a month of specialized expertise will be required for each subsystem. A specialist on hydrological data processing may be needed in most developing countries.

The preliminary systems design will also require such expertise. This phase is estimated to take say ½ - 1 month, depending on the complexity of the subsystem. The expertise of a systems analyst is required when the feasibility of the proposals made is being assessed. The analyst has to design the system in quite some detail in consultation with the hydrologist. This phase takes about ½ - 1 month.

The main requirements for system analysis/programming input comes during the implementation stages of a system. The gauge height/discharge system in Fiji will require approximately 2 man years of such expertise. Since a rainfall DP system is much simpler in nature (incremental data), the staffing requirements for that system will be less, say 1 man year (including files for station information, daily and hourly rainfall). A close interaction between the hydrologist and systems analyst remains essential during all stages of implementation.

A system has to be operated and maintained. In Fiji approximately 0.2 man year of computer expertise will be needed each year to maintain the hydrological DP system. For gradual expansions (e.g. gauging file and data analysis) more support will be required.

At least one hydrologist with knowledge of EDP systems and computer programming is needed to participate in the design and implementation of the EDP system and to adapt or develop software for data analysis. A second hydrologist is needed to co-ordinate DP activities within PWD, to set out standards and procedures, to train national and divisional staff, to supply data on request, etc. These are minimum requirements in Fiji for graduate staff if continuity in hydrological data processing is to be ensured.

G. EVALUATION OF FIJI EXPERIENCES

1. PWD/EDP Services co-operation on systems development

As described in paragraph B.1 the electronic processing of hydrological data started in 1975/76 and was not continued until 1979/80 when key punching of daily rainfall and hourly gauge heights was initiated. Rather basic and provisional systems were operating in early 1982. Following several requests for more systems and programming support to these two computer applications, EDP-Services reviewed the gauge height system in March 1982 (3). A more formal approach was adopted when PWD documented their requirements (4) and software (5). This resulted in a joint PWD/EDP-Services project to implement PWD processing requirements which started in July 1982. A FAO/WMO consultant data processing reviewed the hydrological data processing in June 1982 (6).

Since 1979/80 PWD has become increasingly dependent on the computer system. Manual conversion of gauge heights to discharges has been completely abandoned in the Central/Eastern and Northern Divisions while the Western Division continues this practice only for their priority stations. Instead, office staff has been trained in manual digitizing techniques.

The delays in systems development are mainly caused by:

a. Limited EDP-Services input
b. The poor systems development approach before 1982 (rather informal fashion, no development planning and no documentation)
c. Optimistic planning of the systems development process (1982)
d. Lack of staffing continuity within PWD as well as EDP-Services.

The development of a simple system locally is providing valuable experience to PWD staff. Knowledge of EDP systems within the PWD Hydrology Section is essential for the future of hydrological data processing in Fiji. However, local expertise within Hydrology Section on computer systems is at present far from adequate to ensure continuation in electronic processing of hydrological data. PWD may have to continue to rely heavily on the support from EP-Services and/or outside expertise.

2. PWD/FIJI MET service co-operation

Both PWD as well as Fiji MET Service collect rainfall data. The combined computer system for daily rainfall is largely based on the system used by the New Zealand MET Service. However, this system needs modifications in order to meet all PWD requirements. The hourly rainfall system will have to be developed locally.

To enable the sharing of a computer system many procedures will have to be standardized. This will involve extra work when dealing with organizations with differences in their network operations and processing requirements.

The PWD-Hydrology Section gives high priority to ease the access and use of their data. If possible PWD will guarantee a certain level of reliability. This implies that at this stage of systems development the access to their data will be limited as most data have not yet passed systematic quality checks. PWD and Fiji MET Service will also have to set out procedures and processing policies for various stages of further processing.

Presently the following procedures to access PWD data tapes apply for Fiji MET as well as for other data users:

a. The data tapes can only be accessed through PWD-Hydrology Section.
b. The use of the data has to be specified and agreed upon.
c. PWD data should not be transferred to other files outside Government's EDP Centre.

3. Impact of EDP on the organizational structure

The divisional activities in Fiji at present include the collection, processing, analysis and supply of data. The introduction of a national EDP system requires some of these activities to be centralized. The divisional activities will increasingly be directed towards data collection and basic processing only. Reorganisation at divisional and national level will thus be required.

National hydrological activities should include the processing, publication, regional analysis and supply of data as well as data base development and maintenance. Reorganisation of the Section will enable a more effective use of the limited expertise in Fiji without loss of quality in divisional work.

For manual digitizing, coding and verification of current data (1983) in total 5 staffmembers will be required in divisional offices. Five additional people will be needed to co-ordinate the data processing activities, to supply data to users and to check data on systematic errors. These numbers represent the minimum requirements and do not include staff needed for management and administration, processing of gauging and clearing the coding backlog of data.

4. New development options

If the development of a computerized system locally turns out not to be feasible, or when the progress of data entry and/or systems development is not satisfactory new options may have to be considered. In New Zealand the Ministry of Works and Development TIDEDA data processing system is being converted to run on a micro computer (9). The World Meteorological Organisation is also developing systems to run on micro computers. Such systems may also be adopted or combined with the existing systems. However, the introduction of these systems will initially require substantial inputs of data processing expertise.

CONCLUSIONS AND RECOMMENDATIONS

1. The major problem when introducing an EDP system to developing countries will be the limitations in computer expertise. The serious nature of this problem should be recognized.

2. The volumes of hydrological data presently being collected together with the inadequate manual processing experienced in the past have justified the introduction of an EDP system in Fiji. During the development of such a system since 1979, PWD-Hydrology Section has become increasingly dependent on the system and the services rendered by the Government's EDP-Centre.

3. Data punching as well as system development has been seriously delayed mainly because of limitations in EDP support and a haphazard approach to systems development particularly in the early stages. The punching backlog is enormous (about 40 M characters, i.e. twice as much as the coding backlog) and the overall progress of the development of the computer systems since 1979 is not satisfactory.

4. The Fiji Government should recognize the importance of hydrological data processing and it should realize that continued limitations in EDP support and PWD data processing expertise will probably lead to failure of the system. This recognition should result in an increase of priority in allocations of EDP resources and PWD data processing expertise.

5. If satisfactory implementation of PWD requirements cannot be guaranteed, PWD should aim to become more independent from Government's EDP-Centre e.g. by purchasing data entry equipment. The introduction of a supplementary micro TIDEDA system may then be considered as well.

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