4th African Water Technology Conference

"Water in Africa - the next Decade"

20-22 February 1990

Kenyatta International Conference Centre
Nairobi, Kenya

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Water in Africa — The Next Decade

The **4th African Water Technology Conference**, held in Nairobi, Kenya, on 20-22 February 1990, aims to review the achievements of the last decade in the water and wastewater sectors in Africa and look forward to the 1990s. One specific aim of the conference is to send an African message to the global consultation meeting being held by all the principal financing agencies and the developing countries in India in September 1990.

The World Bank and the African Development Bank are currentlyt preparing a strategy paper for rural water supply and sanitation development in sub-Saharan Africa, and the World Bank, together with the United Nations Development Programme has organized a distinguished panel to lead discussion of these issues on the first day of the conference, following the successful Bank-led seminar on handpumps held at the previous **African Water Technology Conference** in 1987. Nairobi is also the headquarters of the UN Environment Programme and the environment is the dominant subject for the conference's final day.

Conference programme

<u>Day 1 — 20 February 1990</u>

Morning

9.30 Opening by Minister of Water Development

10.00 Keynote speech by Director of Water Development

10.40 Coffee

11.00 *Development and resources*
Sustainable development in community water supply - IL Nyumbu, Zambia and M Seager, Netherlands
Financial management of water supplies in Kenya - G Mburugu
Discussion

12.30 Lunch

Afternoon

2.00 Seminar on water supply and sanitation in Africa led by World Bank/UNDP.
Subjects covered will include community mobilization, finance, choice of technology and human resource development

3.30 Tea

4.00 Resumption of seminar with more papers from panel members and discussion
Considered responses from delegates to previous proceedings.

5.30 End of seminar

Conference Programme (continued)

Day 2 — 21 February 1990

Morning

9.30 *Development and resources*
Institutional approach to water management in several countries - C Lefrou, France
Resource mobilization through marketing - H Vikman, Finland
Discussion

11.00 Coffee

11.30 Community participation in rural water supply - PN Nginia, Kenya
Human resource development in rural water supply - Hon J Gichaga and Mrs JW Maina, Kenya
Discussion

1.00pm Lunch

Afternoon

2.00 *Technology and implementation*
Hybrid solution for West Africa - Schmidt, West Germany
Nairobi City water supply - WJ Odiambo, Kenya
Discussion

3.30 Tea

4.00 Knowledge-based systems for technology selection - Franceys, UK
More water from fractured rock? - Bisson/Ayed, USA
Discussion

5.30 End of day's proceedings

Day 3 — 22 February 1990

Morning

9.30 *Technology and implementation (continued)*
Approach for sustainable rural water supply in Nyanza province, Kenya - Lake Basin Development Authority
The treadle pumps: adaptation for the peasant farmer - Lambert, Zimbabwe
Discussion

11.00 Coffee

11.30 *Pollution control and environment*
Planning for water quality management - J Balek, UNEP
Water quality control in Kenya - O Mwenga, Kenya
Discussion

1.00pm Lunch

2.00 Pollution control and trade effluent policies - Upstone, UK
Training for environmental projects - Selann, Canada/Ahmed, Kenya
How micro-hydro provides environmental benefits - Celso, Italy
Discussion

3.40 Summing-up by conference chairman

4.00 Close

AFRICAN WATER TECHNOLOGY CONFERENCE

20-22 FEBRUARY 1990

THE CHALLENGE OF SUSTAINABLE DEVELOPMENT IN COMMUNITY WATER SUPPLY AND SANITATION

I. L. Nyumbu
Consultant

previously Decade Adviser, Department of Water Affairs,
Ministry of Water, Lands and Natural Resources, Zambia

and

M. Seager
Programme Officer

IRC International Water and Sanitation Centre

Lusaka and the Hague

THE CHALLENGE OF SUSTAINABLE DEVELOPMENT IN COMMUNITY WATER SUPPLY AND SANITATION

1. INTRODUCTION

1.1 The period since the beginning of the International Drinking Water Supply and Sanitation Decade (1981-1990) has seen significant progress, worldwide, in the provision of potable water supplies and basic sanitation. According to WHO (WHO, 1988) over 500 million people throughout the developing world have received improved water supplies, while about 250 million have been provided with better sanitation. However, the goal of water and sanitation for all by 1990 will only be reached in a few countries.

1.2 Experience to date indicates that high population growth and rapid urbanisation have tended to overwhelm the capacities of installed facilities. In addition a significant number of these facilities have quickly become inoperative due to inadequate operation and maintenance, reducing both the effective level of service and extent of coverage. The main challenge for the provision of water and sanitation facilities in future is not only to extend coverage but to ensure that the facilities are sustainable - that they are functioning properly, they are properly utilised, and the facilities lead to the desired positive impacts.

1.3 Sustainability and its achievement for rural water supply and sanitation programmes in Africa is the main theme of this paper. The paper takes a hard look at the concept of sustainability and what it means in project terms, and then discusses a recently proposed framework for sustainability in community water supply and sanitation systems. The paper concludes with an exploration of the prospects for promoting this basic approach to sustainability, and the implications for applying it in practice.

2. THE DECADE IN PERSPECTIVE IN AFRICA

2.1 Coverage and Levels of Service

2.1.1 Many countries in Africa have reported significant improvements in the provision of water and sanitation facilities since the beginning of the Decade in 1981. The overall coverage of water supply and sanitation facilities had increased from 33 percent and 28 percent, respectively, in 1980 to 40 and 38 percent in 1985, at the halfway mark of the Decade (WHO, 1987).

The greatest improvement has been in urban water supply, where coverage improved from 66 percent in 1980 to 78 percent at the end of 1985. Rural Water Supply coverage made a modest increase from 22 percent in 1980 to 25 percent in 1985. Both urban and rural sanitation coverage have lagged behind water supply.

2.1.2 While coverage and levels of service have increased, in real terms the situation has not improved to the same extent. Evaluation reports of major rural water supply programmes in various parts of the developing world point out many examples of recently implemented projects which have fallen into disuse and disrepair. Consequently the extent of coverage and levels of service are in fact lower than the official statistics of coverage indicate.

2.1.3 It has been estimated recently (WHO 1988) that by 1990 at least 800 million people in the rural and peri-urban areas will be without safe water supply, and many more millions will not yet be provided with adequate sanitary facilities. Taken together with the high population growth rates, rapid urbanization, diminishing funding of the sector, and inadequacies in operation and maintenance, universal coverage of water and sanitation facilities is still a formidable challenge requiring innovative strategies.

2.2 Lessons from the Decade

2.2.1 The Decade has provided valuable lessons regarding approaches to the provision of community water supply and sanitation facilities. The most critical of these lessons involves the relationship and partnership between the water agency and the benefitting community at all stages of project planning, implementation, operation and maintenance. The experiences from the Decade have also led to the knowledge that sustainability is not the result of any one project activity but of a number of interlinking "key elements." These elements can be considered as building blocks, together providing the foundation for properly functioning, well utilised water and sanitation facilities, with assured long term impacts. It is now widely appreciated that both the water agency and target community have vital roles to play in order to ensure sustainability of investments in water and sanitation facilities, by together ensuring such elements are in place and properly resourced.

3. SUSTAINABILITY AND RESOURCE COVERAGE

3.1 Sustainability

3.1.1 A sustainable water supply system is one which continues, beyond its implementation, to function properly as originally conceived, is regularly utilised by the users, and continues to deliver its intended benefits to the users. In short the system works, is used and has a positive impact. The same meaning also applies with respect to a sanitation system, except that the target group is primarily the household rather than the community.

3.1.2 Ensuring sustainability has not been easy, and despite the best intentions of recent years it has not been achieved, as evidenced by a number of failed or underutilised schemes and those with little impact. Part of the problem has been the lack of clearly defined guiding principles and frameworks for achieving sustainability. The other part of the problem is the lack of appreciation of the need for clearly defined, agreed and accepted roles of the two principal parties to the community water supply and sanitation system - the community, on one hand, and the water agency on the other.

3.1.3 The long term success of any project begins with careful planning and design. If the goal of sustainability is missed out at this stage and not carefully built in, then it will not be possible to achieve sustainability of the system during its life time. Careful planning will take into account the totality of the project environment - the users, the resources, skills, and organisations available, as well as the corresponding inputs needed as back-up by the agency. The inputs expected from the agency will include technical support (during planning, implementation, operation and maintenance), finances and training to provide the necessary skills for operation and maintenance of the system. Guidance will also be needed on appropriate financial systems (cash raising, record keeping, financial control) to ensure availability of cash for spare parts and major repairs. A catalogue of community-based financing systems has been published by IRC (rec, 1987), to assist Agencies in providing such guidance.

3.1.4 The water and sanitation sector now needs to make a new acceptance of open and timely audits of a project's potential for remaining sustainable, and regular analyses of the resources this will require and where they are to be found. How such assessments might be done will vary from project to project and country to country. Nevertheless it has been possible for a broad group of sector partners to recently develop a proposed framework of key elements which need to be in place before sustainability can be anticipated. (WHO, 1989)

3.2 Elements of Sustainability

3.2.1 The ten proposed key elements of water supply sustainability and extended low cost sanitation coverage are summarised in Table 1, and discussed in detail in the report of the joint work (WHO, 1989). The order of elements in the sequence does not presume relative importance. It is important however to note that each of the elements is considered an essential building block for achieving sustainability.

Table 1: Key Elements of Sustainability

Water Supply		Extended Low Cost Sanitation Coverage	
Number	**Element**	**Number**	**Element**
1.	Community Institutions	1.	Support of Community Institutions and Local Leaders
2.	Developed Skills	2.	Created Awareness
3.	Supportive Attitudes	3.	Involvement of Women
4.	Community Extension Services	4.	Household Priority
5.	Accepted Service Levels	5.	Examples of Low-cost Sanitation Success
6.	Appropriate Technology	6.	Developed Skills
7.	Operational Phase Inputs	7.	Appropriate Technology
8.	O&M Related Supportive Systems and Services	8.	Community Extension Services
9.	Allocation of Responsibilities	9.	Allocation of Responsibilities
10.	Execution of Responsibilities	10.	Execution of Responsibilities

3.3 Resources Coverage

3.3.1 Little will happen in establishing key elements without the right inputs, usually from both community and agency. Quantifying and timing such resources and dividing responsibility between agency, community and individual householders has now become known as the process of "resources coverage." The important relationships between resources coverage, sustainability and the higher order goals of development of water and sanitation - (namely, improved quality of life and health) - are shown in Fig. 1. The figure illustrates the fact that cash raising and cost recovery are important lower level contributing activities within the entire framework of successful water and sanitation programmes. There are also many other inputs/resources, besides money, necessary for achieving sustainability.

3.3.2 The assessment of inputs necessary for each key element, quantification of these inputs and the division of responsibilities, is accomplished through a series of worksheets. The worksheets feed into the overall framework as indicated on Fig. 1.

4. APPLICATION OF FRAMEWORK

4.1 These Principles and Models for achieving sustainability in community water supply and sanitation systems have been under development since 1985 through a series of consultations under the auspices of WHO, with important inputs by the International Reference Center for Community Water Supply and Sanitation (IRC/CWS) and many other partners from the developing countries, ESAs and consultants. The work has now reached an implementation stage, with planned country-level applications in East and Central Africa, and in the Phillipines and possibly Thailand. At the same time ESAs have agreed on the importance of sustainability (WHO/IRC 1987) and will consider supporting specific activities within the framework of investment programmes undertaken in conjunction with developing countries.

4.2 A sub-regional working group meeting to further discuss and try out such a framework was held in January 1989 in Mongu, Western Province, Zambia, with support from the Norwegian Agency for International Development, IRC and the Deutsche Gesellschaft fur Technische Zusammernabeit (GTZ). (DWA/Zambia 1989) following this, Malawi is now carrying out a field application of the proposed framework. The objective of the work, supported by the Netherlands Directorate General for International Co-operation (DGIS), is to field test and adapt the guideline manual, based on the proposed framework, and to provide insights for policy discussion on the issues of sustainability and resources coverage in Malawi.

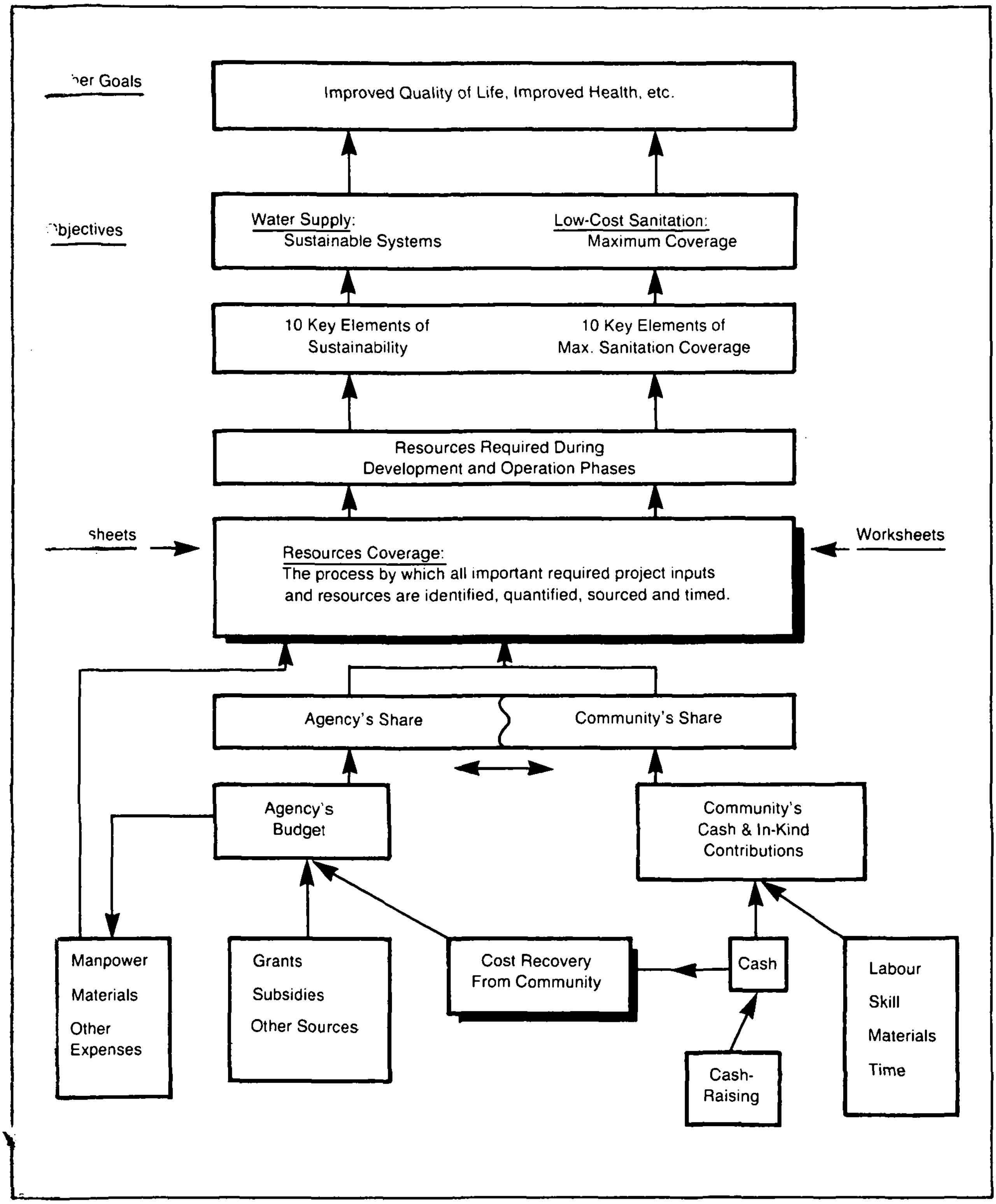
4.3 On-going and planned activities in the promotion and adaptation of the sustainability and resources coverage framework in Africa should greatly assist the planning and implementation of sustainable water supply and sanitation facilities. In turn this will lead to more successful projects in Africa.

5. PROSPECTS FOR SUSTAINABLE WATER AND SANITATION DEVELOPMENT

5.1 The significant developments which have so far taken place in the provision of water and sanitation facilities in Africa, will be undone if the facilities fall into disuse soon after construction. The progress towards further coverage is currently constrained by relatively high annual increases in population, high rate of urbanisation, and diminishing financial commitments to the water and sanitation sector. Thus in order to make the limited investments more effective the schemes should be designed to ensure sustainability - that they work, are used, and have the desired impact.

5.2 However, implementing the sustainability and resources coverage framework will require political will and government commitment. In the past, governments in many parts of Africa provided water and sanitation facilities at virtually no cost to the user. Because of this legacy, it will require political will to reverse the status quo and accept the principle that to the maximum extent possible communities or users should be responsible for their own facilities. The decision framework for allocating responsibilities, quantifying inputs and the timing of such inputs has now been developed through the WHO-initiated work. It should be adopted to suit each project or country, tried out, and then applied more widely.

5.3 The provision of water and sanitation facilities should be seen in every sense as a partnership between the agency (government) and the community. This calls for close collaboration in all phases of the project - planning, implementation, operation and



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led Task Force on Cost Recovery
WH. CWS/89.6

FIGURE 1: SUSTAINABILITY, RESOURCES COVERAGE AND COST RECOVERY

maintenance. However this collaboration calls for multi-disciplinary skills and an integrated approach, as evidenced by the wide range of key elements of sustainability.

5.4 Partnership between agency and community should go further to include the external support agencies also. Sustainability will not be achieved without ESA inputs in the areas of technology, funds, training and technical support. It is only when all the inputs/resources have been identified, quantified, and timed, and all responsibilities accepted and agreed between the three parties - the community/household, the agency (government) and ESAs - that we can ensure rapid progress towards sustainable development in community water supply and sanitation in Africa.

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AFRICAN WATER TECHNOLOGY CONFERENCE
Nairobi, 20 - 22 February 1990

Hannu Vikman

WHO CAN AFFORD WATER AND SANITATION SERVICES IN RURAL AFRICA
- Mobilization of local resources

Abstract

The original physical targets of the International Drinking Water Supply and Sanitation Decade have proved to be far too ambitious in Sub-Saharan Africa and in its rural areas in particular. A projection of the Mid-Decade progress suggests that the coverage of improved water supply in the rural Sub-Saharan Africa would reach 34 %, and the coverage of sanitation 38 %, by the year 2000. Meanwhile, as a result of the high population growth rates, the number of people unserved by appropriate water supply and sanitation would continue to increase.

It is evident that additional resources have to be mobilized. These resources are most likely located in the rural villages. In order to benefit from these resources, the water supply and sanitation sector should attract the user groups by providing services which are needed and appreciated to the extent of readiness to pay.

AFRICAN WATER TECHNOLOGY CONFERENCE
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Hannu Vikman

WHO CAN AFFORD WATER AND SANITATION SERVICES IN RURAL AFRICA
- Mobilization of local resources

1. Population trends and service levels

In spite of accelerating migration from rural to urban areas, Sub-Saharan Africa will remain predominantly rural until the next century. While in some other regions the rural population growth rate has leveled off, in Africa the rural population is still growing rapidly, at the rate of 2-3.5 % per year. An estimate of population trends is shown in Table 1. Due to rural-to urban migration, the absolute growth of rural population will likely continue at a decreasing rate. The estimated rural population in Sub-Saharan Africa in 2000 is 380 million representing about 60 % of the total population in the region.

Table 1 Estimates of Total and Rural Population by Sub-region 1970 to 2000

	Total Population in Millions				Rural Population as % of Total Population				Rural Population in Millions			
Sub-region	1970	1980	1990	2000	1970	1980	1990	2000	1970	1980	1990	2000
West Africa	104	140	190	250	83	78	71	62	86	109	130	160
Central Africa	57	74	100	130	82	73	61	50	47	54	60	[illegible]
East and Southern Africa	100	136	190	250	89	83	74	63	89	113	[illegible]	[illegible]
Total	262	350	470	640	85	79	70	60	222	275	[illegible]	380

At the beginning of the International Drinking Water Supply and Sanitation Decade, only 22 % of the rural population in Africa had access to a safe water supply and only 20 % had access to adequate sanitation. Although significant progress has been witnessed in the world-wide statistics of service level in rural areas, the original physical targets of the Decade remain as illusion.

The development of the rural sub-sector in the Sub-Saharan Africa has been less successful. During the Decade, the population served by improved water supply is estimated to increase by over 50 %, and by improved sanitation facilities by some 80 %.

Yet the number of those unserved would be higher in 1990 than 1980. Moreover, official statistics often significantly overestimate the number of people who regularly draw water from improved water supplies.

Four scenarios representing four possible development paths of the coverage of services from 1980 to 2000 are presented in Table 2. However optimistic the official statistics may be, they are used as the basis of the scrutiny. As a comparison, a projection of the past progress during the first half of the Decade is also shown in the table.

In Scenario A, the 100 % coverage target has been put off until 2000 and the improved service is assumed to be provided at a constant rate to 16 million people, annually.

Scenario B is based on the national targets revised during the implementation of the original, overly ambitious programmes. The projection based on the revised targets suggest, that the coverage of improved rural water supply would be 46 % in 1990, and that of rural sanitation 52 % in 1990. The rate of 9 million additional beneficiaries of improved water supply and 11.5 million beneficiaries of improved sanitation, annually, is assumed to remain constant until 2000.

Scenario C, the number of rural people without access to a safe drinking water supply and adequate sanitation is assumed to remain constant until 2000.

Scenario D, the percentage of rural people with access to improved services is assumed to remain constant throughout the period 1980-2000.

Table 2 Four Scenarios for the Development of Rural Water Supply and Sanitation

Year	1980		1990		2000	
Service provided	Water	Sanitation	Water	Sanitation	Water	Sanitation
Rural population in millions	275	275	330	330	380	380
Scenario A						
Coverage as %	22	20	67	67	100	100
Population served in millions	60	55	220	220	380	380
Population not served in millions	215	220	110	110	-	-
Scenario B						
Coverage as %	22	20	46	52	73	75
Population served in millions	60	55	150	170	240	285
Population not served in millions	215	220	180	160	140	95

Year	1980		1990		2000	
Service provided	Water	Sanitation	Water	Sanitation	Water	Sanitation
Scenario C						
Coverage as %	22	20	35	33	43	42
Population served in millions	60	55	115	110	165	160
Population not served in millions	215	220	215	220	215	220
Scenario D						
Coverage as %	22	20	22	20	22	20
Population served in millions	60	55	75	65	85	75
Population not served in millions	215	220	255	265	295	305
Projection of the Mid-Decade Progress						
Coverage as %	22	20	29	30	34	38
Population served in millions	60	55	95	100	130	145
Population not served in millions	215	220	235	230	250	235

The actual increase of coverage during the first five years of the Decade seems to fall between scenarios C and D. If the annual rate of 3.5 million additional beneficiaries of rural water supply were to continue until the end of the Decade, the service coverage would be 29 % in 1990 and 34 % in 2000. The annual rate of 4.15 million additional beneficiaries of rural sanitation would result in the coverage figures of 30 % in 1990, and 38 % in 2000.

2. Expenditure estimates

The required inputs in the development of water supply and sanitation, following the four scenarios are presented in Table 3. The calculations are based on capital cost of USD 40 per capita and annual O&M cost of USD 2 per capita, representing a combination of service provided by handpumps and piped supplies, and capital cost of USD 25 per capita for rural sanitation.

The fast-growing trend in the recurrent costs of improved water supply is clearly visible in the table. The recurrent costs would escalate from USD 120 million used in 1980 up to USD 760 million in 2000 in Scenario A and to USD 330 million in Scenario C.

The total allocations to the rural water supply sector in 1990-2000 should be USD 12.4 billion in Scenario A, 7.5 billion in Scenario B, USD 4.8 billion in Scenario C and USD 2.0 billion in Scenario D. The allocations to sanitation should be, respectively, USD 4.0 billion, USD 2.9 billion, USD 1.3 billion and USD 0.3 billion.

Table 3 Total Required Inputs in the Development of Water Supply and Sanitation in Rural Sub-Saharan Africa

Costs in million USD (Annual Investments and Recurrent Costs)

	1980				1990			
Scenario	Investments Water	Investments Sanitation	Recurrent Water	Total Water	Investments Water	Investments Sanitation	Recurrent Water	Total Water
A	640	480	120	760	640	480	440	1,100
B	540	410	120	660	540	410	390	930
C	200	150	120	320	200	150	230	430
D	40	30	120	160	40	30	150	190

	2000			
Scenario	Investments Water	Investments Sanitation	Recurrent Water	Total Water
A	640	480	760	1,400
B	540	410	660	1,200
C	200	150	330	530
D	40	30	170	210

The lion's share - about 80 to 90 % - of the investments in the rural sub-sector has been financed by external donor agencies. The recent level of loans and grants to the sub-sector in Sub-Saharan Africa has been about USD 100 Million per annum. Targetting at a full coverage of services within the next 20 years would call for multiplication of resources, as the current external financing would represent some 10 - 15 % of the required capital.

It is evident that the resources from governments and donor agencies will be inadequate for the provision of water for all the region in the next few decades. Additional resources have to be mobilized in order to expand and sustain the services.

3. Features of top-down financing

At present, the sector development is characterized by strong central government dominance, overly ambitious sectoral targets, provision of services as a social good or human right, and insufficient resources for expansion of services. The demand for free or heavily subsidized services is high, if not unlimited, whereas the resources for the supply of services are strictly limited. As a result, practically free services are supplied to small privileged target groups.

Even where water tariffs have been introduced, the revenues hardly cover operation and maintenance costs. Some typical features of tariff structures can be mentioned, e.g.:

- flat rates are generous and provide no incentive for water meter installation, or maintaining the installed meter in operational condition
- domestic consumption enjoys low tariffs, whereas commercial tariffs are substantially higher
- tariffs do not reflect the service level provided: unit cost of water supplied through house connections may be much lower than water supplied through vendors
- there is no relationship between the design criteria for piped schemes and tariff structures; this may result in capacity problems when demand for subsidized house connection supply exceeds the estimates
- consumers who are provided with high service levels and whose water use is excessive receive the highest subsidies.

Donor assisted water supply and sanitation programmes often aim at providing services to the poorest of the poor living in remote rural areas. The official recipient government policies of free water have usually been adopted in these programmes. More penetrating macro-level analyses might have revealed that the recurrent costs of the programmes being launched would absorb an unreasonably large share of feasible future public budget revenues.

4. Mobilization of local resources

If substantial contribution from consumers were required, the demand, expressed in willingness to assume financial responsibility, and the supply could be better balanced. A usual argument against user contributions in investments is the low ability to pay. On the other hand, one could also ask who can afford improvement of services.

The local and central governments will have enough problems in financing the O&M expenditures, if they continue to assume the responsibility for them. It is not realistic to expect the international community to take an increasingly leading role.

The rural poor's ability and willingness, at least readiness, to pay for improved services has frequently been underestimated and underutilized. Several studies and surveys as well as experience have proved, however, that substantial resources are available for truly perceived needs.

In Mali, which is officially among the poorest countries in the world, rural dwellers have considerable cash incomes from nonagricultural activities even in the least developed and most remote areas. High expenditures on durable goods, social activities and loans to others indicate ability to pay cash for valued services.

In Pakistan, handpumps serve approximately 25 million people. These handpumps have been installed and are being maintained privately at no cost to the Government. In some rural areas of Vietnam, the demand for handpump wells is much higher than the capacity of an externally financed programme to implement, and beneficiaries have been ready to pay contributions which exceed the implementation cost.

It is clear, on the other hand, that there are people who definitely cannot pay anything for water, who can hardly satisfy their caloric consumption. Subsidized water, however, may not be the most efficient way to help them.

A more extensive mobilization of consumers' or beneficiaries' resources calls for new strategies and approaches. Promotion and demand generation will become the key issues in the development. The approach should be demand-driven, instead of the current supply-driven strategy. Once the demand for improvements, measured in the willingness to pay, has been created, services could be supplied on a financially sound basis. This, in turn, would be the only way to hand externally supported programmes and projects over to local communities. The demand-oriented approach would, undoubtedly, affect the short-term sector objectives and achievements.

Formulation of overly ambitious top-down objectives, programmes, and projects would be replaced by more responsive strategies. The agencies currently providing services, including even operation and maintenance, and implementing well prepared programmes with fixed physical targets would limit their involvement to the provision of supportive services, such as motivation, training, and supervision. The governments and other relevant agencies should no aim at certain physical targets but, instead, be prepared to respond to certain demand when requested.

Community participation and community involvement have often suggested to be the key to improved sustainability of facilities and services provided. Still, both terms may give the impression, right or wrong, that the communities are persuaded to participate in development programmes they are supposed to benefit from. What is actually required is community or consumer responsibility. The consumers themselves should take the initiative and make the decisions, including those concerning service levels as well as capital and operating costs.

The supply of services demanded and paid by the consumers would and should be responsive to the perceived needs. More innovative and affordable technology should be developed to meet the needs of all socio-economic groups. The targets, service levels, and priorities, including the status of water supply and sanitation among many others, would be set by the consumers.

The water supply and sanitation sector organizations would find themselves promoting and marketing their services and competing with other provisioners of goods and services. This, in turn, would call for a more commercial touch. As experienced throughout the world, argumentation of health benefits has not been very successful in the promotion of rural water and sanitation services. Other benefits, such as convenience, taste of water, and high status, have been appreciated by the target populations.

Examples of successful marketing programmes can be also even in remote rural villages of Africa. Soft drinks, cigarettes and infant formula are popular and available in incredibly remote areas, although breast-feeding, for instance, is cheaper, healthier, and less time-consuming than the use of infant formula.

The massive mobilization of local resources has been suggested and demanded above using mainly one single argument - the unavailability and inadequacy of other resources - which alone seems to be a sufficient justification. Another reason, at least as important, for maximal use of local resources is sustainability.

Even if the Government and donor resources were adequate to cover the capital cost of expansion of services to all, the facilities would most likely lack appropriate operation and maintenance, and become nothing but another generation of white elephants.

PROPOSED CONTRIBUTION TO THE
4TH AFRICAN WATER TECHNOLOGY CONFERENCE

A HYBRID SOLUTION FOR THE WATER SUPPLY OF A PROVINCIAL TOWN IN WEST AFRICA

S.K. Schmidt* and O.C.W. Michael*

ABSTRACT

A mixture of two levels of technology was chosen to provide a decentralized water supply from groundwater sources for the 12 000 inhabitants of the remote town of Beyla in Guinea. Handpumps were installed in most urban quarters, and standpipes fed by solar-powered pumps in the more congested areas. The combination was chosen as the only viable solution in view of the constraints: an aquifer partly polluted by human waste, a lack of physical infrastructure (particularly road access and mains electricity) and an absence of suitable institutional framework at the municipal level.

The facilities were complemented by sanitary installations for public use, followed by the production of precast components for "VIP" toilet construction by private individuals. Accompanying measures included publicity and hygiene campaigns, recruitement and training, and establishment of water committees.

The capital cost of the project was US$ 152 /capita. The completed facilities are managed almost entirely by the population itself.

* Senior Engineer, Dorsch Consult, Munich, Federal Republic of Germany

INTRODUCTION

It takes two full days to travel from the Guinean capital Conakry to the provincial town of Beyla, which lies about 1000 km to the East and near the border to the Ivory Coast. One should have a four-wheel drive vehicle for this trip, but even so it might not be possible to get there during the rainy season at all. Beyla, with some 12 000 inhabitants, was one of a group of nine towns for which the feasibility of new water supply systems was studied in the early 1980s. A few years later the client, Service National d'Aménagement des Points d'Eau (SNAPE), decided to implement the Beyla project, complete with the necessary sanitation facilities. Safe drinking water was to be made available to meet requirements up to the year 1995, based on a unit consumption of 15 litres/person/day. Although a low figure, the latter is sufficient to cover present needs, particularly as in the past water could be fetched only from traditional wells and polluted springs.

There were several constraints to be overcome during the design. For example, how was the water to be transferred to the town if gravity flow is not possible and conventional energy sources for pumping are not available? The town is not connected to a national electricity grid, and diesel supplies for the municipal generator arrive only sporadically (that is, when money is available and the roads are passable). Another point was that there is no local authority capable of running a modern water supply and sewerage scheme from either a technical or administrative point of view.

The first approach therefore was to apply a standard low-tech solution, already well tried throughout the world and used widely in the rural areas of Guinea: drilled wells with handpumps operated and maintained by village water committees. But there were technical problems: there was insufficient space in the centre of the town for the operation of the drilling rig. A more serious problem which became evident after the first hole had been drilled, was that the groundwater in the central area is polluted, probably by the many traditional latrines which have existed there for centuries.

A different approach was therefore chosen to supply the town centre. It comprised five small decentralized systems, each one consisting of a drilled well located out of town, and equipped with a solar-driven pump.

The project measures comprised more than just the installation of the water supply facilities. Thus training courses for local artisans and Guinean staff, and public information and hygiene campaigns were considered integral components of the overall undertaking.

The urban project described here was linked to a rural water supply programme in the province of Beyla as a whole. The discussion in this paper, however, has been limited to the town itself because of the interesting mix of technologies applied there.

FACILITIES

The urban facilities constructed comprised:

* 14 wells (located by geophysical prospection), of which 9 were equipped with handpumps, and five with solar-powered pumps and simple distribution systems; population served: 12,200;

* sanitary facilities such as toilets and showers for public use and in the hospital complex.

The <u>handpumps</u> chosen were Kardia (types K50 & K65), as these had been successfully used in other regions of the country. In the interests of hygiene, convenience of use and aesthetics, attention was paid to the construction details around the finished well. These included an amply-sized concrete slab, surrounded by an open gravel soakaway, a fall towards a concrete drainage channel and disposal to a soakaway or the nearest ditch. The whole facility was demarkated by an open-cell wall to prevent pollution and damage by livestock.

The <u>solar systems</u> consisted basically of a submersible electric pump powered by a photovoltaic generator. Each system was complemented by a rising main, a storage reservoir and a small distribution network feeding standposts in one particular sector of the town. A brief description is given below:

* The <u>solar panels</u> were mounted on the roof of the reservoir with an inclination of 20° to the south. The solar generator was connected to the pump via an inverter (to produce a.c. current from the d.c. supply) and a control box.

* The <u>wellheads</u> for this application were developed as underground reinforced concrete chambers, complete with manholes and stepirons, ventilation duct, valve gear, and washout system.

* The ground-level <u>reservoirs</u> were of GRP construction on a steel frame founded on concrete footings. They were equipped with ball valve, water level indicator, a steel roof truss and a bank of public taps complete with drainage facilities. The structures conveniently combined the requirements for water storage, an exposed site for the solar panels and a multiple standpipe facility.

One of the reservoirs was constructed in elevated form so as to provide sufficient head for the hospital buildings. It was mounted on a 10 m steel tower founded on a reinforced concrete slab.

The standpipes were situated in localised population centres so as to minimise domestic effort in the daily chore of fetching water. The structures included a small guardian's hut. A simple lever-operated stopcock ensured rapid operation and reduced the risk of losses. Supply was by a 40 mm polyethylene pipe, and drainage by a gravel soakaway.

A summary of the five solar water supply systems is given in the following table:

FUNCTIONAL CHARACTERISTICS OF THE SOLAR WATER SUPPLY SYSTEMS

SYSTEM CODE	SERVICE ZONE	RESERVOIRS (cubic m)		ADDITIONAL STANDPIPES (banks)	DISTRIBUTION SYSTEM
		GROUND	ELEVATED		
F30	Market	40	-	3	-
F8	Hospital	-	12	1	yes
F17	Tindikan	40	-	2	-
F16	Sobakono	40	-	1	-
F2	Administration area	30	-	1	(town hall)

Typical technical data for the solar installations is approximately as follows (based on data obtained from system F30 at the market during during commissioning in March/April 1988):

peak specific power:	900	W/m^2
specifice energy:	5.2	$kW\text{-}h/m^2$/day
volume of water pumped:	20.5	m^3/day
static water levels below ground:	11.4	m
dynamic water lev. below ground	18.7	m
depth of pump below ground:	30.0	m
energy conversion efficiency (from radiation to potential):	3%	

The general lithology in the town is:

laterite	0 to 3 m
quat. alluvium (clayey sand & gravel)	3 to 22 m
weathered base rock	22 to 26 m
base rock, metamorphic (gneiss, migmatite, quartzite etc)	22 onwardsm

Principal aquifer: fissures and dislocations in the base rock. The **sanitary facilities** were constructed for two main purposes, viz:

a) the provision of immediate **basic infrastructure** to meet the most urgent needs: these were provided for the public at large, and

b) in the form of **pilot facilities** to act as an incentive to private individuals.

The basic infrastructure comprised Ventilated Improved Pit (VIP) latrines for the three schools, the leper colony and the health centre, and sanitary blocks (flush toilets, showers and washing facilities) at the market and hospital.

The pilot facilities focussed on additional VIP latrines. Ten units were constructed as samples for private use, and a further 200 precast base slabs were produced for installation in both the town and the outlying villages of the province. Technical assistance in the subsequent installation of these facilities was provided under a follow-up programme run by a German volunteer (DED).

ACCOMPANYING MEASURES

As has so often been found to be the case in other water supply projects, a high degree of public participation was recognized as being of prime importance. This took place in the following forms:

a) Publicity campaign: the purpose of this was to ensure acceptance of both the facilities to be constructed and the responsibility for their operation and maintenance on the part of the public. It was carried out by holding meetings between all interested parties (client, local authorities, local elected representatives, artisans and consultant).

b) Election of water committees: assistance was given to the target population in constituting such committees and developing guidelines for their efficient operation.

c) Recruitement of local artisans: this posed no great problems in the town itself, considering the relatively small scope of the urban project and the willingness of candidates to take on part-time employment in the public service.

d) Training programme: covering the project over the whole of the province, the programme was aimed at both Guinean professional staff (a total of 48 man-months) and the artisans recruited (½ man-month for each of 36). The professional staff, which was seconded to the project by the client as counterpart personnel to the consultant, comprised civil and solar power engineers, hydrogeologists, geophysicists, and urban extension workers. Training was mainly carried out on-the-job, but also included overseas training with the consultant and E&M contractor in Germany.

e) Hygiene campaign: The campaign was directed in the first instance at the local health officials and teachers, who were then used as a vehicle to reach the population. This was particularly necessary in view of the wider provincial scope of the project as a whole, for which the consultant's staff alone would have been totally insufficient. The campaign was mainly carried out as seminars and addressed the subjects of hygiene, with particular regard to the use of drinking water, household activities, personal cleanliness, human waste disposal and the local environment.

IMPLEMENTATION

Detailed design was commenced in June 1986, construction works in January 1987, and the last village well was commissioned in June 1988. During construction about 4 months of each year was lost due to the rainy season. Design, construction supervision and accompanying measures were carried out by a team of mixed personnel from the consultant and the client, with responsibility assumed by the consultant. This enabled fees to be reduced and maximum use to be made of local knowledge. Finance for the project was in the form of a grant from the Government of the Federal Republic of Germany.

Logistics were hampered by difficult access to the town, due to the remoteness and the appalling road conditions.

CAPITAL COSTS

The capital cost breakdown for the whole project is given in the table below:

COMPONENT	COST (millions of deutschmarks)	
Drilled wells with handpump		0.3
Solar systems:		
* drilling & civil works		1.3
* m&e equipment		0.6
Sanitary facilities		0.6
Accompanying measures & consulting services		0.8
T o t a l foreign exchange	3.6	
T o t a l local costs (personnel and labour)	0.1	
G r a n d t o t a l	3.7	

This is equivalent to a unit expenditure of some
152 US$ per capita.

MANAGEMENT, OPERATION AND MAINTENANCE

Each solar and handpump system is managed by a water committee selected from the local population. Day-to-day operation is under the control of a well attendant who calls on local mechanics should minor defects arise.

More major defects, where they do arise, can be corrected at three levels:

* a water engineer seconded by the client to the project in Beyla, together with the German volunteer mechanic, available until 1991;

* the client's head office in Conakry, including an engineer trained in solar technology;

* the overseas contractors and consultants.

The stocks of spare parts for the handpumps are held by a private retail outlet, established in Beyla by the pump manufacturer's Conakry representative. For the solar systems, however, spare parts are managed by the client's Beyla sub-centre.

During the inspection for final acceptance of the structures a year after commissioning it was found that all handpumps and solar systems were still functioning satisfactorily and that the beneficiaries were well aware of the significant improvement in their living conditions. This favourable result was certainly due in part to the attention paid to all operation and maintenance aspects, and in particular to the secondment of the two professional staff. Nevertheless it was also apparent that operation and maintenance procedures needed streamlining, mainly with reference to the function of the water committees. Furthermore it became apparent that the construction period was not long enough to enable the hygiene education campaign to reach the entire population. The consultant was therefore entrusted with the task of carrying out a two-year follow-up programme until 1991, thereby ensuring that the project objectives were also fully attained in respect of the accompanying measures.

CONCLUSION

The decentralized hybrid solution of intermediate and high technology offers substantial advantages from both technical and administrative points of view, namely:

* The systems remain operationally independent, so that if one of them breaks down, the efficiency of the others is not impaired.

* The capital costs of installations outside the town centre (where the more expensive piped/solar systems are not required) are reduced to a minimum by using well-tried and mass-produced technology

* Operating costs are low since there are expenses neither for fuel nor for chemical treatment, and personnel costs are minimal.

* Training requirements are modest: operation and maintenance staff comprise almost entirely artisans.

* No complex administrative institution (eg. that for a waterworks) is required at local level since the systems can be adequately managed by the water committees.

ACKNOWLEDGEMENTS

Executing agency:	SNAPE (Service National d'Aménagement des Points d'Eau)
Funding agency:	Kreditanstalt fuer Wiederaufbau
Drilling and civil works:	Prakla-Seismos Geomechanik (FRG) with Fabra (Guinea) as subcontractor
Solar equipment:	AEG (new technologies division) (FRG)
Handpumps:	Preussag (FRG)
Consultant:	Dorsch Consult,Munich in association with Saniplan/GET/Buchholz

FIGURES (this listing is for editorial purposes only)

1. Project location
2. Water supply systems layout
3. Ground reservoir with public standpipe
4. Elevated reservoir
5. Public standpipes at ground reservoir
6. Handpump in urban outskirts

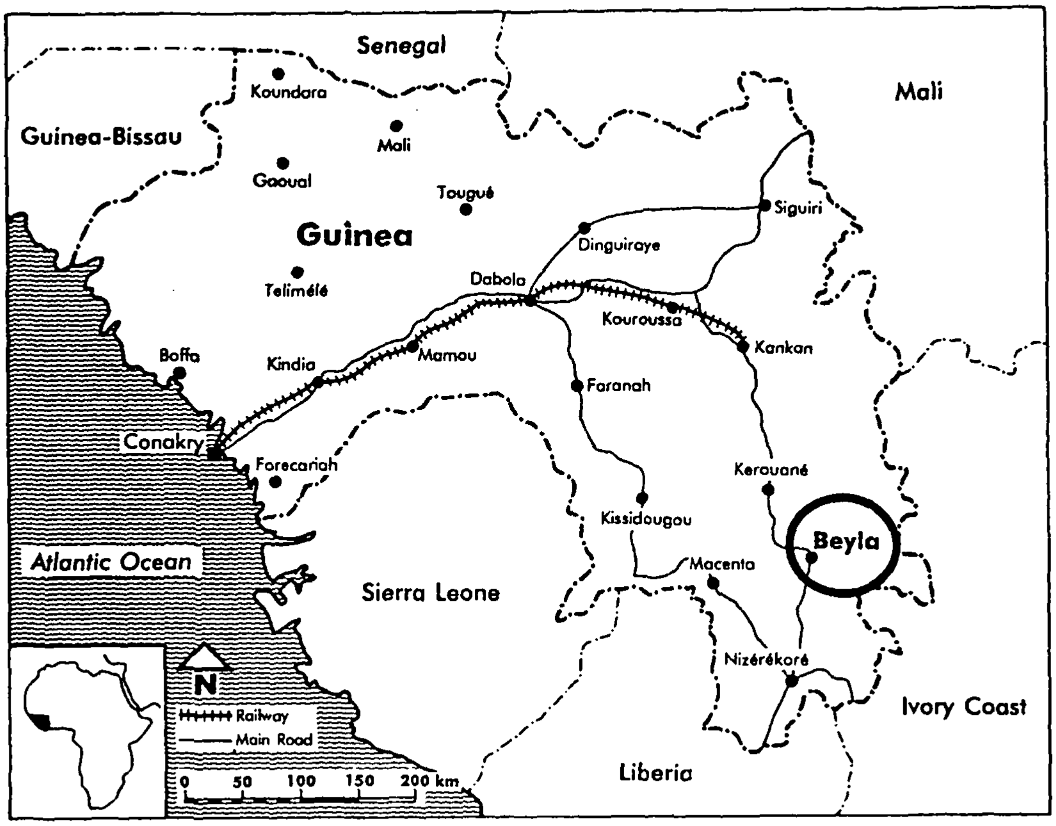
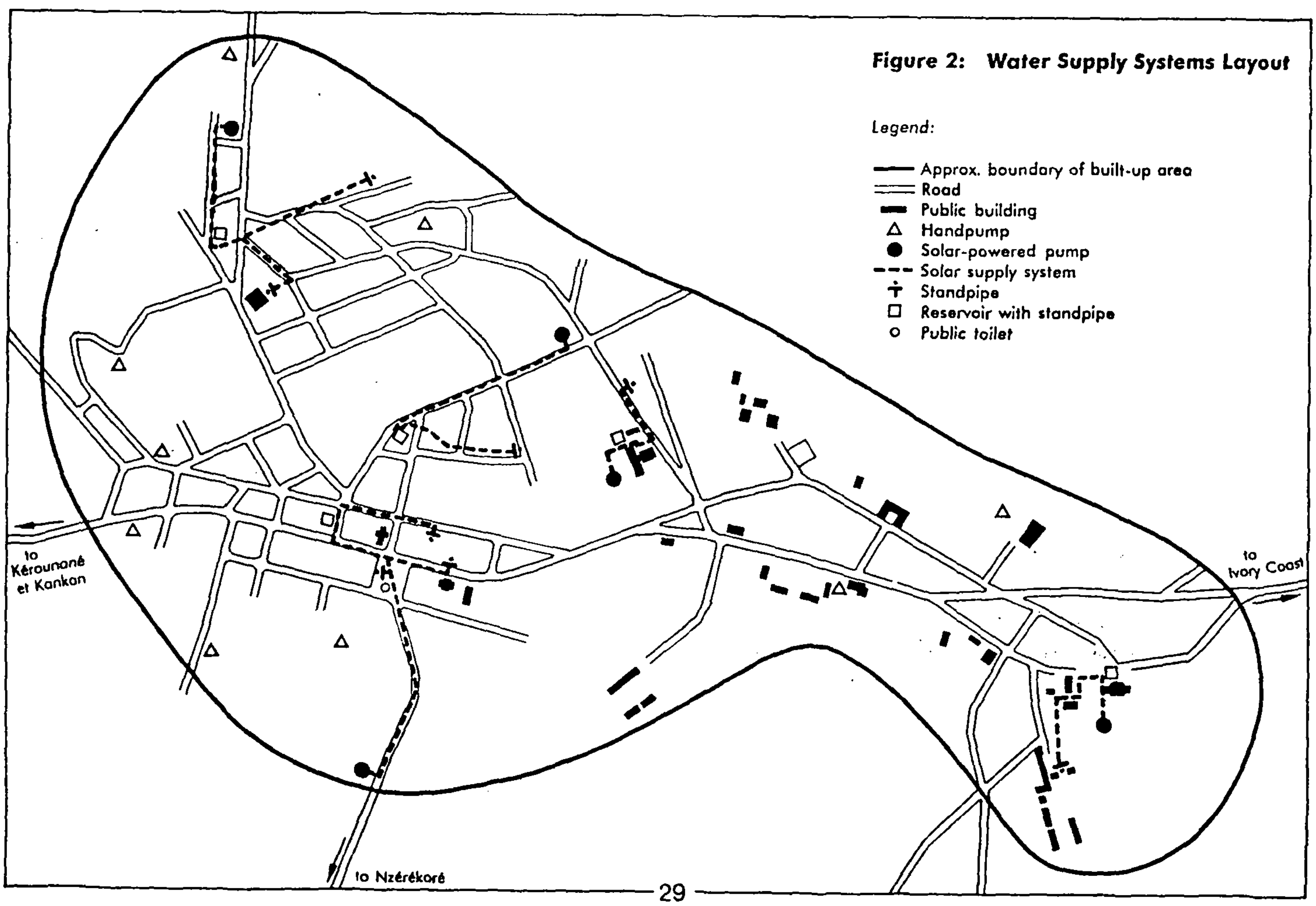
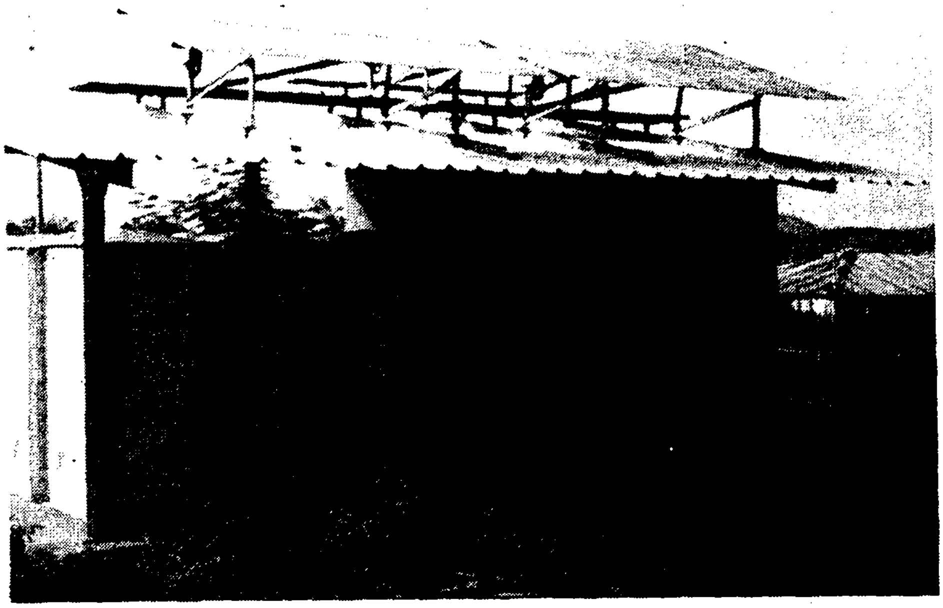


Figure 1: Project Location





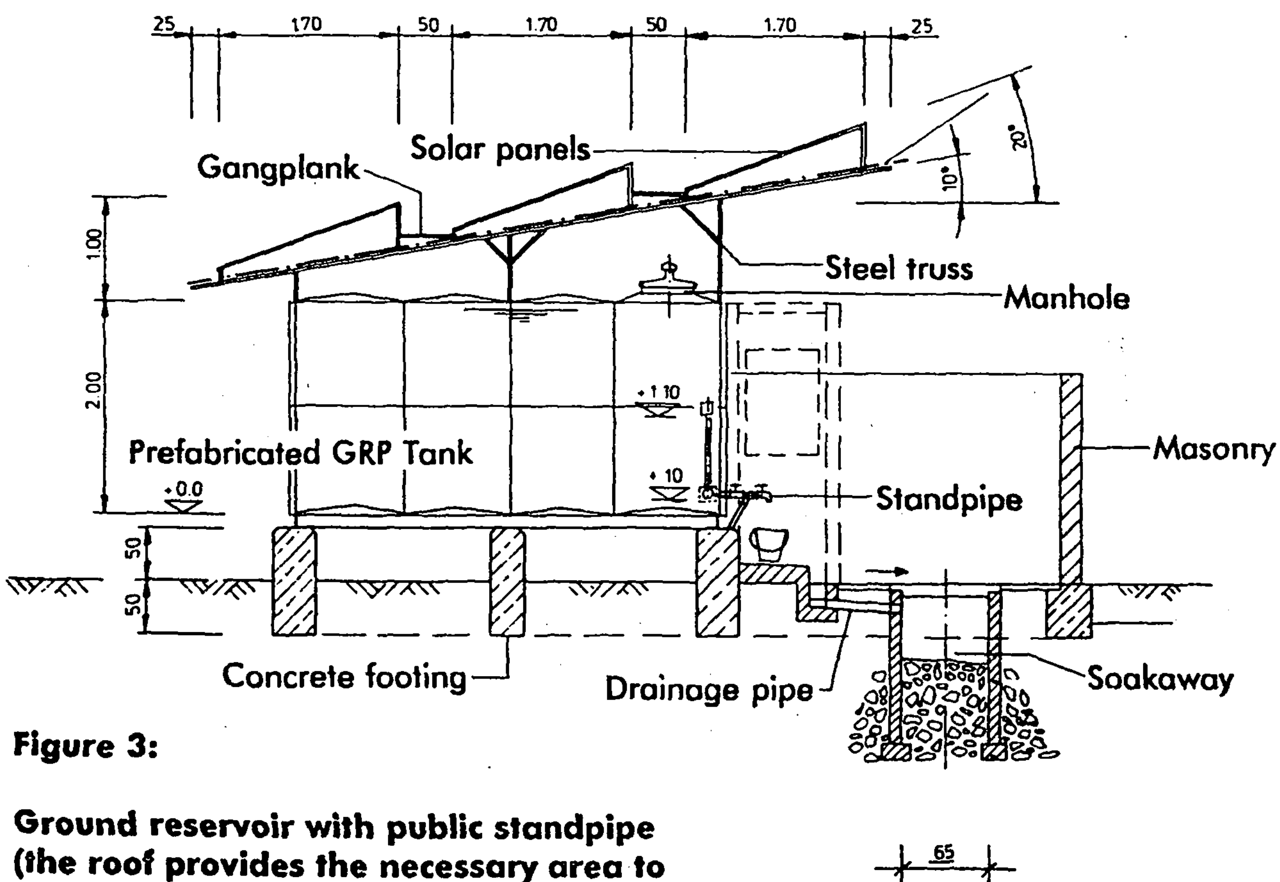


Figure 3:

Ground reservoir with public standpipe (the roof provides the necessary area to power the solar pump)

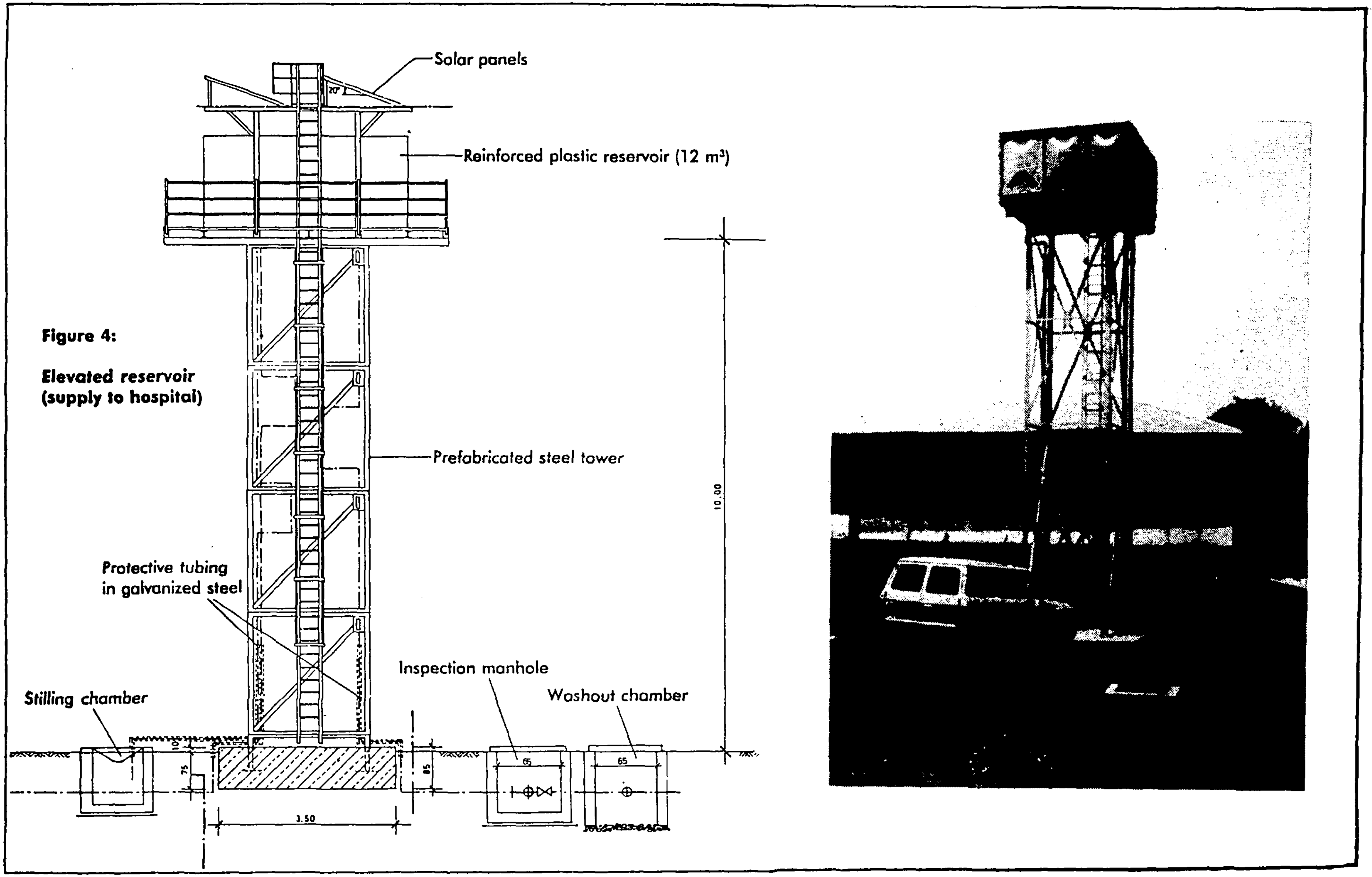


Figure 4:

Elevated reservoir (supply to hospital)

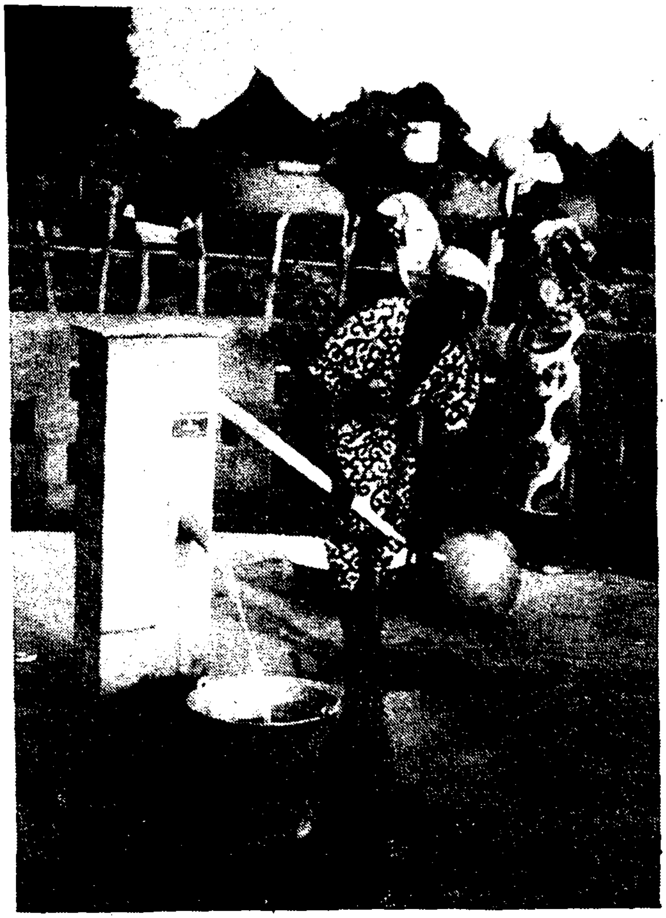


Plate 5: Public standpipe at grund reservoir

Plate 6: Handpump in urban outskirts

MANAGING LEAKAGE - A MAURITIAN EXPERIENCE

AUTHOR - ASHLEY E ROE, SEVERN TRENT WATER UK

Synopsis

A 'Leakage Control Management' project was undertaken in the Mauritian capital city Port Louis, by the Central Water Authority (CWA), Mauritius and Severn Trent Water UK, between April 1987 and December 1989.

The objective was to advise and assist the CWA in the setting up and operation of a systematic leakage control management system and to reduce the levels of unaccounted for water.

The achievements to date include:

- Distribution System Records updated;
- Zoning established;
- 19,000m^3/day (4.2 million gallons/day) water saved;
- £70,000/year saved at marginal cost rates;
- £830,000/year saved at water sales rates.

There are many other benefits to the Central Water Authority in the setting up of a system which is seen as a foundation for good operational management of the reticulation system.

The costs of the project are some £60,000 which gives a payback period of 10 months.

The project has been considered a success such that the methodology is to be extended to cover the whole country during the next three years.

Introduction

Water is a basic need for all the living world and man spends much time and effort in the development and protection of resources and the transportation to the point of use.

In the developing world the transportation of water, mainly by hand, absorbs considerable family and community effort. As economic development occurs so an infrastructure develops to cope with the increasing demands of a more concentrated population.

In the past investment has been targeted on the development of new resources and provision of treatment plants, reservoirs and mains reticulation systems. The construction of this infrastructure has attracted a high and glamorous profile in many water supply organisations. This has resulted in the operation and maintenance of the existing plant and equipment being given a low priority and in many developing countries looked upon as lower status. As a consequence appropriate budgetary allocation for repair and maintenance are often not made with the result that existing assets deteriorate further.

With the costs of developing new resources rising and in many cases combined with the need to replace existing assets, many countries and water supply organisations are recognising that the economic management, operation and maintenance of existing assets is essential. Not only will this preserve assets and lengthen operating lives but where the efficiency of a distribution network is improved it may be seen as the provision of a further valuable water resource.

This paper looks at the experience gained in introducing a concept of operational management to a distribution network in a rapidly developing country. The project concerned has concentrated upon the reduction of leakage levels and unaccounted for water but as a consequence of this has produced improvements in operational management and understanding of the existing reticulation system.

The project was undertaken in the capital city of Mauritius, Port Louis, where it had been estimated that more than 50% of the water put into supply was not accounted for.

The general philosophy adopted was to create a team from within the local water supply undertaking to investigate and repair the existing system. This team was to be supported by the services of a full-time consultant from a UK water authority which also provided support and advice, together with regular visits by a senior consultant.

The objectives of the project may be summarised as:-

Short-term - to break down the Port Louis water supply system into discreet areas, District Meter Areas (DMAs) and to monitor the flow into each area on a continuous basis; to bring down the levels of unaccounted for water in each DMA to an acceptable level.

Medium-term - to monitor the output from sources and into the Port Louis system and determine, using the volume measured as used by consumers, the volume of unaccounted for water (UFW) for the Port Louis water supply system.

Long-term - using the data gathered and the infrastructure developed monitor the distribution system's performance; where the performance deviates from set targets tc investigate, repair and maintain.

Background

Mauritius is a volcanic island which lies in the Indian Ocean, 20° south of the Equator and 57° east of Greenwich, has a population of 1.04 million and an economy which has been expanding rapidly over the last few years.

The expansion of economic activity has produced an increased demand for services. This has come about due to a broadening of the economy in terms of the industrial base and an increase in the expectations of the domestic consumer due to better living standards.

The need for the provision of services is not confined to the water sector alone but encompasses the development of transport, internal and external communications, power and the administrative/legal framework. The provision of services such as water, electricity, transport, etc requires investment in extending, reinforcing and developing the existing infrastructure.

The water sector recognised the need to manage existing assets to maximise their utilisation which would go hand in hand with investment in new sources and the expansion of the reticulation system. The existing water resources, both ground and surface water, are generally assumed to be available as there is adequate rainfall. However, there is an inability to match the rate of growth in industrial/domestic demand for potable water with the development of these resources and to manage the expansion. This has resulted in many areas being supplied for only part of the day.

In conjunction with the development of Water Resources projects, it was identified that a major resource which could be utilised relatively quickly was the reduction in levels of leakage from the reticulation system, by the implementation of a policy of leakage control. This would provide a base for the management of the existing reticulation system which can also be identified with the objective to manage the existing assets.

The Central Water Authority (CWA) of Mauritius began to work on reducing system losses in the mid1970s but in 1979 the work was stopped due to lack of funds. In 1983 a small leakage detection team was formed but was not effective as there was no suitable equipment. Equipment was provided in 1985 with the aid of foreign funding but no real progress was made as the team and equipment were put onto contract work. The CWA, together with the parent Ministry of Energy, Water Resources and Postal Services, recognised the estimated levels of unaccounted for water throughout the country were a serious problem. The CWA therefore decided to seek specialist help in the setting up of a systematic leakage control management programme.

Port Louis is the capital city and centre of business and commerce. The water reticulation system is generally quite old and the system losses were estimated to be greater than 50%. Also during 4-5 months of the year the resources were not sufficient to meet demand and this resulted in intermittent supplies being provided for between 6-10 hours per day.

The CWA developed a proposal for a pilot project to be implemented in Port Louis in conjunction with the UK government's Overseas Development Administration. This would provide for technical support, training and the development of systems, methods and practices in the area of leakage control and the reduction of unaccounted for water.

The ODA appointed Severn Trent Water as consultant for the project, to work full-time with the CWA. Severn Trent have extensive experience in operational management of water supply systems and are one of the leaders in the field of leakage control management in the UK. This expertise was made available through the use of a full-time consultant in Mauritius, backed by short visits from a senior consultant and full UK office support. Severn Trent have provided technical and management advice and support throughout the 33 months of the project which was completed in December 1989.

System Characteristics

The Port Louis water supply system has the following characteristics:

- the city covers an area of 60 sq km
- the population served is 162,500 resident
- the population served is approximately 300,000 daytime
- there are 12 service reservoirs
- there are six sources of supply
- the estimated average production is 68 Mld
- the estimated industrial demand is 20% of total demand
- the length of mains is 278 km
- the number of connection is 19,150
- all properties are metered
- the predominant material for mains is cast or ductile iron
- the predominant material for services is galvanised iron
- intermittent supplies for 4-5 months of the year
- no operational system metering
- water production estimated

Many of the mains and services had over the years been laid at shallow depth or on the surface and with an increase in the volume of traffic these were under stress. It was also apparent that the method of operating the system caused stress to mains and services with daily closure of valves at service reservoirs.

The normal useful life of galvanised iron is in the region of 15-20 years and many of the system leakages were due to corrosion of this material.

Methodology

The methodology adopted took account of the characteristics of the system and that the overall assessment of unaccounted for water was based on estimates of production. It was also realised that the possibility of providing source metering during the life of the project was remote. In fact source meters have now been ordered and will be installed in January 1990.

The need to monitor flows and establish the extent of the reductions achieved was recognised early in the project. The high levels of UFW were attributed to:

- lack of production and supply output data due to absence of reliable measuring devices;

- poor condition of the existing reticulation system due to lack of maintenance in the past;

- poor maintenance standards including the specification of work and materials;

- deficiencies in the recording of consumers' consumption;

- lack of co-ordinated management of the distribution system including the methods of system operation.

From the initial inception report on the project the management of CWA agreed to institute an active leakage control management programme.

The methodology then implemented was based on an active policy and required the setting up of small discreet areas of the distribution system. These areas were denoted District Meter Areas (DMAs) and the flow into and out of each DMA was to be monitored on a continuous basis.

To tackle the programme in a systematic manner required a complete review of the existing system and the creation of a coding system. The coding system was devised to enable each section of the distribution system to be related to a DMA and then to a service reservoir zone and to a source. This system is then used to collect physical and cost data and forms the basis of a systematic approach to operations management.

It was initially envisaged that some 60 DMAs would be required to cover the project area being broken down into reasonable sized sections of the system. The final outcome has been the creation of 36 DMAs of which 10 are trunk mains.

A complete inventory of each DMA has been compiled, which includes data on consumers, population and consumption. Considerable resources were employed in investigating the location and state of the existing network, including the fixing of valves to define the boundaries of each DMA to enable system monitoring and step tests to be undertaken. This work involved the excavation of many trial pits, the data accumulated was transferred to detailed plans which form the basis for assessment of the network's condition with a view to future rehabilitation. The amount of work involved is of a greater volume than originally expected due to the lack of details plans of the network. However, this work is indispensable for the leakage control exercise and will be a benefit for the future operational management of the system.

This initial activity of investigating the existing reticulation system took more than 50% of the project time. The progress was also hampered by:

- traffic density, necessitating working outside normal hours;
- rainy seasons;
- availability of equipment eg lack of compressors, etc;
- intermittent supplies.

These problems were addressed during the project and satisfactorily resolved.

The next step necessary to establish the DMAs was the measurement of flows and an initial assessment of the size of permanent meter required was made using turbine meters. Once the size of meter had been determined a Kent Helix 2000 mechanical meter of the Woltman type was installed. This meter was used to monitor the flows into the DMA and as an aid to leak location, by using it for step tests. The monitoring of flows was carried out by both manual readings and the installation of data loggers to produce the diurnal patterns for each DMA. Once a base flow had been established by both cumulative daily and minimum night flow data the work on leak location was begun.

Step testing was used to identify the section of the system within the DMA in which the leaks were located and then pinpointing was carried out by aural sounding and the use of modern electronic equipment.

Once a leakage had been located repairs were instituted within 48 hours and the results monitored on the meter using the data loggers. Some 1,460 leak repairs to mains and services were carried out during the project with a high proportion on galvanised iron services.

The three phases of the project are shown below with the first two phases substantially completed by December 1989 and the third phase put into practice.

SET UP SYSTEMS	
- Initial design	
- Data collection	PHASE I
- Purchase equipment/materials	
SET UP DMAs	
- Site investigation	
- Install meters	
- Test boundaries	PHASE II
- Produce system plans	
- Compute DMA UFW	
- Reduce UFW	
SYSTEM MONITORING	
- Monitor flows	
- Set UFW targets	
- Repair as necessary	PHASE III
- Update plans	
- Check and reduce pressures	
- Overall supervision of UFW levels	

The system monitoring phase is seen as critical to the long-term success of the project. A methodology of constant monitoring of DMA flows, Fig 1, has been developed and implemented.

Fig 1

The team created, Leakage Control Unit (LCU) to carry out the implementation of the programme may be seen as project oriented. Having set up the infrastructure the team will move to another distribution system leaving the day to day management of the system to the local operational managers. There is, however, a need for supervision of the performance of the operational managers to ensure that targets set are attained. Initially this role will be undertaken by the LCU apart from its main task of setting up DMAs in other distribution system. The management system being implemented is shown in Fig 2.

Resources and Training

The resources employed on the project may be categorised and summarised as follows:

External Support
- STW full-time assistance
- UK support and advice

Equipment
- Measuring
- Data Capture
- Computer
- Software
- Leak Detection
- Pipe Location
- Vehicles
- Plant

Manpower
- Engineering
- Technical
- Administrative
- Supervisory
- Skilled labour force

The project has introduced new technology and equipment to monitor flows and pressures and to detect leaks. This equipment, which is the latest available for leakage control activities, includes:-

- Micro Computer with printer, plotter and software
- Data Loggers (Spectrascan)
- Pressure Recorders
- Electronic Pipe Locators
- Metal Detectors
- Electronic Leak Detectors
- Leak Noise Correlator (Microcorr)
- Turbine Meters
- Pressure Transducers
- Electronic Meter Pulse Units
- Under pressure Drilling and Tapping Machines

The use of this equipment required the CWA staff to be trained mostly on site on the ground. All the equipment has, after some initial problems, performed satisfactorily apart from the leak noise correlator. The problems are still being investigated and it is hoped to resolve them in the near future.

The new equipment and the introduction of the DMA philosophy requires training in the use of new techniques and the setting up of administrative procedures to enable efficient management of the system. Development of the systems and practices, taking into account the local conditions, methods of working, facilities, etc was undertaken as part of the project.

With regard to general training, seminars were held to introduce staff to the concepts being realised under the programme. These staff were from senior managers to supervisors in all disciplines and two staff were sent to UK for intensive leakage control training for a three month period.

Achievements and Results

With the problems encountered due to the lack of source output metering all the savings have been computed at the lower system level of the DMA. These savings were deduced from the reduction in the minimum night flows and equated to some 19,000m^3/day (October 1989).

An assessment of UFW for the whole country has also been undertaken which shows a reduction over the period of the project from 46% to 43%.

The trend in increase of water put into supply has also been analysed from data beginning in 1982/3 and this shows a definite decrease in the water produced over the period of the programme in Port Louis. This data is available to July 1989 and is shown in Fig 3.

Fig 3

The savings made in the Port Louis programme can be equated to monetary values using marginal costs and the selling price of water.

The marginal cost is taken as an expression which collates the individual components of additional expenditure necessary to produce one additional unit of water, in this case cubic metres. These costs are normally additional electricity units consumed and chemicals added, in some cases marginal costs may also include pumping from expensive and reserve sources and additional overtime payments. The marginal cost excludes all fixed charges against a plant, such as labour, maintenance, interest on capital employed, etc. Only the variable charges directly related to increased production are used. The marginal cost, calculated for the financial year 1987/88 is an average of Rs.0.255/m^3.

The selling price of water is based upon data for the lowest volume unit price billed to domestic consumers as per the tariff May 1988. This is Rs.3.0/m^3 but it should be noted that the non-domestic tariff is higher.

Using the above costs and the volume savings to date the value of water saved is:

Rs 1.7 million (£70000) at marginal cost rates
Rs 21.0 million (£830000) at water sales rates

However, the costs of undertaking the work must be offset against the savings made. The costs of establishing DMAs to October 1989 were some RS 1.24 million (£50000). If the cost of equipment purchase is added to this the total costs equate to some Rs 2.54 million (£102000), but much of the expenditure on equipment will be utilised in other systems.

If the cost and savings are plotted for the life of the project, Fig 4 shows the points at which a theoretical 'profit' is being made. This 'profit' may be seen as the point at which the costs of establishing the system have been repaid.

Fig 4

The costs of repairs and leak detection have not been included as these costs would have been incurred by the CWA as a result of complaints, etc. They are the normal costs incurred by operating either a passive or active leakage control programme when bursts occur and cause a nuisance, either by reducing consumer supplies or water issues.

A further benefit which may be attributed to the introduction of a leakage programme is the possible delay in financing required for capital projects, deferment of capital expenditure. From an analysis undertaken it was calculated that to develop a borehole source to produce 24000m^3/day would cost £80000. If this expenditure is delayed the costs of borrowing that money to develop the source may be seen as a further saving to the organisation. It should also be borne in mind that the costs of operating a new source would be added to the marginal cost of water supplied.

The project has been a success with the following results and benefits:

- overall plans drawn and updated from scattered records and site details;
- zoning of the distribution system agreed with operational managers;
- plans drawn up for each zone and junction;
- 36 District Meter Areas (DMAs) established;
- system instituted to record the condition of mains and services;
- 95% of the resident population covered by District Meter Areas;
- data collected on population, length of mains, system demands, numbers of properties etc;
- 28 mechanical meters up to 300mm dia installed or refurbished;
- 10 differential pressure meters refurbished;
- workshop established for the repair of instrumentation and differential pressure meters;
- 2 No technical staff sent to UK for 3 months for specialist training;
- expenditure of some £50000 on the setting up of the DMA system;
- 19000m^3/day of treated water saved;
- an estimated saving per year at marginal cost prices of some £70000 and £830000 at selling cost prices;
- more efficient reticulation system;
- running costs reduced;
- capital investment deferred;
- accurate system records;
- improved management control information.

One further benefit that has been observed in 1989 is that there has been no need to date (Dec) to introduce supply cuts and intermittent supplies. In previous years supplies would normally have been cut in October/November.

Conclusion

The methodology adopted in introducing the programme by setting up a dedicated team, the Leakage Control Unit, to build the required infrastructure has been a major factor in the success of the project. With the advent of new technology and systems of work there is a need to bring about general changes in work methods and practices and the LCU is seen as a vehicle to pilot these changes.

The presence of Severn Trent's full-time staff has acted as a catalyst to bring together the resources required to achieve the objectives set. These resources include appropriate manpower, transport, plant, materials, equipment and finance. The successful outcome of the project has depended very much on the development of a team to undertake the project blending the local and foreign talents. This has enabled changes to occur in the management philosophy and the developing of the talents of individuals to engender the team approach to work.

The location and repair of leakage does not require high technological skills but it requires persistence and high organisational and management ability. This, combined with individual motivation, concentration and enthusiasm enables the infrastructure to be set up to give the operational managers a tool with which to manage their system.

The approach adopted of building a team from the water authority with the consultant as a full-time member and organising the methods by which the work can be continued is a key to the success of any project. The work of establishing the monitoring infrastructure throughout the country is now beginning but the monitoring of the levels of leakage in existing systems is essential. To ensure that the work continues to programme and that the leakage targets set for Port Louis are met, Severn Trent will have a continuing role for the next two years with periodic visits by experts to monitor and assess progress and, where necessary, provide advice to resolve problems.

Acknowledgement

I wish to acknowledge the helpful comments and assistance throughout the project of Mr R A Woodvine. The project was carried out by Severn Trent International of the United Kingdom, financed by the Overseas Development Administration of the British Government.

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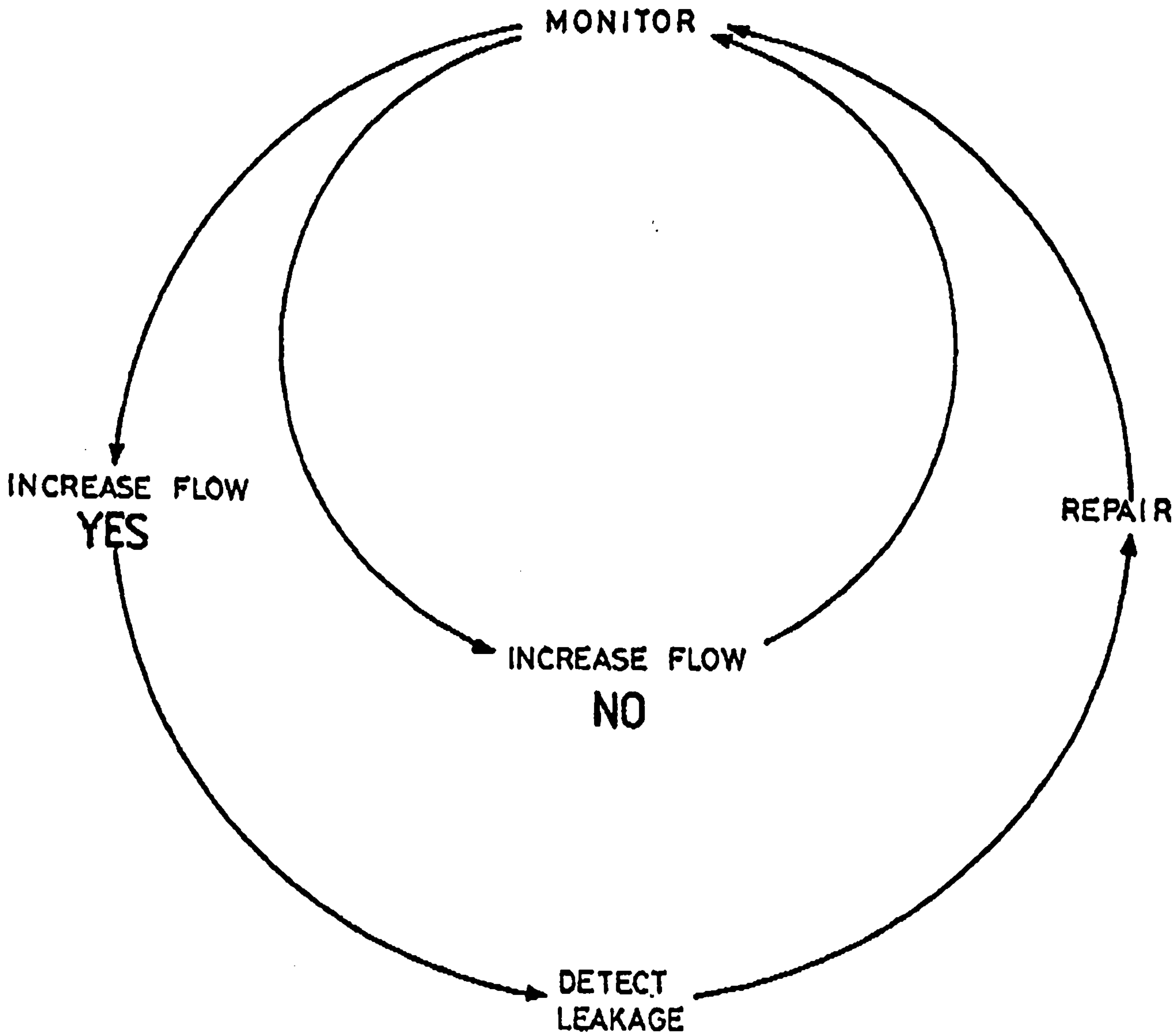
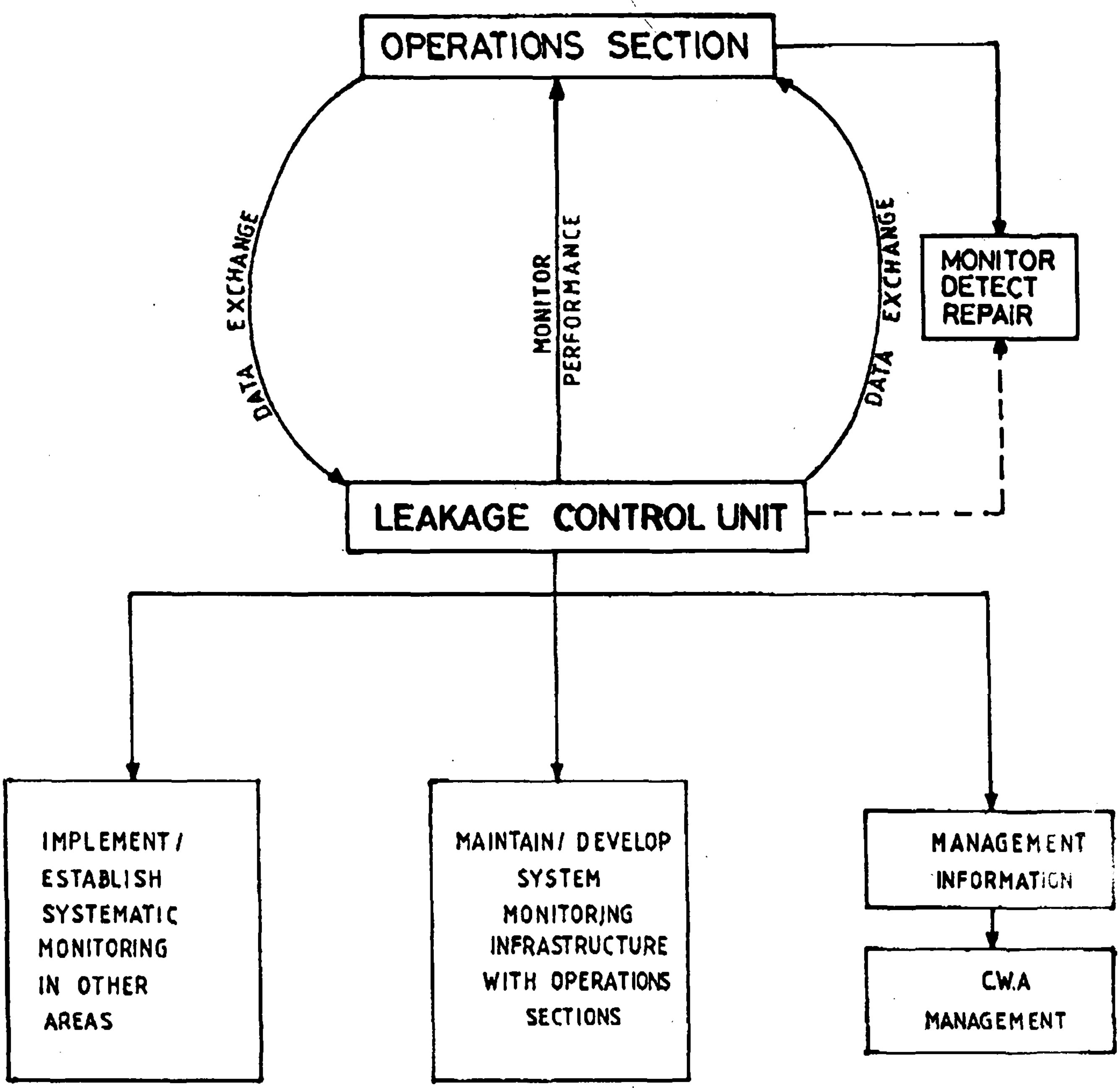
System Monitoring

METHODOLOGY



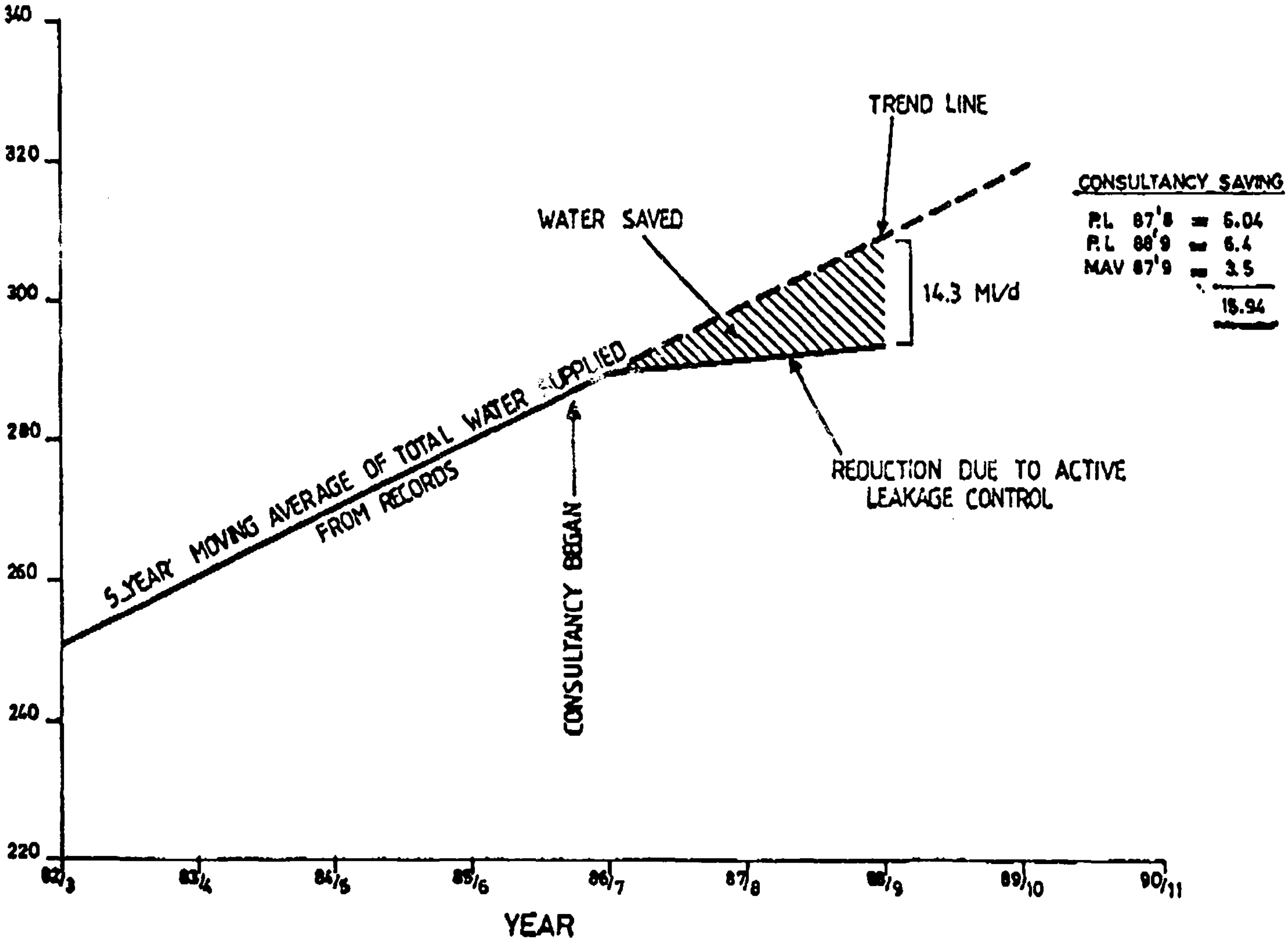
LEAKAGE CONTROL

Management System

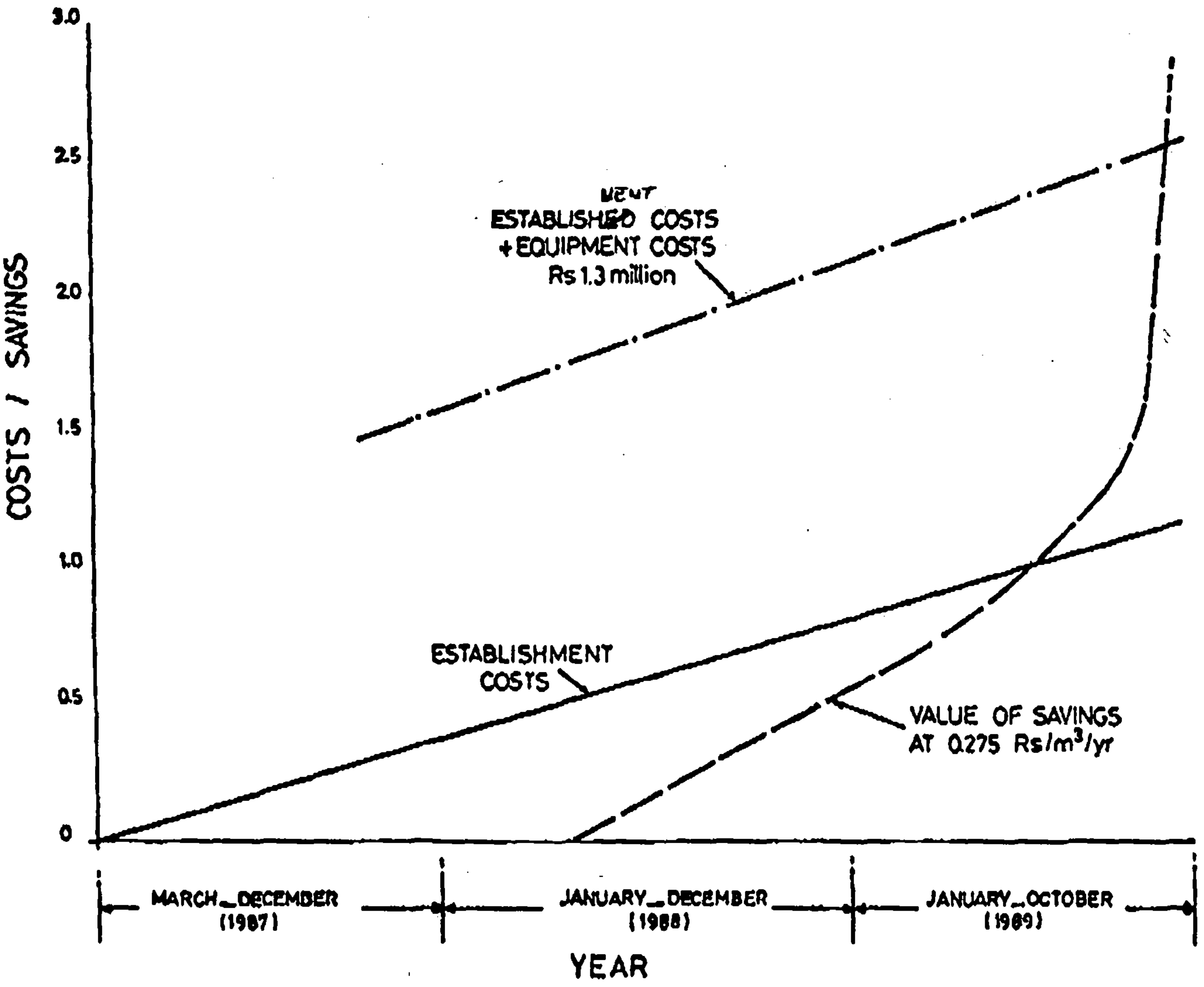


MAURITIUS WATER SUPPLY

EFFECT ON WATER INTO SUPPLY OF LEAKAGE CONTROL STRATEGY



COSTS / SAVINGS



4th African Water Technology Conference, 20-22 February, 1990
'Water in Africa - the next Decade'

KNOWLEDGE BASED SYSTEMS FOR COMMUNITY WATER SUPPLY AND SANITATION

Abstract

There is now a clear understanding of the range of low cost technologies available for community water supply and sanitation. However, it has become apparent that expertise in technology alone is not enough. Whichever technical system is chosen has to be what the people desire and feel comfortable with, has to produce significant health benefits, has to be affordable and has to be manageable both by householders and by responsible government institutions.

Engineers and planners do not find it easy to manage so many different factors. To meet the needs of scattered populations requires an increased engineering input per person served at a time when even dense population groupings are not adequately served. Computer based information technology has the potential to strengthen the expertise required for adequate coverage. Knowledge Based Systems can guide the planner through a series of interactive questions and answers and recommend possible project approaches. Two such systems are described, one for choosing a handpump and one for selecting sanitation systems. These are based on a low cost expert system shell and can run on the most widely available Personal Computer hardware.

Richard Franceys
Lecturer at the Water, Engineering and Development Centre (WEDC)
Loughborough University of Technology, England

KNOWLEDGE BASED SYSTEMS
FOR COMMUNITY WATER SUPPLY AND SANITATION

Learning from the Decade

The experiences of the water supply and sanitation decade have led to a much better understanding of the range of technologies available for both rural and urban populations. Many technical problems have been overcome as equipment has improved and new materials have been developed such as plastics in handpumps and ferrocement in water tanks.

It has also become clear that the technology by itself will not promote health and quality of life. Unless the consumers are involved, systems will not be maintained correctly and will fail. There is therefore now a greater emphasis on community participation, ensuring that the end users are involved at all stages of the planning, implementation, operation and maintenance of their own schemes.

Following on from this commitment to involve the beneficiaries there has been a new emphasis on cost recovery and financial viability (Briscoe and de Ferranti, 1988). Unless the chosen system is affordable (irrespective of who actually pays for it) it is unlikely that sufficient funds will be available locally for maintenance.

It is clear now that for a successful scheme the different but interrelated components of health enhancement, social acceptability, technology, economic and financial viability, institutional support and environmental awareness all need to have been considered.

This takes considerable skill, inevitably a higher level of skills per person served than much larger conventional systems. And for many projects these skills are required in the rural areas where the majority of the people still live but where the majority of the professionals are loath to live. Better design and implementation takes increased time and commitment.

All the statistics show that there is still a very large amount of work to do with a tendency for schemes to go out of action faster than new ones are installed.

Africa and the Decade

This analysis has particular relevance to the African continent. The recent report by The World Bank, 'Sub-Saharan Africa, from Crisis to Sustainable Growth' (1989) suggests that since 1961 economic growth in the 45 sub-saharan countries has averaged 3.4% per year but as this is similar to population growth, living standards have not changed; over the last 30 years, the population has doubled to almost 500 million and at the present growth rate of 3.3% the number will double again by 2010 . . "the high rate of growth means that Africa's economies and social services must sprint ahead for living standards even to stand still". One commentator (The Independent, 1989) suggests that "the most scathing aspect, however, is the virtual dismissal of technical assistance to Africa as useless. Although hundreds of technical experts have been dispatched to the continent by well-intentioned donors, African productivity has declined in many sectors". The report says "with about $7 per capita being spent annually, donors and recipients are clearly not getting value for their money".

The next Decade

How then might these problems be overcome to begin to meet the needs of the poorest in the years to come ? Two approaches are recommended. The first is to accept that economies of scale are not always producing the desired benefits. Many systems could be reduced in size to more manageable elements which could then be 'sold' to households and communities much like any other consumer item (Franceys, 1988). A second approach is to enable engineers and other professionals to be more productive by use of the new information technology, that is computers.

The use of computers, where they are seen as an everyday tool such as a calculator, can prevent mistakes, has the potential for improving the quality of the work and can free time for better control of construction quality or even for community discussions. There may be an added advantage in that the use of new technology such as computers is seen to confer status on their users and so enhances the level of professionals involved in low cost 'appropriate' technology.

Computers can be used for the ordinary tasks such as word processing and more specialised tasks with spreadsheets to improve planning and financial information. They may also be used for specialist design techniques such as the preparation of water distribution networks. However the main consideration in this paper is the use of 'Knowledge Based Systems' or 'Expert Systems' which can assist the planner or engineer in solving a particular problem such as in the choice of a water supply or sanitation system.

Knowledge Based Systems

The development of Expert Systems grew out of early research work into Artificial Intelligence on computers. Although not claiming any 'intelligence', "the term expert system is usually reserved for interactive programs that enable a user to seek advise on a specific topic rather as if he were holding a conversation with an expert." (Montgomery, 1989) The simpler systems, which work more on an algorithmic or decision tree basis rather than an inductive reasoning 'heuristic' level, are known as 'Knowledge Based Systems' (KBS).

Instead of text books a micro computer is used and information is assessed in consultation between computer user and computer. Like a human expert, a KBS gives advice by drawing upon its own store of knowledge and by requesting information specific to the problem at hand from the user. The essential criteria for determining whether or not a subject is suitable for an expert system is the answer to the question 'can the knowledge on the subject be translated into 'if-then' rules in other words, any rules on the subject should be encodeable in the format 'if a=b then c=d' (Sawyer, 1984).

Expert systems have already been successfully used in civil engineering generally and for water and waste engineering in particular. For example, systems exist to:

identify the need for external leak detection monitoring;
analyse unknown contents of waste containers;
interpret groundwater sample data;
assist operators of activated sludge plants in improving plant performance;
and suggesting low cost treatment processes for rural water supplies;

Because of the limitations of adapting any rules to real life, computer systems are mostly used as human assistants (with humans always making the final decisions) rather than as 'stand alone' autonomous systems (Gevarter 1984). They are not there to replace a human expert, but to extend the experience and confidence of that expert.

Steels (1989) comments that "the notion of expert systems is increasingly being trivialised, leading to false user expectations and superficial results." The Knowledge Based Systems described below, developed at the Water, Engineering and Development Centre, are not trivialising any special computing concepts but do represent a first stage of understanding of the knowledge required to improve water supply and sanitation programmes. In this respect they may be seen to convey 'shallow or surface knowledge' rather than the 'deep knowledge' which may be seen as the ultimate goal. However, it is the developer's belief that KBS's have a valuable role to play and as their effectiveness becomes apparent they can be enhanced.

At the simpler level a KBS may be seen as different way of presenting information which is already available in books and design guides. But the ideas and information are presented in a KBS in a concurrent, interrelated form rather than a consecutive form - the value of the simple computer based approach lies in the ability of the system to prompt the user to include all the necessary information, not just the technology but also the community aspects, the finance and economics and the institutional requirements.

Computers and Equipment

The most commonly available computers in the world today (PC's or IBM Compatible MicroComputers, which are now counted in the tens of millions) work to a common standard and programs designed for one machine normally run on other machines. This makes it worthwhile to prepare more specialised programs, knowing that it will be possible to run them in a different setting.

As these computers become available for the first time in an organisation there is a danger that they become the preserve of 'the computer expert'. However, the great advantage of desktop computers is that they can become an everyday tool of the planner or engineer, to be used in the same way as a typewriter, a calculator or even a pad of paper.

A Knowledge Based System is one type of program to run on a microcomputer. It consists of two basic components: the 'knowledge base' and the 'inference engine'. The knowledge base contains all the rules and statements which represent the expert's decision-making logic, and the inference engine is the 'mechanism' which searches it to extract conclusions, that is the process of developing evidence in order to arrive at new conclusions (Hochgrebe, 1988).

Most of the KBS's being developed at present use a program 'shell', purchased from a programming company. The developer processes his knowledge and experience to fit into this shell. The cost of the shell can be greater than the cost of an individual microcomputer and in addition the developer has to purchase a 'run time license' which gives the right to distribute the shell to prospective users along with the developed knowledge base.

The major strength of a KBS over conventional computer programs is the ability to allow use to be made of qualitative knowledge (expertise and experience or 'soft' data), natural language and to allow interactive, user friendly consultations. They are normally used to model complex situations with too many variables to be solved using a linear approach.

Developed as an advisory facility, knowledge based systems aim to identify all the relevant factors affecting a problem situation (checklisting) and suggest strategies rather than to give 'the only possible and true answer' for complex circumstances. In this respect expert systems support decision making, instead of pretending to make the decision for the planner.

The relevance of KBS's for developing countries lies in their potential for high level information transfer between local and international knowledge - particularly where inter-disciplinary expertise is required.

Knowledge Based Systems for Developing Countries

Systems are now being developed for a whole range of activities. One helps with design of small hydro-electric projects; the authors stress the idea that for a successful installation of a hydropower scheme "the services of experts from the many fields of engineering and economics" need to be involved in an assessment but that this is normally too expensive for small projects. "Assessments are therefore often made by a person with expertise in one aspect of the project only"...who may be "well versed in his or her own field, but have scant knowledge of the other design areas involved. The Edinburgh expert system is being designed to provide engineers with the collected knowledge and expertise of experienced practitioners, so that it will reduce the possibility of non-viable schemes being promoted". (Anderson, 1988)

Research at the Water, Engineering and Development Centre has led to the initial development of four prototype Knowledge Based Systems to assist community water supply and sanitation: 'Handpump selection' and 'Sanitation selection' described below, 'Water supplies in disaster relief' (Ockelford, 1989) to assist in emergency or refugee situations and 'Design of small dams' (Nichol, 1990).

Knowledge Based System for Handpump Selection

The KBS on handpump selection uses the experience gained in the UNDP/World Bank project on laboratory and field testing of handpumps (Arlosoroff S, et al, 1987). The Knowledge Based System was developed by Eckhard Hochgrebe using a 'VP Expert shell. This shell is reputed to be the best selling expert development system in the world. It has the advantages of low purchase cost and a single run-time license irrespective of the number of copies. It is also one of the simpler programs so that the entire program with the handpump knowledge base can be contained on a single 5 1/4 inch floppy diskette which facilitates dissemination and use.

Because of the way in which the data was available, this particular program acts substantially as the interactive front end of a database. Information on each pump is held on disk and the user is asked a series of questions regarding the maximum lift, maximum daily output, maintenance systems, corrosion resistance, abrasion resistance and manufacturing locale. At each step there is the possibility of choosing comments to explain the question and the reasoning behind answering it. As the user becomes more experienced these comments can be omitted. On conclusion of the questioning, the program searches the database for the pump or pumps which best fit the chosen criteria. The list is displayed and the user is offered further information on each pump, including the results of the testing programme, the country of production and address of supplier and an indicative price.

FOR WHICH MAXIMUM LIFT IS A HAND PUMP REQUIRED ?

(E.g. for any pumping lift between 7m and 12m, choose 'up to 12m'.)

up to 7m up to 12m up to 25m
up to 45m

Enter to select

WHAT IS THE MAXIMUM DAILY OUTPUT (IN CUBIC METRES) THE HAND PUMP HAS TO DELIVER ?

'max DO 1 5' stands for: 1.5 cu m maximum daily output
'max DO 4' stands for: 4.0 cu m maximum daily output
'max DO 8' stands for: 8.0 cu m maximum daily output

max DO 1 5 max DO 4 max DO 8

Enter to select

COMMENTS ON MAXIMUM DAILY OUTPUT

For many hand pump supplies in developing countries, a per capita demand of 20 l per day can be assumed.
Three maximum daily output categories ('max DO') are being used here:

'max DO 1 5' : 1.5 cu m/ day for 75 users per day
'max DO 4' : 4.0 cu m/ day for 200 users per day
'max DO 8' : 8.0 cu m/ day for 400 users per day.

If additional demands (e.g. for micro irrigation or animal watering) have to be allowed for, the number of people to be supplied might have to be reduced accordingly to stay within the provided daily output categories.

(PRESS any key to continue with the comments.)

WHICH MAINTENANCE SYSTEM SHOULD BE USED FOR THE TYPE OF HAND PUMP TO BE CHOSEN FOR THE PROJECT/PROGRAMME CONCERNED ?

'Central M' stands for: Centralized Maintenance System
'AreaMech M' stands for: Area Mechanic Maintenance System
'VillageL M' stands for: Village Level Maintenance System

Central M AreaMech M VillageL M

Enter to select

AT WHICH MANUFACTURING LEVEL SHOULD IT BE POSSIBLE TO PRODUCE THE HAND PUMP TO BE CHOSEN (IF AT ALL) ?

(If no in-country production of pumps is intended, type ? as your choice.)

'WDev IndB' stands for: Well Developed (or Advanced) Industrial Base
'Mod IndB' stands for: Moderate (or Medium-Level) Industrial Base
'Low IndB' stands for: Low Industrial Base

WDev IndB Mod IndB Low IndB

Enter to select

BASED ON THE CHOSEN PROJECT CRITERIA THE FOLLOWING 1 HAND PUMP(S) HAS (HAVE) BEEN SELECTED BY THE EXPERT SYSTEM:

(It should be noticed that the decision and responsibilty to use any hand pump cannot lie with this expert system, its author, or the World Bank.
If no pump has been selected, PRESS / Q C and try again with reduced criteria, if project conditions allow.
For pump information, select a pump and press ENTER. If you require a print out of this information press 'Shift' 'PrtSc'

AFRIDEV

Enter to select END to complete /Q to Quit ? for Unknown

As shown in Figure 1, the program is simple to use, not requiring the input of specific figures but asking the user to specify a given range. Hochgrebe (1988) suggests that the comments section could be improved further, "providing comprehensive information built up like a good introductory reader and supported by good visual displays, figures and graphs. Such a computer based reader could allow the user both a) to read from page to page and b) to access any particularly marked cross-references, in the style of a good dictionary. Thus one branch of the expert system would be assigned for the experienced analyst who wants fast results, while the other branch would become a combined education and selection facility."

Hochgrebe concludes "anyone who knows the particular project conditions for which a handpump is sought, but is not yet familiar with the selection approaches used, can obtain sensible results within 20 to 30 minutes by using the KBS which would be difficult to achieve using the original selection tables."

The program is also of value for evaluation of existing projects as well as the relatively rare selection required for new projects. It could quickly be determined whether the pumps themselves were a likely cause of failure or whether the more usual institutional factors were to blame.

Knowledge Based System for Sanitation Selection

The KBS on sanitation selection was prepared by Eugene Larbi, again on VP Expert, initially using an algorithm prepared by the author (Franceys, 1990).

The target group of users of this programme is expected to include professionally trained project engineers and project planners who will be involved in the preliminary design stages of sanitation projects. No special knowledge in computer usage is required for consultation but it is expected that users should be conversant with conditions in the project area and the requirements of the recipients for whom the excreta disposal system is required.

The program takes as its starting point the method of anal cleansing and offers comments as to why this is significant. Depending upon the answer the user is then asked about water availability, affordability, population density, demand for reuse of faecal waste, availability of mechanical pit emptier, land availability, and permeability of ground. Again, comments are offered at each stage but questions are only asked where they remain relevant. The program ends with a recommended sanitation system and a disclaimer to stress that the KBS is only a guide to the decision making process and that the final choice still depends largely on the preference of the community or household.

Larbi (1989) believes that the program, partly illustrated in Figure 2, could be extended to include construction details of the chosen system, operational and maintenance requirements and

```
Consideration of ANAL CLEANSING.

Options available in this criterion are:
  - water
  - soft paper
  - hard material
  - bulky material

Press the ENTER key to display comments on this criterion
which would help you to decide on which option to choose.
COMMENTS ON ANAL CL
```

Enter to select   END to complete   /Q to Quit   ? for Unknown

```
Consideration of WATER available for flushing and/or anal cleansing.

Options available in this criterion are:
  -10 litres
  - 3 litres
  - 1 litre
  - 0 litres

Press the ENTER key to display comments on this criterion
which would help you to decide on which option to choose.
COMMENTS ON WATER
```

Enter to select   END to complete   /Q to Quit   ? for Unknown

```
COMMENTS ON WATER AVAILABLE:

The water supply service is an important criterion for selecting
a sanitation system for an area.For households with only hand-carried
supplies,conventional sewerage or septic tanks with soakaways are
technically infeasible as are sewered pour flush systems since
insufficient sullage would be generated (minimum recommended amount of
sullage for successful running of such systems should be 50lcd).
In households with piped supplies,feasible alternatives are narrowed
down to systems which incorporate means of disposing of sullage such
as sewerage,septic tanks,cesspits,aqua-privy and pour flush latrines.

(Press any key to continue with consultation)
```

```
How much water is available for flushing
and/or anal cleansing?

Note:
If anal cleansing material is water,then the answer
to this question cannot be 0 litres.
10 LITRES          3 LITRES          1 LITRE
0 LITRES
```

Enter to select   END to complete   /Q to Quit   ? for Unknown

```
The most appropriate method/methods of excreta-disposal
for the conditions given is a system of
DIRECT SINGLE PIT POUR FLUSH LATRINES.
NOTE:
IF GROUNDWATER OR HARD ROCK IS ENCOUNTERED LESS THAN 2m BELOW SURFACE,
THEN PITS MAY BE RAISED ABOVE GROUND LEVEL TO SUIT CONDITIONS.

The above named sanitation system(s) was/were based upon these criteria:
                       ANAL CLEANSING MATERIAL:  water
                               WATER AVAILABLE:  3 LITRES
  AFFORDABILITY OF CAPITAL AND MAINTENANCE COSTS:  LOW
              POPULATION DENSITY OF PROJECT AREA:
                      DEMAND FOR FAECAL WASTE:  NO
           AVAILABILITY OF MECHANICAL PIT EMPTIER:  YES
     AVAILABILITY OF LAND FOR NEW/EXTRA LARGE PITS:
             PERMEABILITY OF SOIL IN PROJECT AREA:  PERMEABLE

(PRESS ANY KEY TO CONTINUE)
```

typical costs and potential for householder involvement in construction.

The expert system shell also has the facility to assign 'confidence limits' to the rules base. At present these have by default been given as 100% indicating a definite choice. In some areas confidence factors below 100% could be attached to conclusions to show the relative certainties placed upon them.

Proposed hierarchy of knowledge based systems

Following on from the work on these initial programs it is envisaged that a 'family' of knowledge based systems might be prepared for use in low cost water supply and sanitation programmes. Because of the cost and complexity of joining all the sectors together into one computer program (and the danger of appearing to give a single 'correct' answer) a series of programs looks to be advisable. At the top of the hierarchy an overall planning Knowledge Based System would enable the user to estimate demand and potential resources and constraints. This is equivalent to the sector planning and pre-feasibility stages of the Project Cycle and could result in suggestions such as 'groundwater development with handpumps' or 'gravity flow water systems with VIP latrines'.

Kelsey (1988) believes that Expert Systems will be most useful at these preliminary planning stages where the domain of expertise is relatively narrow. The expertise required is not necessarily narrow if all the non-technical factors described above are included. This leads to less specific answers which in turn ensures that the user continues to think about the problem without simply accepting the computers result.

At a second level the feasibility of the initially recommended method of meeting the demand would be assessed in a Knowledge Based System. For example, there might be KBS's on Gravity Flow Systems and on Surface Water Abstraction and Treatment and on Groundwater Development with an additional sub-program on Water Abstraction and a further sub-sub-program on Handpumps.

At a final level, where qualitative factors are no longer significant a conventional program would be used for detailed design such as determining pipe sizes on a branched network. See for example the TAG programs (World Bank, 1985) and others described by Lauria (1988).

Conclusion

Can the use of computers ever be justified for the promotion of low cost water supply and sanitation ? Or are they simply yet another inappropriate technology which will fail after an expensive trial run ? The author believes that knowledge based systems have considerable potential to assist in overcoming the knowledge and skills gap which is limiting the replication of known technologies to millions of people.

However, it is always worth noting the dangers. Harper (1988) comments that "computers can be a typical example of an inappropriate technology if they are used inadvisably; they can perpetuate dependence, reduce replicability, inhibit local participation and constrain local job opportunities." It is necessary to "ensure that local field staff are trained to use computers, and do use them." We have to "avoid any impression that computers are only to be used by a higher level of staff, or only by headquarters."

It appears that in the long term, computer based information technology will play an ever increasing role in the storage and transfer of skills, knowledge and information. To meet the urgent needs of the millions without adequate water supply and sanitation it would be beneficial to use modern methods to enhance appropriate technology now - rather than allow these programmes to fall even further behind.

Acknowledgement

The two knowledge based systems described in detail in this paper were prepared by Eckhard Hochgrebe (Handpump selection) and Eugene Larbi (Sanitation selection) as part of the Master's Programme for the Degree of Water and Waste Engineering in Developing Countries, Loughborough University of Technology.

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MEGAWATERSHEDS EXPLORATION MODEL

Robert A. Bisson
Dr. Farouk El-Baz

MEGAWATERSHEDS EXPLORATION MODEL

Robert A. Bisson

BCI Geonetics, Inc.

Laconia, NH 03247 USA

and

Farouk El-Baz

Boston University

Boston, MA 02215 USA

ABSTRACT

The megawatershed model is a concept of the behavior of groundwater in large-area watersheds. It is designed to enhance success in the exploration for groundwater, particularly in fault-controlled regions. In such regions surface and subsurface water flow may be strongly influenced by structural features. The latter constitutes zones of secondary permeability through which large amounts of water may flow.

Recognition of the significance of such a model was largely due to the availability of space photographs, which cover large areas of the Earth and allow the interpretation of regional patterns, and the correlation of drainage with structure.

The model takes into account the water source from precipitation, the catchment area, the infiltration process, the transmission mechanisms, and the water storage capacity of the system. An example of the application of the model to groundwater exploration is given in the Red Sea Province of eastern Sudan.

INTRODUCTION

The Megawatersheds Exploration Model was developed by the authors as a tool to enhance success in groundwater exploration. It is an exploration model rather than a quantitative hydrogeologic model.

The term megawatershed in this context describes the broadest possible three dimensional catchment area and transmitter of water, originating from one or more recharge zones, and with surface and subsurface flow strongly controlled by regional structural features in the bedrock. Some of these structural features act as zones of secondary permeability, through which large amounts of water may flow (Figure 1). In this case, *mega* refers more to order-of-magnitude effects on groundwater flow in these three-dimensional fracture controlled systems than to areal basin size.

The purpose of the model is to better define these *order-of-magnitude effects* to assist in the discovery of large amounts of high quality groundwater, here termed "high-grade water" located within zones of secondary permeability. The *"high-grade water"* is attained when the measured yield from a well is an order of magnitude greater or more than the average yield of other wells in the region.

BACKGROUND

Large regional aquifer systems occur in many parts of the world. In many cases, the subsurface movement of water over long distances is a necessary ingredient of conceptual models of the dynamics of such aquifers. Most of the known regional systems, such as The Great Artesian Basin of Australia, the chalk aquifers of France and England, the Nubian Sandstone systems of North Africa and the Ogallala Formation of the High Plans Region of the USA are generally believed to occur entirely within sedimentary rock formations.

Also generally accepted is the view that aquifers in these sedimentary rock formations derive their characteristics from the imposition of climatic and hydrometeorological conditions upon the regional geology. With the exception of certain limestone terrains, primary properties of rock permeability and the geometry of associated sedimentary formations were in the past seen to represent the only major parameters affecting the occurrence of groundwater in sedimentary basins.

The premise of the megawatershed model is that, in addition to large watersheds underlain by sedimentary rocks, where primary porosity is assumed to control groundwater movement, there are also regional basins consisting of interconnected fracture systems. These can occur within watersheds underlain by both crystalline and sedimentary rocks.

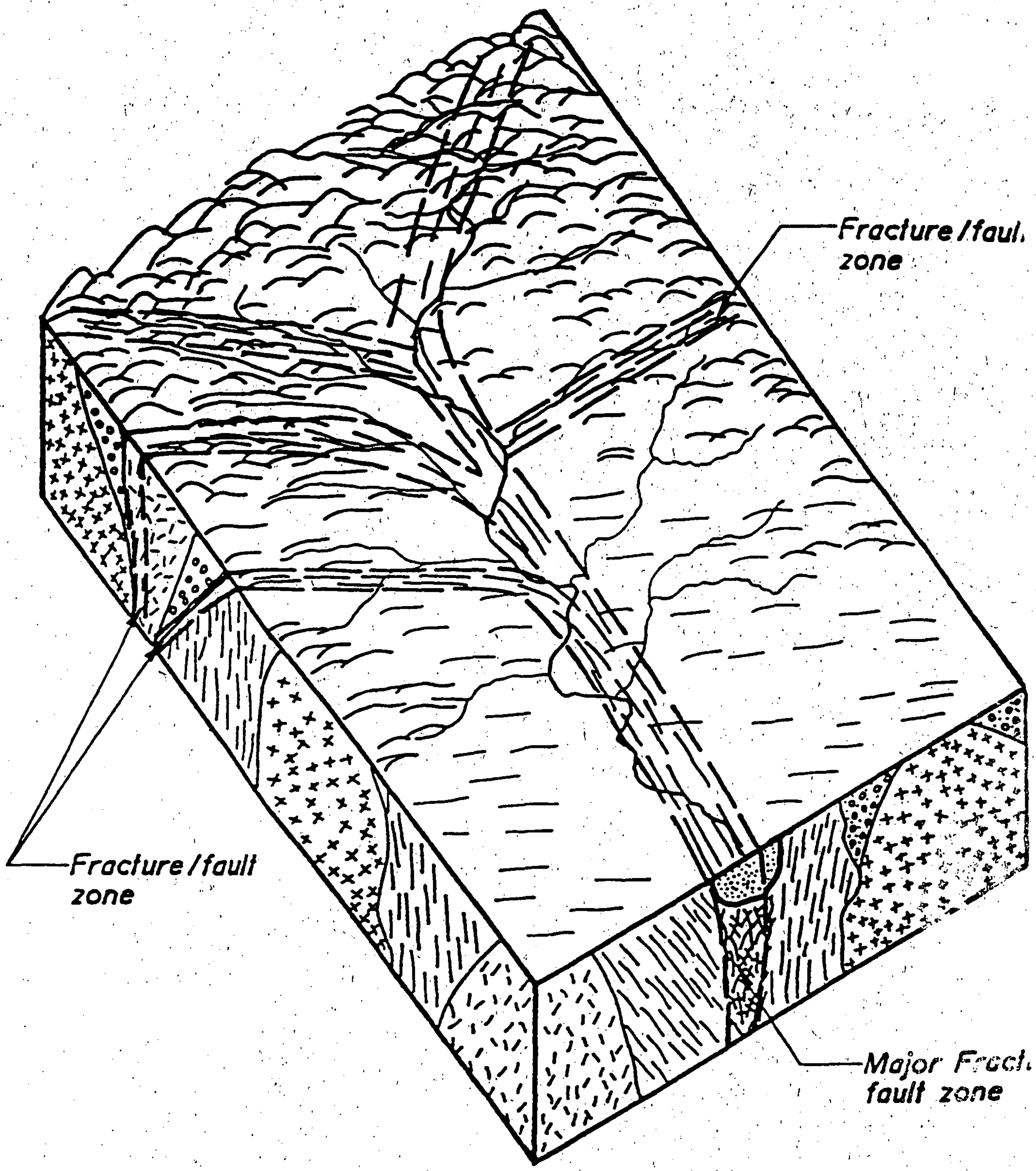

Figure 1. Schematic Illustration of the Control of Drainage by Major Fault/Fracture Zone.

Formal studies of groundwater behavior related to bedrock fractures have been carried out for more than a century. As early as 1835, William Hopkins, in *Researches in Physical Geology* listed his observation of rectangular arrangements in topographic features, drainage patterns, faults, mineralized veins, joints and alignment of springs. Dana (1847) contended that controlled re-establishment of the regional fracture system takes place along pre-existing patterned stress field lines; later confirmed by Cloos (1948) and Meinesz (1947). Hobbs (1911) stated that the development of land forms, in some areas, is largely the result of systematic bedrock fracture control and that these fracture systems propagate and manifest themselves on the earth's surface in the form of drainage alignments, linear topographic trends, soil-tonal anomalies and vegetation alignments; later confirmed by Hilgenberg (1949), Hill (1956), Henderson (1960 and Badgely (1965).

Historically, the propagation force has been attributed to earth tides, isostatic rebound, active crustal stress patterns, ocean floor spreading and differential compaction over an irregular basement. L. Casagrande (Mollard, 1957) indicated that a greater hydraulic gradient exists in the overburden above a fractured zone of bedrock. Downward movement of groundwater will cause a leaching of fine-grained particles and consequent subsidence. The fractured zone, under certain conditions, may act as a vertical conduit for discharging groundwater, accounting for higher soil moisture and corresponding vegetation alignments. Angelillo (1959) in his regional analysis of the Mohave River basin groundwater regime graphically described a stress-field-induced and fractured-rock-controlled basin recharge and discharge system.

The advent of modern earth orbital platforms with remote-sensing instrument payloads, in the 1970's, combined with a concurrent wide acceptance of applied plate-tectonic theory, encouraged a new generation of explorationists to re-examine existing concepts in a new light.

In recent studies of aquifer systems, for example, Buckley and Zeil's (1984) study on eastern Botswana, the role of secondary permeability is seen to be an important part of the aquifer hydrodynamics. Increasing attention is being given to the superimposed secondary effects of structural and tectonic influences on the primary hydraulic properties of the rock formations. For example, the hydrogeology of the Triassic sandstones of central England (Price, 1985), the chalk of eastern England (Nunn, et al., 1983), and the Tertiary limestones of Florida (Cederstrom et al., 1983), are now known to be strongly influenced by faults and their associated fracture systems.

In another example, Zacharias and Brutsaert (1988) show that while the recharge characterization of a watershed as a single unit may be a useful approximation, it can also have its limitations. The total groundwater discharge from a watershed is the sum of flow contributions from various sections along the aquifer such as infiltration at the head waters, transmission, and storage along the channelways at the discharge areas, each of which have unequal behavioral properties, (i.e., the steeper parts of the drainage basin behave differently from those that are more gentle). Results of their studies show that secondary permeability greatly increases the total watershed base flow and the recharge calculations.

MODEL COMPONENTS

In order to explain the flow system of a particular aquifer with respect to an entire watershed, it is common to develop a simple conceptual model which describes the physical conditions of each of the components of the hydrogeologic cycle. This includes a description of the source of the water (usually precipitation), how the water moves to and within the watershed (infiltration and transmission), how the water is stored within the aquifer, and the nature of discharge from the system.

In the case of the megawatershed model, in addition to an evaluation of primary aquifer characteristics, results from descriptive site examinations, laboratory studies and computer modelling of fluid flow in fractured rock are also used to document the behavior of groundwater in all parts of the watershed.

Water Source

Although many exceptions exist, such as the potential Okavango Delta recharge of a Kalahari Megawatershed (Bisson, 1985), in most cases, groundwater has its direct source in precipitation. In many arid regions the average lowland or basin rainfall is usually low and the evaporation rate high. For example, in Libya rainfall varies from less than 25 to 400 mm per year, with potential evaporation rates at 1,700 to 6,100 mm per year, yet flow from a well field adjacent to springs in the Libyan desert has been measured at 250,000 cubic meters per day (45,000 gpm). In another case, La Moreaux et al. (1985) in their study of the Kharga Oases in the western desert of Egypt, found a mean annual rainfall of 1 mm, with potential evaporation rates similar to those cited above. Yet individual wells at the oases flowed at more than 15,000 cubic meters per day (2,700 gpm). Elsewhere, similar regimes of low rainfall, high potential evaporation, and anomalously productive springs have been noted as in the Sinai Desert (Issar, 1985).

Studies of some of these areas have stated that local recharge can not account for the measured discharge (Abufila, 1984; Ahmad, 1983). One possible answer is that recharge is coming from further away, in mountainous terrain. The "orographic effects" of mountainous terrains on rainfall can induce precipitation amounts which are considerably greater than in lowland regions (Figure 2). Given the distinct possibility that this meteoric water might enter subsurface fracture conduits connecting the mountains to the distant desert springs, mountains may be a reasonable recharge source to consider. For example, the potential groundwater recharge rate from the Chad and Egyptian mountains to the Kufra and Sarir well fields (600 miles away) has been estimated at more than 70 million cubic meters per day (Alam 1989) -- considerably more than the two million cubic meters per day drawn from the well fields.

In some areas, where elevations and climate dictate, rain may occur as snow. Angelillo (1959) suggests that the snow pack may increase infiltration by decreasing rapid runoff (except during rapid spring melts). The times of slower melting would allow for constant subsaturation of the porous media below the snow and thus increase the infiltration rates. This would also increase the amount of water available for recharge.

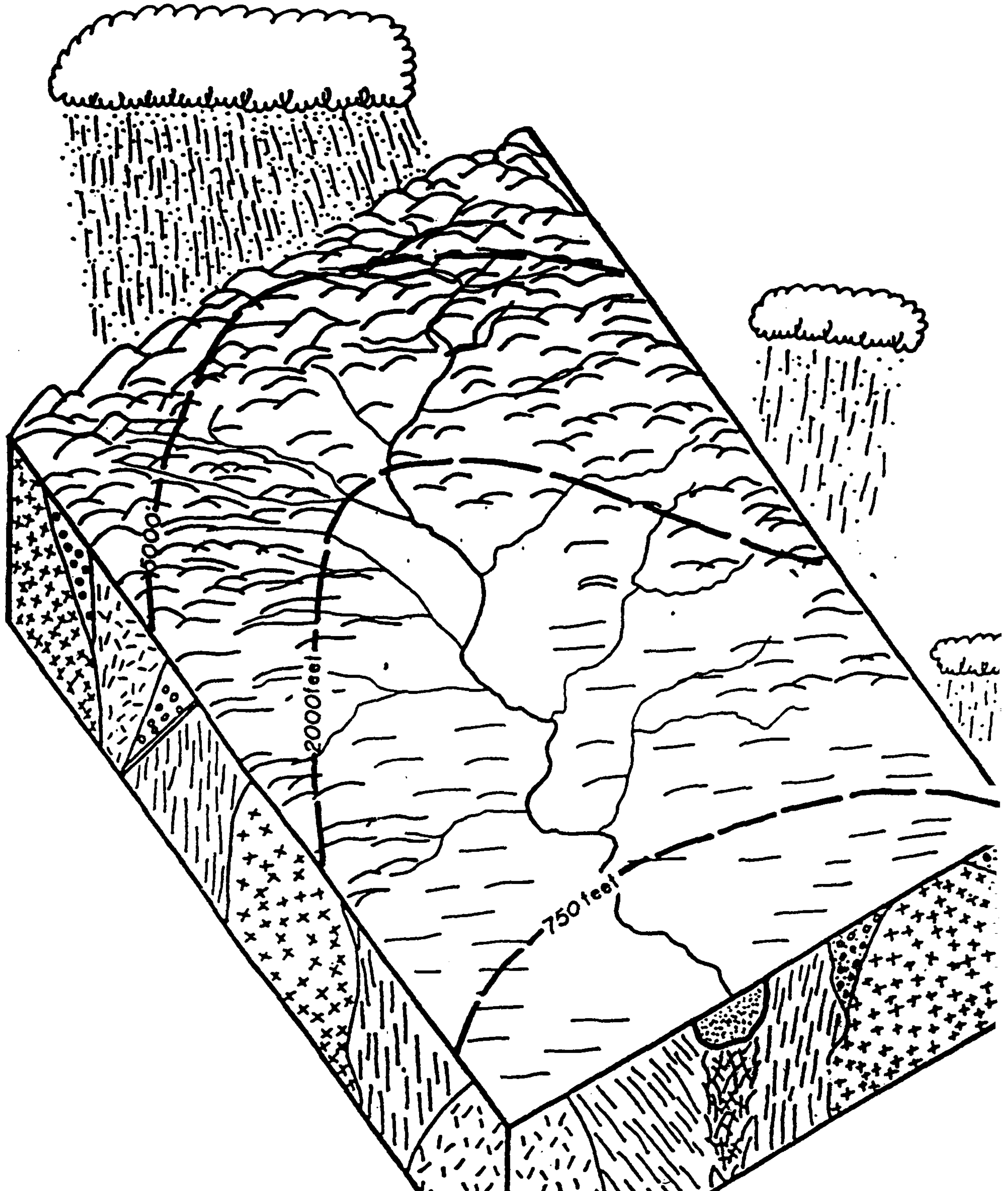

Figure 2. Orographic Effects on Precipitation Due to Topographic Variations in the Terrain.

It is also well established that over the past 200,000 years, the climate in many arid regions was different, with local rainfall rising to 1,000 mm instead of the current 100 mm or less. Alternating wet and dry climates were the rule during the Holocene (El-Baz, 1989). Geo-archaeological evidence indicates that the North African Sahara enjoyed wet climates 4,000 to 11,000 years ago, 20,000 to 35,000 years ago, about 60,000 years ago, about 140,000 years ago, and about 210,000 years ago. Rainfall during these periods would have been enough to support much vegetation and animal as well as human populations. Much of that water, which created river courses and vast lakes (El-Baz, 1988), would have been stored in groundwater aquifers.

Therefore, some of the water stored in the present day aquifers is likely to be paleowater. Issar (1985) found that the water from large springs in the Sinai Desert was 20,000 to 30,000 years old. La Moreaux (et al., 1985) proposed the same for water found at the Kharga Oases in Egypt.

The apparent age of such waters may also be due to the great distances that some of the water at these oases might have travelled (tens to hundreds of kilometers), along subsurface conduits, between source and spring (Abufila, 1984; Ahmad, 1983). The very slow natural velocity of water through an aquifer results in a major age difference along the length of the system. In effect, the age of the water coming out of desert springs is much older than the groundwater near the source of recharge.

We caution against establishing the presumption that recharge is not sufficient, or that the "paleowater" discovered in major desert basins will be "mined out" and not replenished. Before such a conclusion is made, the calculation of potential recharge must include more measurements of the possible increase in recharge due to (1) spatial and temporal variations in precipitation versus the very limited baseline precipitation data of remote arid environments; (2) the effects of increased infiltration associated with zones of secondary permeability in mountainous areas; and (3) the effects of regional, increased transmissivity from enhanced secondary permeability imparted by fractures and faults. In addition, the induced infiltration effects on long-term, large scale pumping of wells must be considered as a probable outcome in the development of these resources.

Infiltration

An important part of a recharge estimation is related to the size of the catchment area (watershed) and the amount of water that is estimated to infiltrate into groundwater conduits. It is obvious that large catchment areas (>20,000 sq km) have the potential to yield more water for recharge (Figure 3). However, smaller basins (<1,000 sq km), in some cases, also have the potential to yield high grade water.

The potential for high-grade water yield is related to the permeability of materials directly underlying principal rainfall areas. This surface permeability strongly influences infiltration rates to unconsolidated and consolidated formations, with varying storativities and transmissivities, related both to primary and to secondary attributes of permeability.

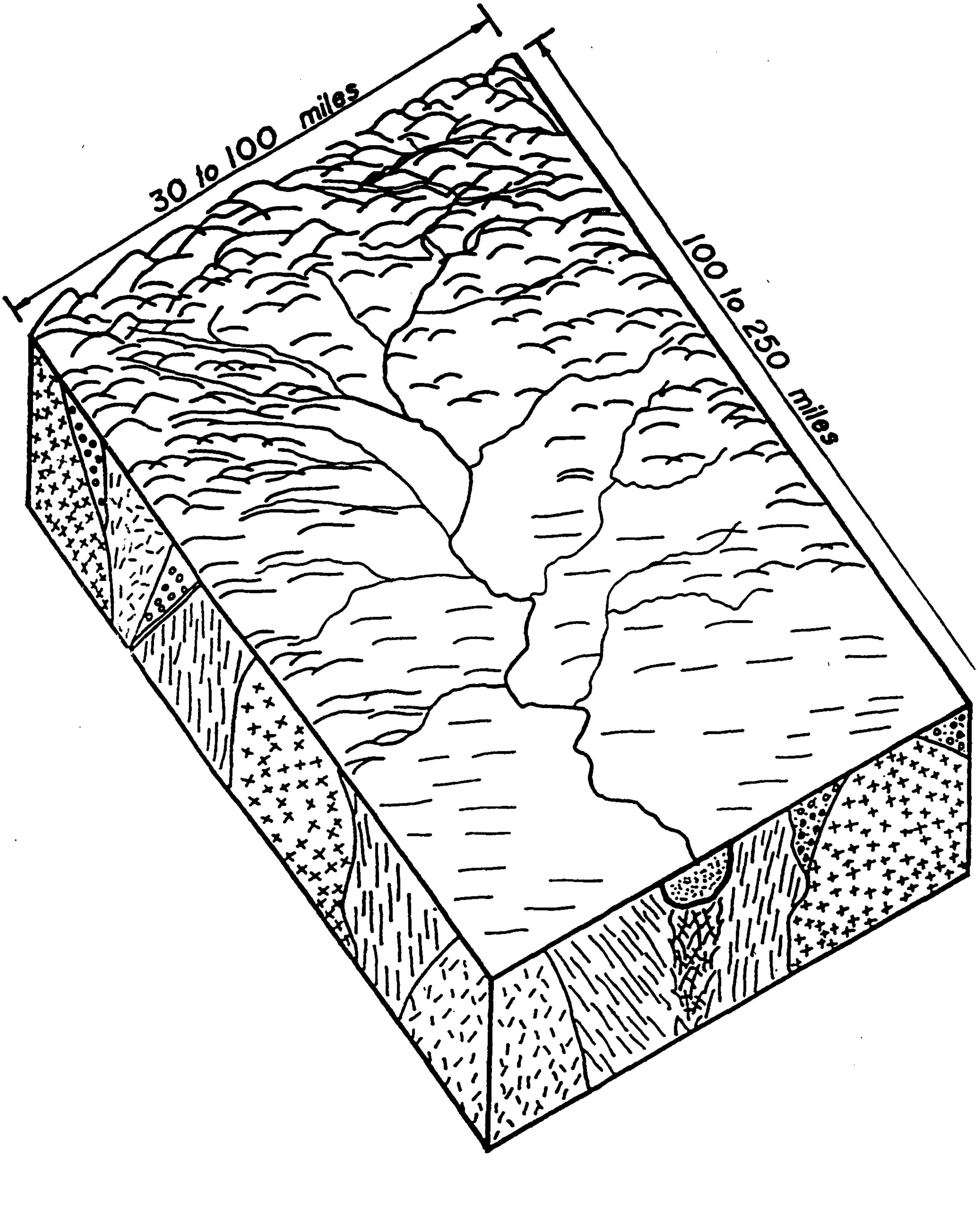

Figure 3. Drawing Illustrating the Catchment Area in a Large Basin.

Precipitation magnitude, an equally important factor, is spatially highly variable, often due to local terrain (elevation) effects. When natural conditions result in highly permeable materials (especially, fractured rock surfaces) being subjected to heavy precipitation events, as in many arid mountainous areas, the condition exists for substantial actual infiltration amounts in spite of high "potential evaporation" or other theoretical impediments to groundwater recharge.

The combination of these "remote-recharge" factors may account for the major fraction of available new water for arid areas megawatersheds. Of course, infiltration rates will vary with those physical and chemical qualities that control runoff and evaporation, including surface texture, porosity, degree of soil saturation, amount/type of vegetation, and slope. For example, if the surface texture is smooth with a low permeability, then runoff will be high and the amount of water that infiltrates will be small, even if the watershed is large (and vice versa).

In basins that contain fracture/fault zones (Figure 4), the infiltration rates are likely to be extremely variable. Rocks that are cut by these fracture/fault zones erode faster, leaving a highly irregular surface with large, polygonal, tubular, and disk-shaped voids. The largest frequency of these surface voids is generally adjacent to and within brittle fault zones. At some distance from these zones, the density decreases, the surface becomes much smoother, and the porosity decreases rapidly; so does the infiltration rate.

Often there is some interconnected permeability in the fractured zones with a much lower permeability in the surrounding rocks. It is possible that a low infiltration rate in the surrounding unfractured crystalline rock (less than .10 mm per day) exists along with a very high infiltration rate in the fractured rock (greater than 440 mm per day), as similarly estimated by Chow (1964). Fracture/fault zones often constitute local or regional topographic lows. This may result in a channeling effect, where water flows from smooth, impervious terrain into porous, fractured media.

These fracture zones of potentially high infiltration may occur in both non-porous (crystalline rocks) and porous media. The enhanced secondary porosity, rough surface texture, and increased transmissivity of fracture zones may cause increases in infiltration rates over the surrounding host rock and allow more water to infiltrate into groundwater conduits. Assuming that the infiltration rates of the fracture zones are higher than those of the surrounding rock, the amount of water that is potentially available for recharge increases proportionally to the surface area of the exposed fracture zone. This effect may result in a multi-fold increase in the infiltration rate, over what would normally be calculated, without the effects of secondary permeability.

Transmission

In the megawatershed model, the subterranean faulted and fractured zones possess high infiltration rates and form three-dimensional polygonal drainage patterns with fractal properties and often have surface expression (Barker, 1988, Barbara and Rosso, 1989). The fractal character means that small-scale fractured rock and drainage patterns are reflections of larger-scale patterns that are similar in shape and

Figure 4. A Strip of Aerial Photographs of Fault-controlled Drainage in the Red Sea Province in Eastern Sudan.

orientation. Many of the smaller fractures observed in outcrop display shapes and orientations similar to those observed on a regional scale. The smaller features that help to increase infiltration may be linked to the larger structural conduits thus allowing a portion of rainfall that infiltrates at the head waters to be transmitted along subsurface conduits. Eventually some portion of this subsurface water will exit (discharge) at a spring or well down gradient. The channeling of groundwater into subsurface conduits, associated with linear fault/fracture zones, may often result in economic amounts of extractable groundwater.

Numerous studies have shown a positive relationship between fracture traces and lineaments and zones of increased well yields. Lueder and Simons (1962) presented some evidence that wells with relatively high yields in Alabama, are found close to lineaments, whereas wells with medium to low yields are more randomly distributed. Sonderegger (1970) reported that in northern Alabama, wells located on fracture traces have yields four to five times that of wells located off of fracture traces. Siddiqui and Parizek (1971) showed that of eighty wells sampled in central Pennsylvania, those located on fracture traces, assuming a zone of fracturing 10 meters across, had a median productivity 5.5 times greater than off-fracture trace wells, and 9.4 times greater yields than wells located at random. Cederstrom (1972), in relating drainage development to the regional fracture system in the Piedmont region, found that many valleys and valley intersections are fracture controlled (confirmed by Parizek, 1976). He indicated that five wells located on major fracture valley intersections yield 1 mgd each.

Faust et al. (1984), in their analysis of the Baca geothermal system in New Mexico calculated that water moved along fault systems and permeable horizons a distance of 20 miles and discharged along a fault at the Jemez springs. The calculated discharge was approximately 1.2 million gallons per day. Emery and Cook (1984) analyzed the results of test pumping a BCI Geonetics-sited production well in Connecticut, U.S.A., that intersected a fault zone in crystalline rock where the initial test yield was over 700 gallons per minute. Huntoon and Lundy (1979) found extremely high transmissivities associated with faults in the Casper aquifer in Wyoming. Discharges up to 1080 gallons per minute were measured along the faults. La Moreaux et al. (1985) measured a flow of 2,750 gallons per minute along faults thr the Kharga Oases in Egypt. (Kohut et al. (1984) test pumped a well in fractured gra rock at 250 gallons per minute and calculated a transmissivity of 6.3 x 10^{-4} m^2/s.) Smith (1980) found high flow and transmissivities associated with fault zones in Lincolnshire aquifer in England. Flow was measured at 3,700 gallons per minute with transmissivities up to 6.9 m^2/sec. In Italy, water flow from a fracture cutting a tunnel was measured at 9,500 gpm (with 882 psi) and a total flow into the tunnel from several fractures was measured at 32,000 gpm (World Water, June 1989).

From these studies it is clear that fracture/fault zones can transmit large quantities of water and in many cases contribute to the discovery of high grade water.

Tsang and Tsang (1987) studied a 14,000 square meter area of crystalline rock in Sweden and found that 50% of the total groundwater flow was accounted for by 3% of the area due to the preferential flow of water along open fracture zones. In addition, there is preferential flow *within* the individual fracture system. Moreno et al. (1988)

studied the flow of groundwater within a single vertical fracture system and found that only 10 to 20 percent of the fracture actually participated in the groundwater flow. They pointed out that specific conduits were developed along interconnected disk-shaped voids between areas of fill and wall contact. It may be likely that 50% of the groundwater flows through fracture conduits (three-dimensional braided network, with fractal properties) that occupy less than 1% of the volume of the watershed. This is a strongly anisotropic feature in the subsurface flow and it has important ramifications with respect to groundwater exploration.

The anisotropy that is developed because of these preferential conduits strongly influences the behavior of groundwater in fractured terrain. As a result, zones containing high grade water can occur. But the target aquifer represents perhaps 1% of the total volume of the host rock region and thus presents a challenge to the exploration hydrologist.

The superposition of increased infiltration associated with zones of secondary porosity, open fracture conduits (increased transmissivity), increased drainage density associated with fault/fracture zones, and an increased gradient can result in an increased groundwater flow, and thus, increased recharge. Smith (1980) proposes the concept of "rapid recharge" when such open fracture systems are a dominant part of the groundwater flow. His study in Lincolnshire, England, revealed fracture zones of rapid flow with extremely fast response times. However, it is possible that a fraction of the groundwater recharge is conveyed to the system almost "instantaneously" in order to account for the observed events.

If the above observations of fast response times and anomalously high yields in fracture zones (high grade water) is reasonable, then we may assume some degree of fracture interconnectedness, along a reasonable gradient, from the zone of groundwater infiltration to the zone of groundwater discharge. The degree of the fracture interconnectedness and thus the flow through the subsurface system will vary due to many factors. The hydraulic conductivity of fracture systems is dependent upon the density of the fractures, the aperture of the fracture, the degree of roughness, the tortuosity (ratio of traveled path over linear path) the interconnectedness of the fractures and the hydraulic head. The number of rigorous studies on the fluid flow through highly fractured terrains over the length of a watershed is limited, but the following general observations can be made:

Fracture Characteristic	Effect on Flow
Fracture width-aperture	The permeability of smooth walled fractures is directly proportional to the cube of the fracture width (Sterns & Friedman, 1972)
Fracture density	Permeability increases as the fracture density increases (Sterns & Friedman, 1972)
Fracture Connectedness	The larger the connectivity of the fracture network and intersection of fractures, the greater the permeability

The density of fractures needed for flow to be established is called the percolation threshold (deMarsily, 1985). Throughout the length of a subsurface fracture conduit, many finite or discontinuous clusters of fracture zones would have to become connected at a level exceeding the percolation threshold. This would form a continuous fracture zone over the length of the watershed, with a relatively high transmissivity (Figure 5). In most fractured regions, the fracture density increases closer to a major structural weakness. As the fracture density increases and/or the ratio of joint length to joint spacing increases, so does the probability of fracture connectedness (Gale, 1982) and thus the probability of sufficient transmissivity.

Surface Roughness	The effects of roughness vary depending on the aperture. When the flow is nearly laminar, as within wide fractures, the effect is minimal (Moreno et al., 1988, Sterns and Friedman, 1972)
Tortuosity	The effects of tortuosity vary depending on the aperture. When the flow is nearly laminar, as within wide fractures, the effect is minimal (Tsang and Witherspoon, 1985).
Pressure Gradient/ Hydraulic Head	The more parallel the extensional fractures are to the gradient, the larger the permeability (Endo and Witherspoon, 1985; Sterns & Friedman, 1972; Gale, 1982).

The pressure is expressed as potential energy (e.g., pounds per square inch). The hydraulic head is defined at a point and is the measure of groundwater level using a piezometer, compared to a reference pressure and elevation. The hydraulic head (or pressure) is composed of a gravitational head due to change in elevation and a pore pressure due to the confining pressure imparted on the pore fluid.

In near surface fracture systems with wide apertures that are parallel to the gravitational gradient, it is likely that the pressure within that system will be dominated by gravity. This pressure will remain dominant until the confining pressure (of the rocks) exceeds the gravitational pressure (of the water).

In fractured, porous-medium aquifers at depth, the confining pressure (rock) may exceed the gravitational pressure (water). In these cases the pressure within the fracture/fault systems that are transmitting large volumes of water through the basin is increased by the confining pressure of the surrounding rocks as the pore fluid under pressure moves from the host to the fracture zone. The combination of increased confining pressure, increased gradient, and increased transmissivity could result in unusually high yielding "artesian" wells that could endure for centuries.

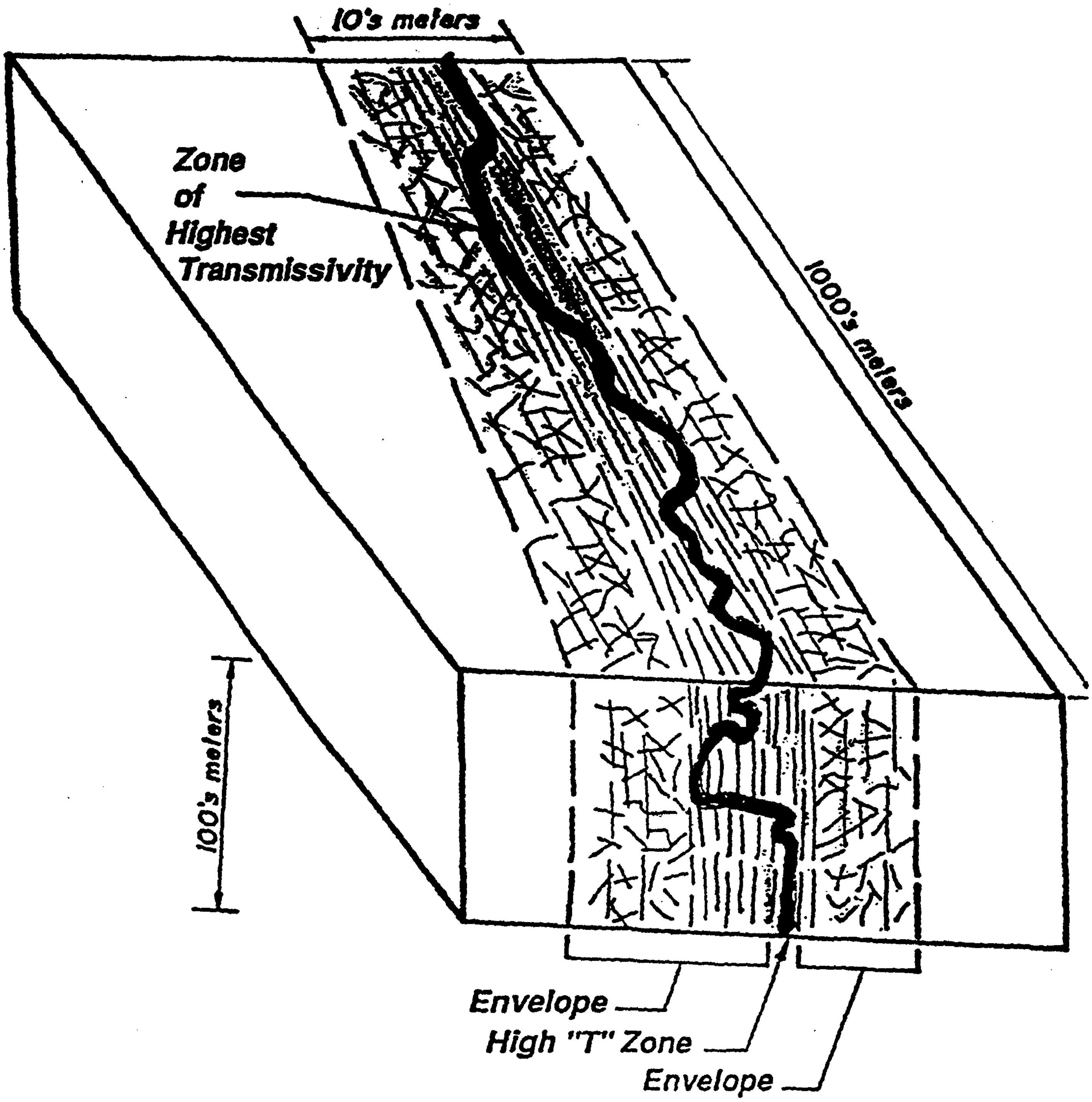

Figure 5. Detailed Illustration of a Fracture Zone Aquifer Consisting of a Highly Transmissive Zone and an Envelope with High Storativity.

In summary, the fractured rock conduit that is likely to transmit large amounts of water will:

- have a high density of fractures;
- have fractures with wide apertures (extensional);
- be parallel to gravitational gradient;
- receive adequate recharge; and,
- be over-pressured

When these conditions coexist, the subsurface fracture zones will serve as conduits for the transmission of high grade water along preferential zones that comprise a small percentage (one to three) of the total volume of material in the watershed. It is possible that the transmissivity along these conduits will be considerably higher (two to three times) than that normally calculated for permeable zones that do not have the overprint of a well developed secondary porosity.

Storage

The total yield (specific yield) from an aquifer is proportional to the amount of water held in storage, the amount of water transmitted (pumped) out of storage, and the rate of water replenishment (recharge). Discussion of the characteristics of a fracture zones with high transmissivities also applies to the analysis of specific yield. A unique characteristic of fracture zones is that they may contain both a zone of high transmissivity with low storativity (in the fracture conduit), and a zone of lower transmissivity with higher storativity (enveloping the fracture conduit) (Figure 5).

The previous discussion indicates that open fracture zones parallel to the hydraulic gradient are capable of transmitting large quantities of water and that they may also be recharged rapidly. This occurs within the fracture conduit. The fracture envelope around this conduit is less transmissive but serves as storage that replenishes the open conduit and is also replenished by this conduit (Figure 5). These characteristics of a continuous bedrock aquifer (composed of the fractured rock adjacent to a highly transmissive zone, either discreet or in combination with alluvium or some other porous medium) (Figure 6) define an important part of a megawatershed groundwater exploration target.

In addition, in the vicinity of the target aquifer, the fracture should have a moderate non-dispersion factor. This means that the width of the aquifer and its associated conduits and micropathways is not so large as to disperse the amount of available recharge over a broad area composed of discontinuous aquifers. A large dispersion factor would disperse the available resource and decrease the potential yield of any single target aquifer. Conversely, a small dispersion factor, where the extent of the aquifer is narrow, severely limits the potential storage and yield of the target aquifer.

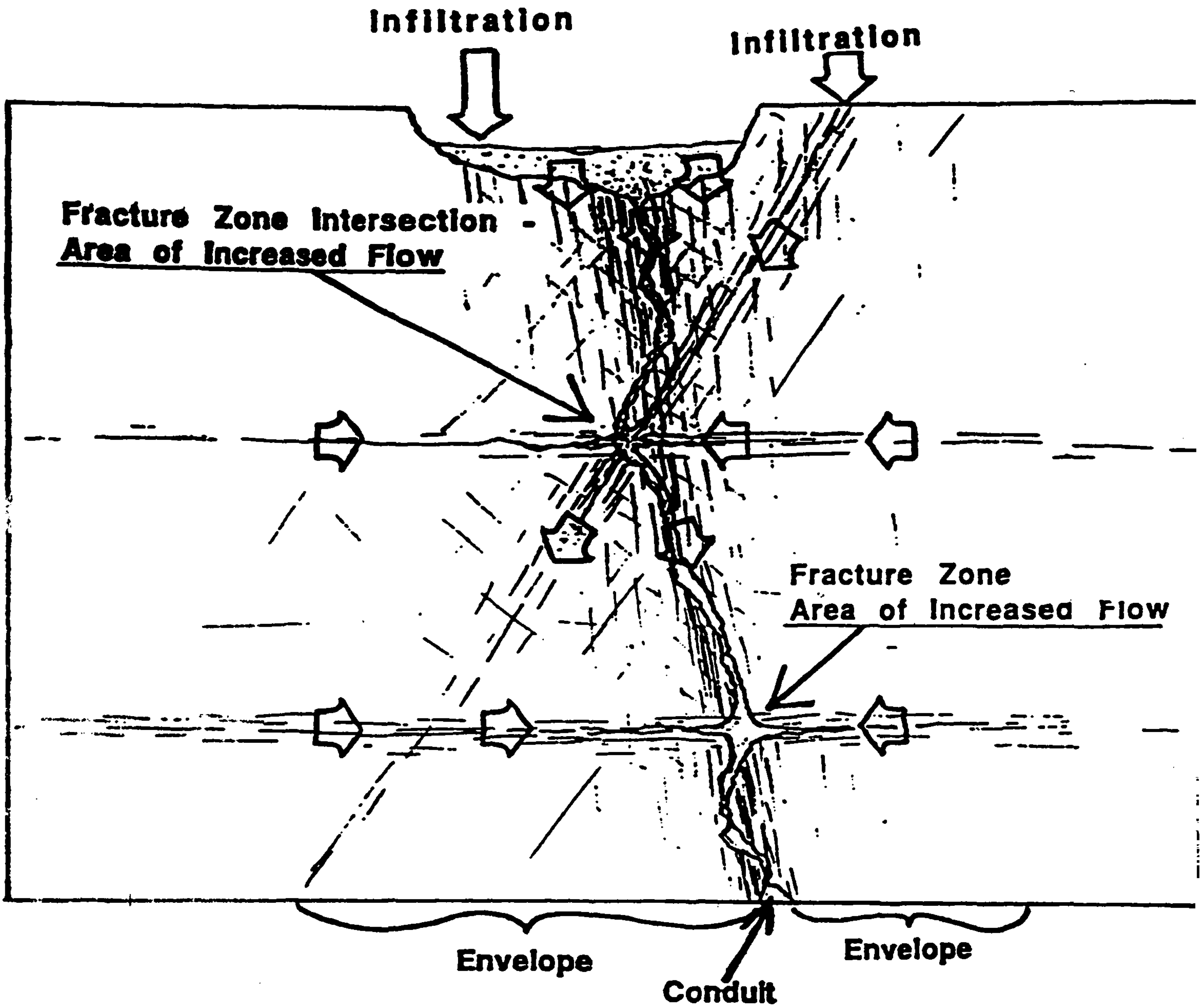

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Figure 6. Cross-sectional View of a Fracture Zone Aquifer Illustrating the Relation of Flow to Fracture Intensity. Arrows Shows Direction of Groundwater Flow. Dominant Flow is Perpendicular to the Page.

In most cases defining the groundwater resource and its potential for long term sustainable yield will require more sophisticated modelling than that applied to porous media. Some form of multiple porosity model may need to be applied due to the following:

(1) the conduit of the fracture zone will have porosity and transmissivity values that differ from the surrounding materials;

(2) the fracture zone envelope will have values significantly different from the host rock or the conduit; and

(3) both host rock and fracture zone porosity (conduit and envelope) will be significantly different from that of overlying sediments.

In such regions, the application of a double porosity model might be the best way to explain the flow characteristics. The open conduit would be characterized by a rapid flow and a rapid recharge whereas the surrounding fracture envelope (and the alluvium) would be characterized by much lower transmissivity values but greater storativity.

For a fractured porous medium, Gale (1982) favors a "coupled discrete-fractured porous medium model" where faults and shear zones are defined as individual features, the permeability of the host rock is a feature and the joint characteristics another feature. For modeling a groundwater storage unit as illustrated in Figure 7, some modification of Gale's approach may be warranted. We propose using a discrete, individual characterization approach, for the conduit and the fracture zone, and an averaging or continuum approach for the host rock and the sediment. In addition, the model will define the interactions between media of differing porosity.

The model should be used to characterize the partial groundwater contributions to the total potential sustainable yield from each of the following:

(1) the sediment aquifer;
(2) the conduit within bedrock;
(3) the fracture envelope within bedrock; and
(4) the interplay between these three features with regard to the pumping rate and the recharge.

Further research will shed light on the characteristics of various portions of these complex aquifer characteristics and how they may change as the hydrogeologic parameters vary, and how these changes effect the potential sustainable yield of the resource.

From experience, we know that these fracture-controlled aquifers can exhibit large variations in quantities and qualities of water. The primary goal is to produce the greatest yield of the cleanest water with the lowest economic cost and environmental impact. The megawatersheds model (which attempts to address the complexities of bedrock aquifer systems), provides the groundwater explorationist with a qualitative

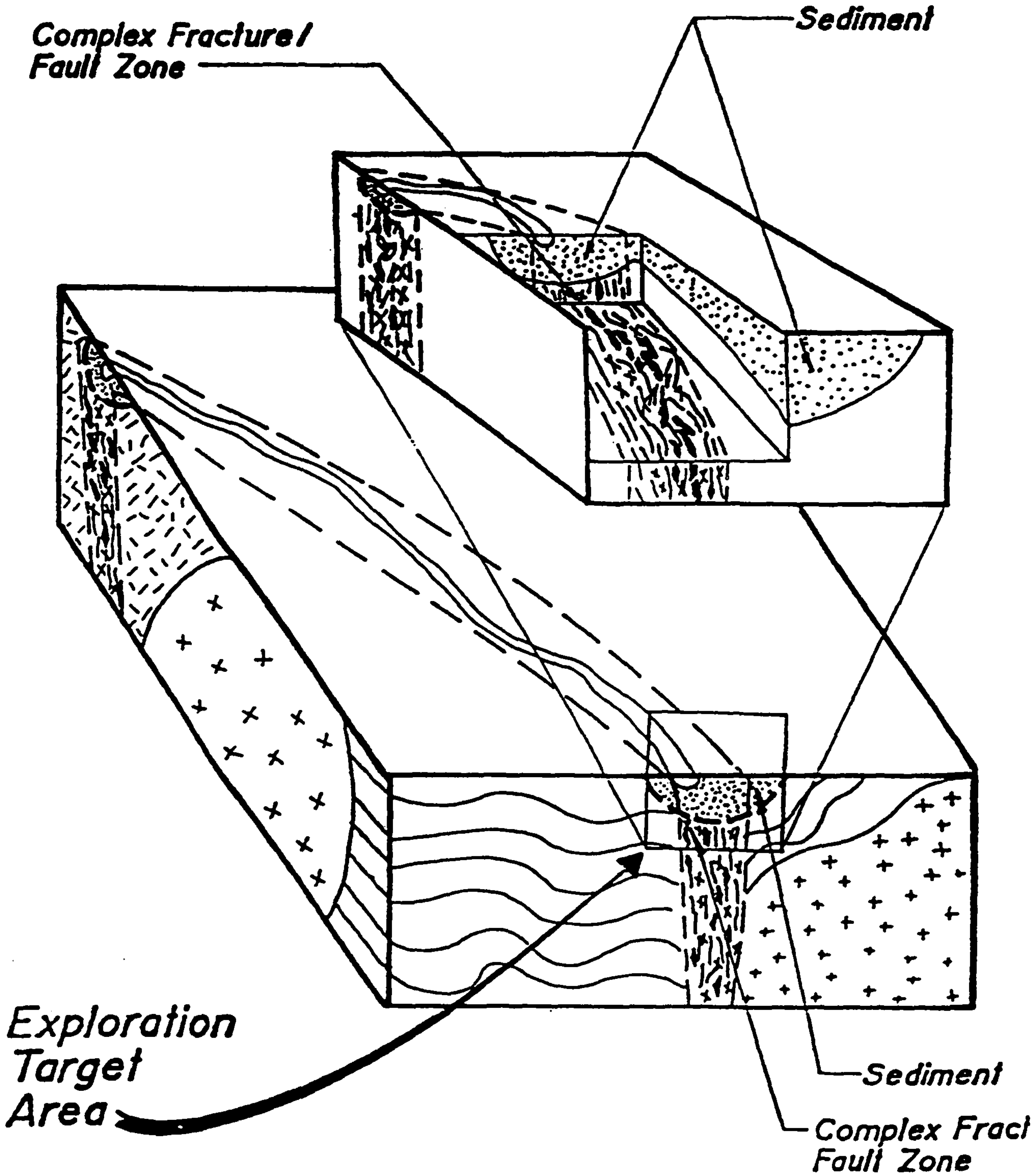

Figure 7. Ilustration of an Alluvium/Fracture Trap Showing Location of a Major Fracture/Fault Zone with Alluvium Acting as a Water Trap. Note the Complex Nature of the Fault/ Fracture Zone.

perspective. Ongoing development and revisions of the model will better incorporate further on-site evaluations of watersheds and possibly include some computer modeling as data is compiled over time.

Groundwater Discharge

The concept of high grade water associated with fracture zones is further supported by the occurrence of large fresh water springs at the distal ends of basins. These springs may occur on the coast, as in Libya, or they may occur in a rift valley as in the Sinai. As stated above, the flow rate in either case is anomalously high. The springs may also occur offshore. Large fresh water springs are known off the Mediterranean and Red Sea coasts of Africa. In many other coastal regions of the world, from the American coasts of Florida and California to the Arabian Gulf, large amounts of fresh and brackish water have been encountered.

This suggests that there is a connection between basin edge occurrences of high grade water and highly transmissive fracture zones that are connected to drainage basins. This is supported by the fact that high grade water cannot be accounted for using standard local recharge and primary porosity models (Issar, 1985). The high grade water might be induced along zones of higher permeability, e.g. fault and fracture zones, and these zones might be connected to broader areas of recharge either through fractured rock alone or in combination with a rock unit possessing primary porosity.

HYPOTHETICAL MODEL COMPARISON
EGYPT / SUDAN RED SEA REGION

General Assumptions

The megawatershed model dictates that certain hydrogeologic assumptions apply due to the effects of secondary porosity and permeability. The following comparison of three different models for a proposed wellfield, with natural environmental characteristics found in the narrow, coastal plain of the arid Red Sea Provinces of Sudan and Egypt, will help to illustrate these assumptions and the resultant order of magnitude difference of aquifer characteristics.

The watershed example for these model comparisons is a 300 square km basin with 150 mm average rainfall (leanest in the mountains), very little vegetation, soil or weathered rock cover, over an essentially exposed crystalline rock terrain. Alluvium is confined to "pockets" in the mountains, plus along certain reaches of wadis and in alluvial fans between mountains and sea coast. The three models are based on different hydrogeologic and geologic assumptions. The general model assumptions are as follows:

Model 1: Economically Accessible groundwater is stored only in alluvium in the coastal plain and fractured rock has a negligible effect on groundwater storage or flow. Recharge is limited to overland flows that extend beyond the mountains and infiltrate into coastal alluvium. Direct mountain recharge is not significant.

Model 2: Economically Accessible groundwater is stored in alluvium and, locally (within 100 m of the well), in fracture zones. These local fractures contribute minimally to storage and, at best, may simply enhance local groundwater flow efficiency into a bedrock well.

Model 3: Economically Accessible groundwater storage and flows are strongly influenced by a regionally extensive network of subsurface fractures that extend essentially throughout the basin (Figure 8) and are largely in hydraulic contact with overlying alluvial deposits in the mountains, while possessing confined and semi-confined aquifer characteristics in the coastal plains. Recharge from mountain rainfall is assumed to contribute directly to this "megawatershed" (Figure 9).

Each of these models attempts to describe the nature of the aquifer connected to strategically located well fields. The values calculated for Models 1 and 3 are considered minimum and maximum values respectively, given the following:

Catchment area	300 sq. km
Average annual precipitation	150 mm
Total annual rainfall	45 million cu. meters

Wellfield Recharge Estimations

In this arid environment, a large part of the hypothetical 45 million cubic meters of annual rainfall evaporates or becomes part of the runoff associated with flash floods. Part of the precipitation infiltrates into the subsurface, is transmitted to the aquifer and to economically accessible well fields near the coast. Models 1 and 2 assume that the alluvium is the only place where significant infiltration, transmission and storage can occur and that only local, coastal, rainfall and overland flooding contribute to recharge. Because of the limited areal extent and thickness of the alluvium and the assumed minor role of local fracture networks in Models 1 and 2, the net percent of rainfall contributed to infiltration is low (1 to 3%).

Further, once the water becomes part of the subsurface, it must be transmitted to the aquifer at the target well fields, if it is to be considered part of the potential yield calculations. The alluvium is considered in all three models to be generally of uneven thickness and surficial groundwater is, in some locations, forced nearer to the surface causing large amounts to evaporate. In addition, some groundwater stays trapped within the alluvium and is not transmitted to the well sites.

Given the constraints of Model 1, estimates of 5 to 10% transmission of infiltrated water to the well sites are considered reasonable by the authors.

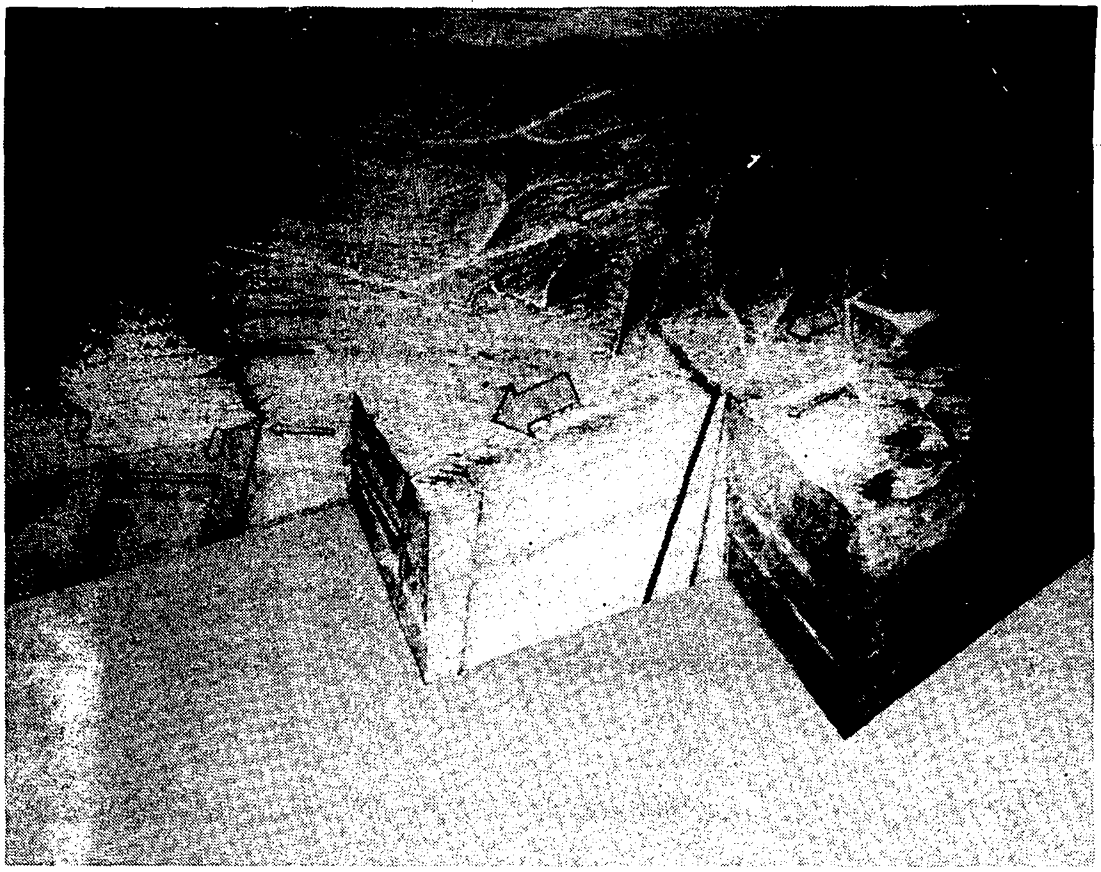

Figure 8. Perspective Illustration of the Megawatershed Model Applied in the Red Sea Province of Sudan. Arrows Indicate Overland and Underground Flow Paths.

Figure 9. Perspective Illustration of the Megawatershed Model Applied in the Red Sea Province of Sudan. Arrows Illustrate Mountain Recharge to Fracture Systems and Alluvial Storage.

In Model 2, a slight increase of .5% is added due to the influence of local fractures.

In Model 3, the effects of secondary porosity and permeability over much of the catchment area result in considerable increases in the estimates of infiltration, transmission and storage of groundwater. The numbers below illustrate this:

Hydrogeologic Parameters

	Infiltration	Transmission	% Rainfall	Cubic M/year
Model 1	1 - 3%	5 - 10%	.05 -.3%	2.25×10^4 to 1.35×10^5
Model 2	1 - 3%	5.5 - 10.5%	.055-.315%	2.4×10^4 to 1.4×10^5
Model 3	3 - 9%	10 - 30%	.6 - 3%	2.7×10^5 to 1.35×10^6

The result of these calculations, expressed as average annual active recharge, are summarized below:

Potential Recharge Comparison

Model 1	370 m^3/day	68 gpm
Model 2	384 m^3/day	70 gpm
Model 3	3,700 m^3/day	678 gpm

From these hypothetical model comparisons, it is clear that Model 3 provides an order-of-magnitude larger amount of recharge than Models 1 or 2.

Storage Calculations

In all these models, calculations of storage assume a continuous aquifer over which average values of effective porosity can be extrapolated.

The alluvial storage in Model 1 is limited to an already confined surface drainage, extending from the base of the mountains, 20 km downstream to the proposed well fields sites. The alluvium is considered to average 10 m in thickness and to average 30 m in width. The porosity is 0.2.

In Model 2, the alluvial storage remains as in Model 1, but is supplemented by a local fracture system, consisting of two intersecting fracture zones, each 100m long, 10 m wide and 100 m deep and one horizontal fracture (200 x 100 x 1m), with an average porosity of 0.05.

In model 3, the alluvium is also considered as potential storage as in Models 1 and 2, but this is supplemented by a fracture zone network consisting of three vertical fracture zones extending nearly the length and width of the overall catchment area and one extensive horizontal fracture zone at depth. The width of each vertical zone is 20m, depth 200 m and combined length of 30 km. *For purposes of simplicity, the considerable impact of the active mountain alluvial recharge and storage is ignored in this Model.* The dimensions of the horizontal zone are 20 km x 5 km x 1 m. All fracture zones have an average porosity of 0.05.

Potential Storage Comparison

	Volume (m^3)	Porosity	M^3	Total M^3
Model 1	A- 6.0×10^6	.20	1.2×10^6	1.2×10^6
Model 2	A- 6.0×10^6	.20	1.2×10^6	1.21×10^6
	F- 0.22×10^6	.05	11000	
Model 3	A- 6.0×10^6	.20	1.2×10^6	9.2×10^6
	F- 160.0×10^6	.05	8.0×10^6	

The above calculations predict the maximum amount of water that could be in storage under ideal conditions for each model. It is likely that both the alluvium and the fracture networks are not homogenous and are not hydraulicly connected in a uniform manner. This means that a part, perhaps 50% of the groundwater in storage, is not available for easy extraction at the given well site. This results in potential yield calculations as follows:

1/ Note: Model 3 exception of mountain alluvium.

	Transmittable Storage	Potential Yield	
	M^3/Year	M^3/Day	GPM
Model 1	6.0×10^5	1,644	302
Model 2	6.05×10^5	1,650	304
Model 3	4.60×10^6	12,600	2,311

The most important aspect of the megawatershed model is that it predicts an order of magnitude higher groundwater flow at a site that fits the parameters of the model. Thus, it predicts the occurrence of high grade water.

These model comparisons only serve as an example of the implications of the inclusion of fractured rock porosity and permeability in basin model calculations for safe yields. The procedure could be applied to any area that contains surface and subsurface drainage controlled by fault/fracture zones. The comparisons also support the original premise of the megawatershed model, which describes the boundary conditions related to the occurrence of high grade water associated with a watershed-wide three dimensional fracture network.

The exploration significance of the model is that it can be used as a pathfinder, to lead groundwater exploration teams to previously unsuspected targets that could yield large amounts of "high grade" water.

CONCLUSIONS

The key features of the megawatershed model are as follows:

- In arid coastal regions, bedrock-transmitted mountain precipitation, resulting from orographic effects, may considerably increase the amount of water available down-gradient over what is available from local coastal plain recharge.

- Zones of highly fractured bedrock terrain possess infiltration rates higher than the surrounding materials.

- High fracture density and linear extent of these zones may contribute significantly to increased potential groundwater recharge.

- Surface areas of alluvium with high infiltration rates may connect with highly permeable fracture/fault zones.

- These fracture/fault zones may interconnect over large areas and thus provide a larger subsurface catchment area from which water flows, thus increasing the potential recharge. This may be represented as a surface expression of rectilinear drainage.

- The fracture conduits containing high grade water are restricted in lateral extent (width), are non-uniform, and comprise a small percentage of the total subsurface volume.

- The envelope (and any hydraulicly connected sediments) surrounding the fracture conduit serve as storage.

- The best fracture/fault zones are those that have a high density of wide fractures parallel to a reasonable hydraulic gradient.

- Highly favorable targets are those that contain geologic formations with primary porosity in hydraulic connection with fracture/fault zones and connected to the main source of recharge.

Exploration for, discovery of, and accurate mapping of these anomalous zones of groundwater flow are a tasks that require the combination of many disciplines; remote sensing, climatology, geomorphology, structural geology, hydrogeology and geophysics. Conceptual models, such as the megawatersheds model, help the exploration team to apply these disciplines in an efficient manner while increasing their probability of success.

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Manually operated irrigation pumps.

Authors: R A Lambert and R D Faulkner, *WEDC and Civil Engineering Department, Loughborough University of Technology, UK*

1 Abstract

Manual[1] pumps have a useful role to play in micro-scale or garden irrigation. Two manually operated irrigation pumps, the rope-washer and the treadle have been adapted for use in Zimbabwe. The rope-washer is a low-cost pump that can be made at village level. The treadle pump is widely used in Bangladesh for small plot irrigation but considerable alterations are required to the manufacturing processes involved and the technical performance of the pump to make it suitable for the Zimbabwean context. While the Bangladesh model was a simple suction pump with discharge through an outlet channel the situation in Zimbabwe demanded a pump that could discharge under pressure through a pipeline. The pump could then be used for irrigation from water sources situated outside and below garden plots, for example sandy river beds in Zimbabwe's low-veld regions. Zimbabwe has a relatively large and sophisticated formal manufacturing sector but the informal artisan sector is also important for the rural economy and more closely resembles manufacturing possibilities in other parts of the continent. Therefore the treadle pump was redesigned so that it could be manufactured and repaired with the very basic facilities common at artisans' welding shops.

This paper describes the rope-washer and treadle pumps, gives details of the modifications to the treadle pump to allow for pressurised discharge, outlines the technical suitability of the pumps in a variety of pumping situations and presents some implications for further work.

2 Introduction

With the failure of large-scale irrigation schemes in Africa to live up to expectations considerable emphasis has recently been given to the promotion of small-scale initiatives. However, as Adams and Anderson (1988) have pointed out, scale is not the key factor in this poor performance and many small-scale schemes offer "the usual thoughtless bureaucratic large-scale development in small chunks". Initiatives based on single farmer units, such as the introduction of motorised pumps to replace indigenous water lifting technology in Nigeria, can bring about a massive increase in production (Kimmage, 1989) but may cause severe problems in terms of equity and the environment.

There is a strong case for examining those systems that have proved successful in the past and using these as the basis for expansion and improvement. An example of successful and sustained irrigated production is to be found on the dambos of Zimbabwe (Bell et al 1987). Dambos are defined as shallow, seasonally waterlogged depressions at or near the head of a drainage network. During the rainy season crops of rice and maize are grown in gardens situated on the the moist areas of the dambo. During the dry season vegetable crops are grown using residual moisture and simple irrigation techniques such as the use of the watering can or occasionally motorised pumps which draw water from shallow wells that are rarely deeper than 5 m (Lambert et al 1987). Bell et al (op cit) have noted there is considerable potential to expand the present extent of dambo cultivation from an estimated 20,000 ha up to circa 75,000 ha. The introduction of more powerful irrigation technology could allow an increase in the intensity of cultivation during the dry season. Past experience in Zimbabwe, when intensive mechanised cultivation was employed (Rattray et al, 1953)

[1] In this context manual refers to human operated pumps and includes both hand and foot operated models.

with detrimental consequences for the soil and water resources of the dambo areas, shows that the mode of exploitation is critical.

In addition to the dambo resources of Zimbabwe recent research based at the University of Zimbabwe has indicated the potential of alluvial and sand-river resources in the lower, hotter and poorer areas of the country (Lambert and Owen, 1989). Up to 30,000 ha could be irrigated using these resources, with water lifts being generally in the 4-12 m range. In many situations the water would have to be pumped from sandy river beds over the river bank to the irrigated plot; in others wells could be sunk on the irrigated plot and the water lifted vertically. As yet these resources have not been exploited for garden irrigation to the same extent as the dambo resources.

Irrigation by the use of watering cans is a time consuming and laborious task. Results from the research project which forms the basis of this paper show that members of a household may together spend up to 300 hours per month using watering cans to irrigate crops, a form of human energy utilisation that is very laborious. The only practical alternative currently available that of motorised pumps remains out of reach of most of these small-scale farmers for a variety of reasons. Such pumps are rarely available off-the-shelf, have a high capital cost and with limited access to credit very few farmers have the cash to buy them. Investing such a large amount of capital in the fluctuating business of horticultural production is very risky and means that the farmer must be committed to such production for a number of years. The transition from a system based on watering can technology to one based on a motorised pump involves a significant quantum leap in management. Limitations on plot size, poor transport to the market and the difficulties of obtaining spares and fuel further militate against the adoption of such pumps. Even if all these obstacles could be overcome, there remains the problem of controlling the extent of utilisation of such powerful technology so that water resources will not be irreversibly depleted.

An alternative is to explore ways in which human energy may be utilised more efficiently. Manual pumps have received considerable attention over the last decade for domestic water supply but their potential for garden irrigation has been largely unexplored (Arlosoroff et al 1987). There is evidence that human powered pumps for irrigation can fill the gap that exists between the watering can and the diesel pump, both in terms of output and in terms of cost (Lambert & Faulkner, 1989). The use of human energy provides a strict limit on the amount of water that can be extracted and means that there is virtually no danger of water resources being significantly depleted (Bell et al op cit).

3 Pump selection

Domestic water pumps have a number of drawbacks for irrigation, principally because they have not been designed with the financial and operational constraints of the farmer in mind. They are relatively expensive, being designed for high lift and to withstand the rigours of community use over long periods, and are not ergonomically designed to give the sustained high flow-rates that are necesary for irrigation. Nevertheless, several manual pumps have been developed for irrigation. A number of these pumps were selected for investigation, including the treadle and the Rower which have been widely used in Bangladesh, the rope-washer pump (RWP) which is a low-cost village made pump and the Bumi pump, a diaphragm pump manufactured in Zimbabwe. Research efforts have been focussed on the treadle and the rope-washer, partly because the Bumi and Rower pumps require no modification for manufacture in Zimbabwe and partly because of the superior performance obtained with the rope-washer and the treadle (Lambert and Faulkner, op cit). Figure 1 shows the principle of operation of the RWP sited at an open water hole.

The rope-washer pump is inexpensive and can be made from very basic materials with a pipe, rope and old tyre being the principal requirements. It is suited to manufacture and repair in village conditions but does not lend itself to centralised production as a packaged unit. Therefore its widespread adoption will depend on an effective training and extension exercise. In its present form, the pump is hand-operated and can be fitted to hand dug vertical lined wells or inclined shallow open waterholes (see figure 1). It is not suitable for use on narrow boreholes or tubewells. There is no technical limit to the depth from which water may be drawn with the RWP but, due to human energy constraints, lifting sufficient water for irrigation from depths in excess of 10m is difficult. This is a very variable cut-off figure because in areas where the water table is deep then there may be a greater incentive to raise that water for vegetable production. It is ideal where wells are situated within gardens and at an elevation where the raised water can flow to the irrigated plots. Where the wells are at the lower end of a garden, an earthen platform may be constructed to increase the command area of the pump.

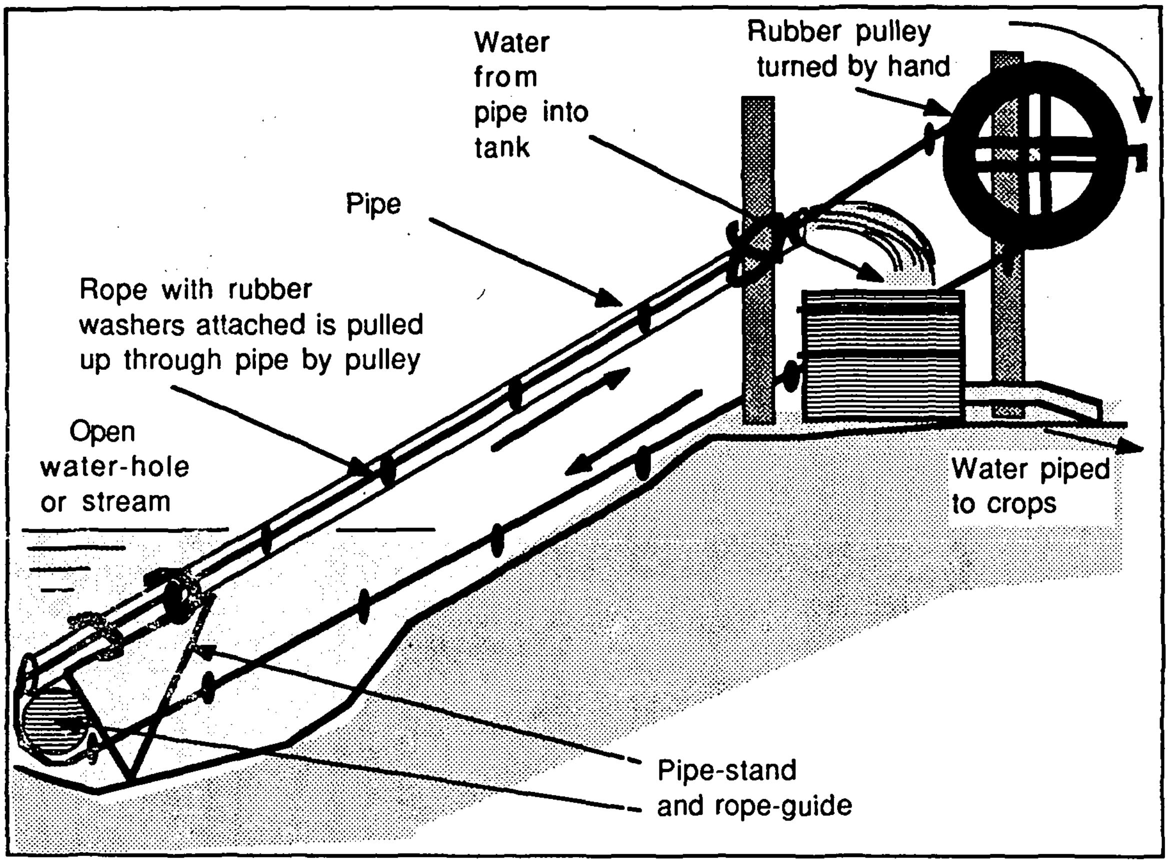

Figure 1: The rope-washer pump

However there are situations where the rope-washer is unsuitable such as when water must be raised above the level of the pump. Extracting water from sand-rivers and pumping it over the banks is one such situation. Pumping water into overhead tanks is another. Such situations require a pump capable of pressurised discharge and are illustrated in figure 2.

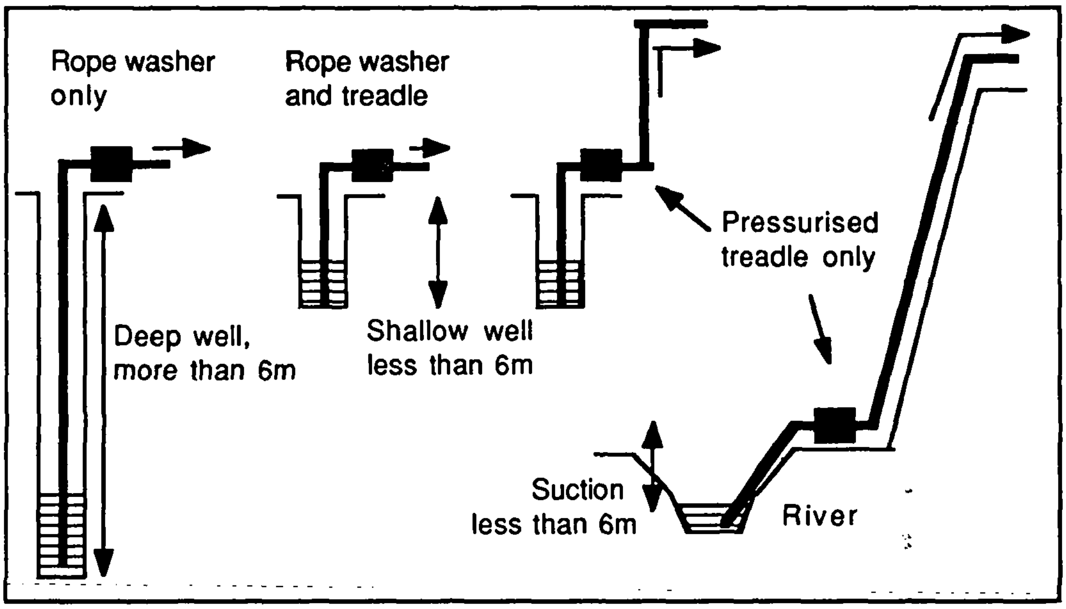

Figure 2: Pump suitability for different requirements

The principle advantage of the treadle pump used in Bangladesh lies in the fact that it can make use of the powerful leg muscles in an action very similar to one of the most familiar human actions, walking. However it may also be operated very effectively by hand. In the initial stages of the project a number of these suction treadle pumps were obtained for trial. A major limitation was the fact that they were simple suction pumps, with a maximum lift of about 6 metres in Zimbabwe, and no cabability of discharging under pressure. The design of the suction treadle pumps has been described by Barnes (1985) and only the basic principle of operation is shown in figure 3. During operation the operator's weight is placed on one of the wooden treadles, so pushing the attached piston down its cylinder while simultaneously pulling the other piston up the second cylinder by means of the rope passing over the pulley. A simple manifold links both cylinders to the inlet pipe. Inlet valves are made from hinged and weighted rubber flaps and outlet valves are incorporated in the piston unit.

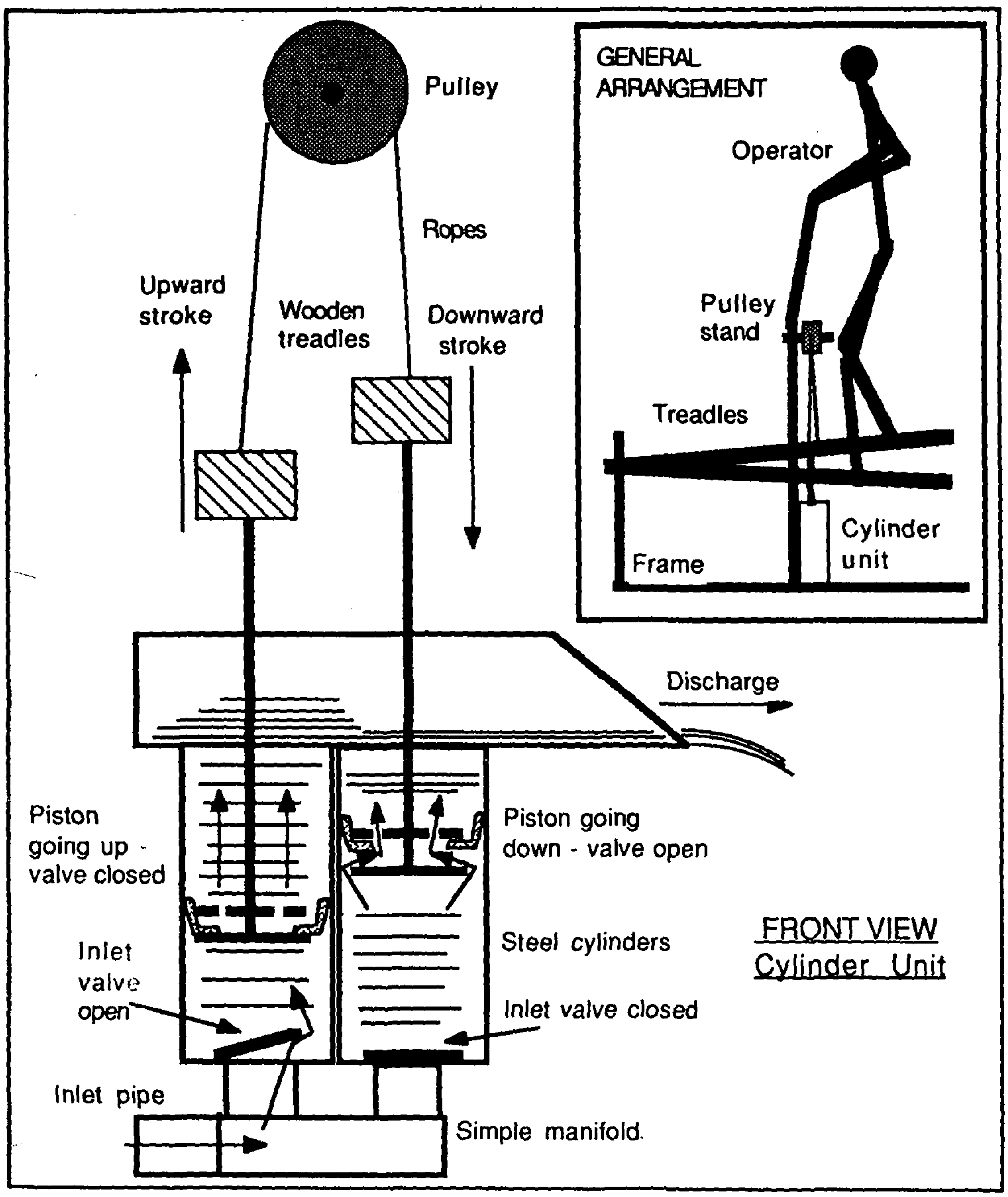

Figure 3: The suction treadle

4 The pressurised discharge treadle pump

4.1 Design philosophy and criteria.

The first part of the design process was to establish whether or not Zimbabwean farmers would be prepared to utilise the treadle mechanism. A number of pumps were installed in farmers plots for evaluation. Initial reactions were very positive, with the pump being particularly attractive to young boys and girls, although there was reluctance among some women to climb up on the treadles when a large number of strange men were present, a reluctance which disappeared when the strangers had gone. Having established the acceptability of the principle of treadle operation, the pump was redesigned to allow discharge under pressure through a pipe.

Peasant farmers purchase a wide range of agricultural equipment, from ox-ploughs to wheel barrows, and are quite ingenious in keeping it operational. The success of farmers in keeping such devices functioning and the existence of an informal repair and maintenance network of village artisans dedicated to this task, suggested that this was an appropriate context for the design of the pump.

In the design process it was assumed that the pumps would be made by a commercial manufacturer and sold at a profit to the farmer. In Zimbabwe, commercial manufacture of machinery and equipment for use in rural households occurs at many levels of organisation. Zimbabwe has a strong formal sector, with many successful light engineering companies but the informal sector, while receiving a lot of academic attention, has received little practical support. Yet any trip to the bus-stand in Harare's high density areas reveals the strength and vitality of informal trading and manufacturing. Therefore it was decided to design the treadle pump so that it could be manufactured by small-scale metal-working artisans using basic facilities. The most sophisticated pieces of equipment needed for this design are a welding machine and handheld drill.

In the sections below some details of the principal design features are given. Full design drawings are being produced as part of the project and may be obtained by contacting the authors separately.

4.2 The manifold box

The first requirement was to redesign the manifold and valving arrangement to allow for pressurised discharge. The redesigned manifold, shown in figure 4, consists of three chambers, the inlet, valve and discharge chambers. The valve chamber is divided in two, with the cylinders separated hydraulically from each other. The discharge chamber has a cover plate which is bolted externally on to a flange plate. The manifold box has no moving parts aside from the valves, which may be removed by pulling out by hand when the cylinders and the cover plate are removed. Welded mild steel plate is used throughout. As with the original design, depressing one treadle simultaneously raises the other. On the upstroke, suction opens the inlet valve and draws water in through the inlet pipe while the corresponding outlet valve is kept closed. On the downstroke, the pressure closes the inlet valve, opens the outlet valve and forces the water out through the discharge pipe. A pulley stand is welded to the manifold box and an adjustable handle is bolted to the top of the stand. The pulley is mounted on a steel shaft which rests in hard wood bearings set into this stand (see also figure 6).

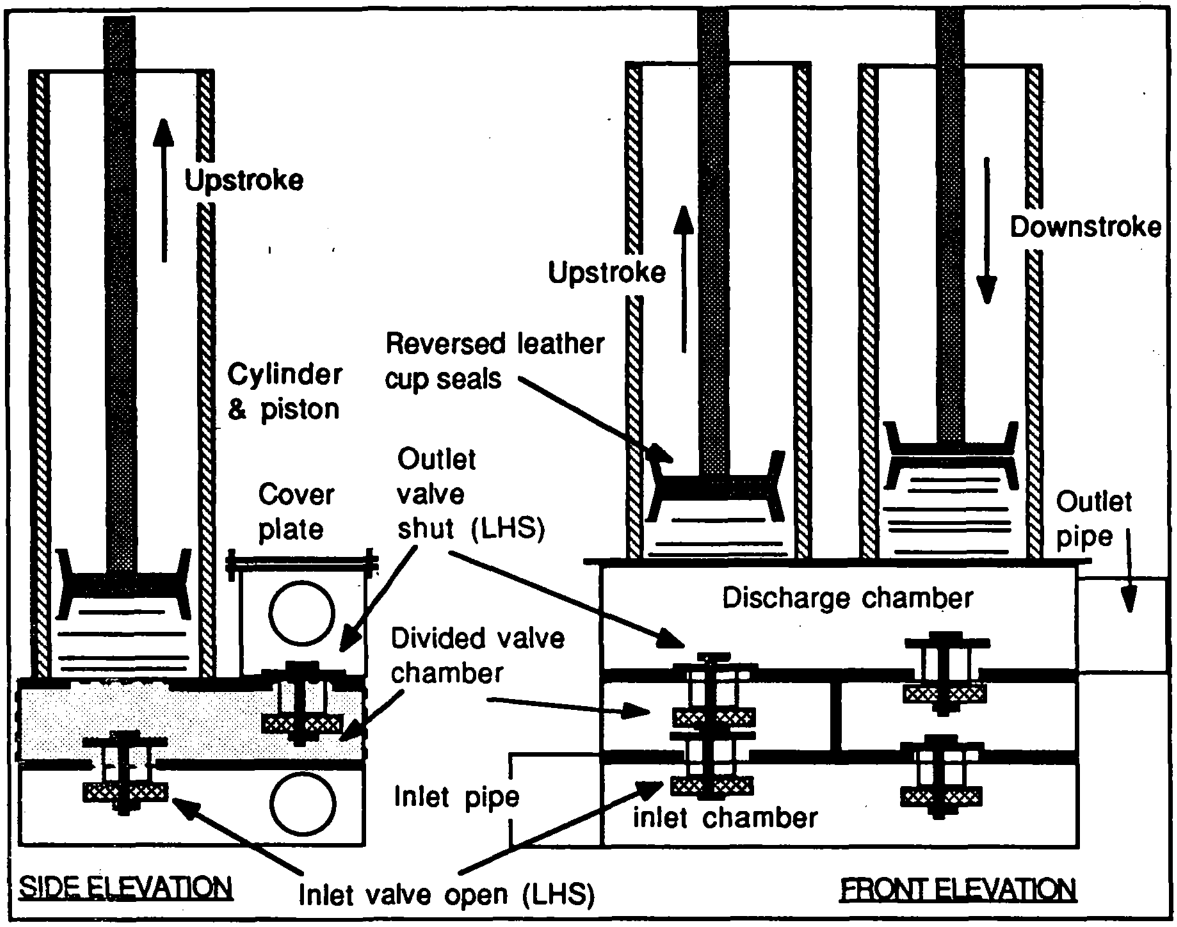

Figure 4: The pressurised discharge manifold box

4.3 The valves

In the original design, hinged rubber flap valves were used with the rubber flap held to the valve plate by means of a nut and bolt. This was difficult to reach with ordinary tools, being at the bottom of a long narrow cylinder. In addition corrosion problems meant that it was sometimes virtually impossible to remove the nut and bolt. Therefore the valves were redesigned so that they could be easily removed by hand from the manifold for inspection and repair. The design of the valve is shown in figure 5. A rubber seal, cut from an old inner tube, provides the seal on the valve plate. A steel disc is set on top of the rubber seal and both sit on a box-section guide spacer which allows the valve to move vertically but allows only a minimum of lateral movement. Excessive vertical movement of the valve is prevented by a stiff rubber valve-holder which can be cut from a section of old car tyre. The stiffness of the rubber holder is determined by its thickess - about 6-8mm usually, depending on the type of rubber. It should be cut to the maximum length and thickness that will allow easy insertion of the valve so as to prevent the valve jumping out during operation. The valve assembly is mounted on a central bolt and kept in place on the bolt by a nut or a split pin under the bottom washer. The split pin arrangement is less susceptible to seizing due to corrosion. The valve is inserted by pushing down strongly and forcing the flexible rubber holder to pop in through the hole. Removal is by tugging the valve sharply upwards.

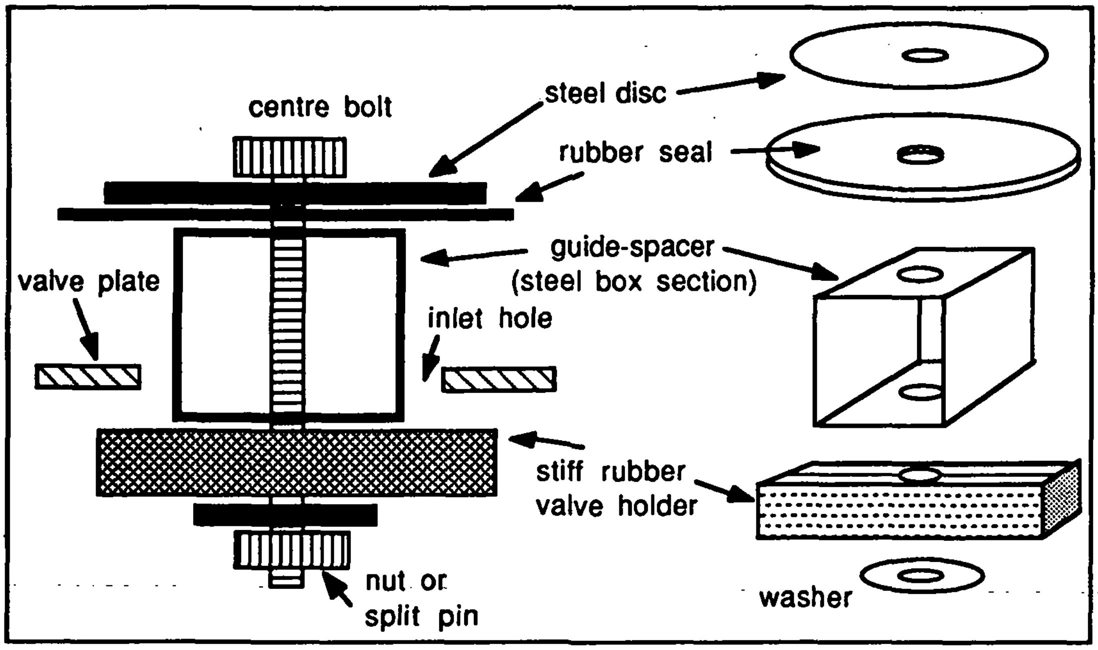

Figure 5: Valve details

4.4 The pistons and cylinders

Each piston is constructed using two leather cup seals. These leather cup seals are placed back to back to give both a suction and delivery pressure head. They are bolted to a piston rod using steel discs.

Steel tubing with internal walls smooth enough for use as pump cylinders is not readily available in Zimbabwe. Therefore heavy duty PVC piping, cut into 400 mm lengths, was used. For high discharge at low heads large diameter piping, of 110 mm outside diameter, was chosen. This allows sustained pumping to a head of about 10 m with flows of between 1 and 2 l/s, depending on the number, size and fitness of the operators, and the pump configuration chosen (see frame description and figure 6 below). The cylinders sit on top of the manifold box on a rubber seal - several layers of rubber inner tube may be used. The edges of the pipe should be filed to remove sharp edges. The cylinders are held in place by means of a collar arrangement which is bolted down to the manifold using only one nut. Assembly and removal of the cylinders is thus a quick and simple matter. For situations in which higher lifts are required, smaller cylinders may be used. These will require smaller pistons and cylinder collars.

4.5 The frame

In order to reduce costs to a minimum, treadle pump units made in Bangladesh consist of the cylinder unit, pulley and pistons. The pump is then assembled at site on a farmer constructed wooden frame. Initial reaction to this arrangement in Zimbabwe was negative and a frame mounted design was developed. This has the added advantage of allowing the pump to be easily moved between wells and removed to the home for safe keeping. It also facilitates use on sandy river beds where permanent installations would inevitably be seriously damaged or swept away during a flood. As manufacture takes place in an urban centre, it must be possible to dismantle the pump for transport by bus and to reassemble it later at the farm.

The frame, shown schematically in figure 6, is made of angle iron sections welded together with the cylinder-manifold-pulley unit bolted on using simple clamps. The treadles pivot at the front of the frame and a treadle stop at the rear prevents the treadles from hitting the top of the cylinders and also acts as a step for mounting and dismounting the pump. The front pivot and the treadle stop are bolted to the base frame. The piston rods are attached to the treadles using movable clamps. The position of the cylinder unit may thus be adjusted on the frame to suit the strength of the operator and the particular lift required. With the cylinder unit close to the front pivot (figure 6A) increased discharge head or lighter operation is achieved at the expense of reduced flowrates. Maximum flow rates are achieved when the cylinder unit is at the furthest point from the front pivot (figure 6B). In addition to adjusting the position of the cylinder unit the operator has considerable flexibility in choosing where to stand on the treadle. Moving away from the front pivot increases the leverage, and hence the possible discharge head but reduces the length of stroke of the piston and hence the discharge flowrate. For comfortable operation being able to move along the treadle is vital in order to achieve a balance between the weight of the operator and the pumping force required. If the force feels too light then the operator may be unable to develop a satisfactory rhythm, if the force is too heavy then the effort will be unsustainable.

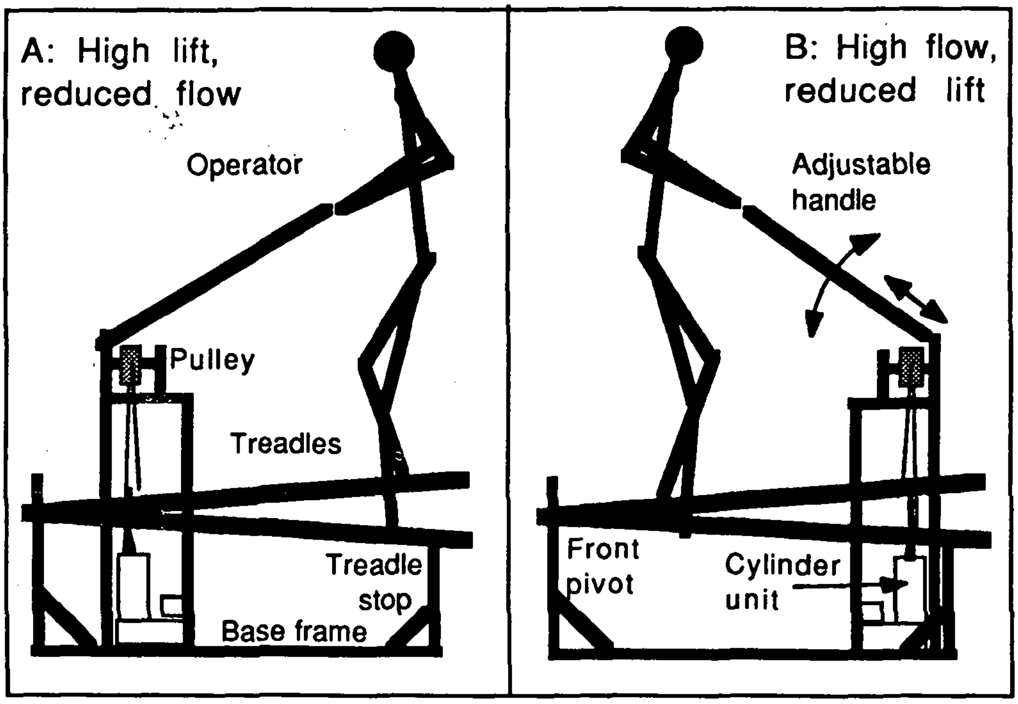

Figure 6: Treadle frame and operator configurations

4.6 Silt protection

Protection from silt will greatly extend the life of the pump. Leather cup seals easily absorb grit and will quickly wear PVC cylinders. A pipe located close to the silty bottom of a body of water sucks silty water at high velocity directly from the bottom. Protection from silt may be achieved by reversing the direction and reducing the velocity of flow. This can be done by fitting a large tin can such as a paint pot (with no holes in the sides), to the inlet end of the pipe as shown in figure 7. This ensures that water is drawn in over the top of the can and not from the bottom and siltier regions. Because the diameter of the can mouth is greater than that of the pipe mouth inflow velocities are greatly reduced.

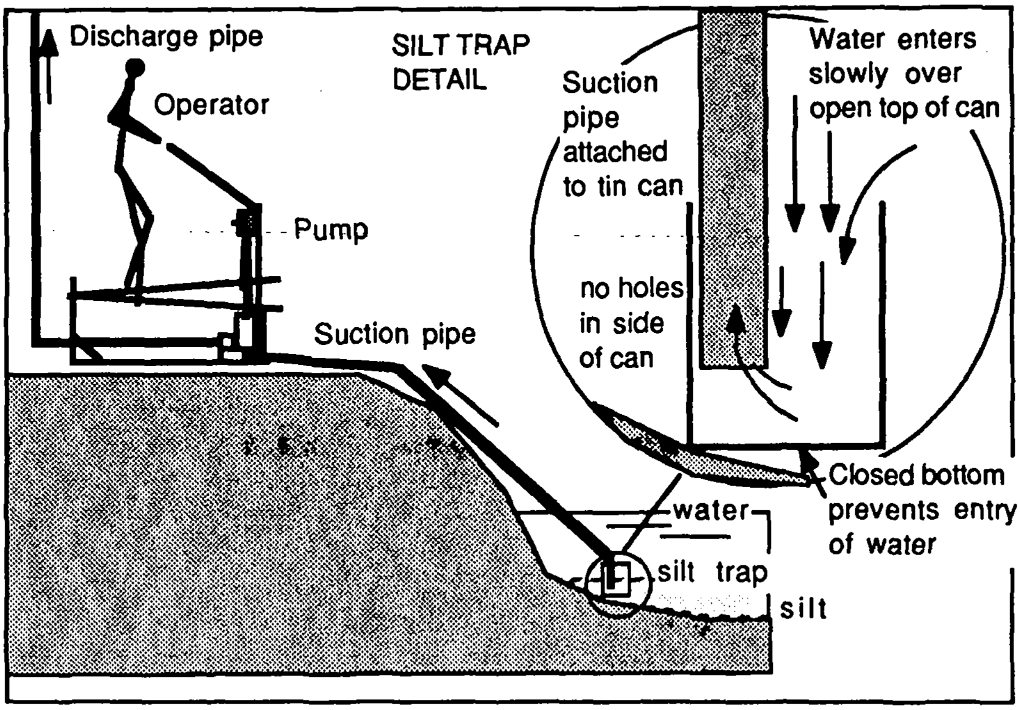

Figure 7: Silt protection

4.7 Repair and maintenace.

Standard 12mm bolts may be used in all connections except on the cover plate of the manifold discharge chamber where smaller bolts are necessary. A small bolt size may be used for the valve assembly although a split pin may be preferred. Thus standard tools, such as those used in ox-plough repairs, may be employed to inspect or adjust any part of the pump. With the exception of the wooden treadles, the PVC cylinders and the rubber seals, the pump is fabricated from welded mild steel, and so major metalwork repairs may be carried out in any workshop equipped with welding facilities.

The moving parts of the pump, the pulley, treadles, pistons and valves are all subject to wear and tear. The pulley, which can be made of wood or steel can be lifted off the pulley stand. A replacement pulley and treadles can be made from local timber. Use without adequate protection in silt-laden water will cause accelerated wear of the cylinders and leather cup seals. However leather cup seals are very flexible and will accommodate to considerable changes in cylinder internal diameters before replacement is necessary. Replacement cylinders and cup seals must be purchased. The rubber seal of the valve may require replacement from time to time. This can be done using sections of old inner tube.

5 Comments

The pump requires priming at initial operation. This may be done by filling the cylinders with water poured in from a bucket and pumping vigorously to initiate suction. If the leather cup seals have dried out they must be allowed time to soak and soften in water to develop their sealing properties. When the cup seals are new they should be soaked overnight and worked by hand to make them soft and pliable. The cup seals must not be oiled as this will inhibit their water absorption, reduce their flexibility and could contaminate the water source.

During operation piston movement is not entirely vertical due to the pivoting of the treadles and looseness in the connections. This may result in some leakage either on the pressure or the discharge stroke. A small amount of leakage on the pressure stroke is quite acceptable and helps to maintain a water seal above the piston during the suction stroke. Correct alignment of the pistons over the cylinders minimises this problem but because the cylinder unit and the individual pistons may be adjusted to any position the correct alignment may not always be achieved by the operator in the field. Further work is being carried out to investigate how this problem may be reduced.

The unit is portable but is quite heavy and when fully assembled requires a minimum of two people to carry it.

The price being charged, in 1989, by the small welding shop in Harare for the pressurised pump was Z$550 (approx US$275), excluding piping. This compares unfavourably with the rope-washer pump which may be installed as a complete unit on a farmers well for Z$150. However it can be purchased as an "off-the shelf" item which may appeal to some farmers and non-governmental organisations. Dissemination of the RWP must rely much more heavily on an effective training and extension strategy.

The big advantage of the modified treadle is that it can discharge water under pressure. However the intake is limited by the maximum suction lift which is approximately 6 m in Zimbabwe. Thus the treadle is most suited to shallow wells and abstraction from sources, such as sand rivers, which require pressurised pumping. The rope-washer is recommended in situations where pressurised pumping is not required.

High flows over long periods are sustainable with the treadle. In laboratory investigations with a single operator pumping for 15 minutes including rest periods, the treadle pump delivered flow rates of over 0.4 l/s for a lift of over 14 m. This is equivalent to a power output in excess of 60 W and compares with sustainable power outputs achieved with the rope-washer of about 40 W. The sustainable high output of the treadle is largely due to the use of the leg muscles rather than to any breakthrough in pump mechanical efficiency. In fact there is some indication from our work that the rope-washer pump has at least as good an operating efficiency and that output is limited because the RWP is hand operated. Some attempts have been made to adapt the rope washer to foot operation using a pedal arrangement. This has not proved very satisfactory to date and a treadle operated arrangement is being designed. If successful this would have the added advantage of allowing the RWP to be mounted on a raised platform with the operator remaining at ground level.

7 Conclusion

There is a need to increase the choice of irrigation technology available to the small-scale farmer in Africa. Manually operated pumps can play an important role in bridging the gap between the watering can and the diesel pump. Two designs, the hand operated rope-washer and the foot operated treadle, have been adapted for manufacture and use in Zimbabwe. The treadle pump is being manufactured in an artisan's workshop in Harare. The rope-washer pump is being manufactured and installed at village level. Refinement of the pump designs is continuing with particular emphasis being given to the development of a simple treadle adaptation for the rope-washer.

The next logical stage in development of these pumps is to have a pilot project with widespread testing of the pumps in the field to get feedback from the farmers on problems they encounter and further requirements for improvement.

Acknowledgements

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PLANNING FOR WATER QUALITY MANAGEMENT IN INTERNATIONAL RIVERS AND LAKES WITH THE EMPHASIS ON DEVELOPING COUNTRIES*

J Balek
UNEP, Nairobi

Abstract

Earlier this year, a draft of the "Code of Conduct on Accidental Pollution of Transboundary Inland Waters" was finalised by the senior advisers to ECE Governments. Economic Commission for Europe supported by UNEP has prepared the document to guide European Governments in the protection of transboundary waters against pollution resulting from hazardous activities in case of accidents or natural disasters and in mitigating their impacts on the aquatic environment.

In highly industrialised and heavily populated Europe, the problems related to the pollution of international waters became serious a long time ago; in many developing countries these problems have been considered as of secondary importance. However, rapid development and population rise should provide a warning and preventive measurements have to be taken well in advance. Actually, in some developing countries, the situation has become already serious and industrial pollution, inadequate sewage treatment and solid waste deposits are apparently uncontrolled.

Appropriate planning for water quality management on an international scale becomes an important topic in recent years.

Introduction

In legal terms an accidental pollution of transboundary inland waters means any introduction, directly or indirectly, of hazardeous substances into transboundary inland water as a result of incidents originating wholly or parlty within an area under the jurisdiction of another country.

While such a definition may satisfy legal and institutional requirements, the water resources professional needs to determine technological limits and criteria which can be applied in the water quality assessment.

In principle only water quality standards based on measurable indices are suitable to determine when the situation has become critical. Because recommended standards vary from country to country it is always necessary to set up limits acceptable in the international schemes.

The Code of Conduct as prepared by ECE experts is concerned with accidental pollution and as an accident is defined as a departure from normal or authorised operating conditions of an activity causing or threatening to cause water pollution. In many parts of the world, however, equally if not more dangerous is slowly but steadily increasing pollution from small unidentified sources, which, as individual impacts, perhaps cannot be considered as accidents, but which, in a cumulative effect, cause heavy continuous pollution. To control such pollution is often more difficult than to solve individual accidental events.

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*The designation employed and the presentation of material throughout this paper do not imply the expression of any opinion whatsoever on the part of UNEP.

Control of transboundary water quality

First we may need to define what transboundary waters are. Generally, transboundary waters are river stretches along which State borders run; surface and subsurface water flowing from country to country, flows of which cross the state borders, and still waters — surface or subsurface — divided by the state borders. While with flowing surface water the transport of pollutants can be fairly easily identified and predicted for low-lying cross-sections by applying laws on channel hydraulics, in standing and subsurface water series the pollutants are instead distributed through dispersion and the long-lasting effects are only predictable with difficulty. In flowing water series, the timing of the accident (particularly time of travel and duration of the event) can be estimated more easily; in standing waters, the effect may continue for an indefinite period. Thus pollution of groundwater resources becomes more serious than that of rivers, because accumulated effects may develop the pollution after a prolonged period, however, with irreversible consequences.

For effective control of pollution, each type of aquatic environment may require technically different solutions, but, nevertheless, general protective measures remain the same, In all cases, the following steps can be identified:

- setting up of water quality standards,
- establishment of monitoring network,
- unification of the observational methods,
- provision for monitoring, acquisition, processing and storage of water quality data,
- exchange of information among the member States about the ongoing activitites which may threaten to cause water pollution,
  joint water management planning and development,
- joint agricultural planning and development including co-ordinated land use practices,
- co-ordinated basic and applied research

As is generally known, such a type of full co-operation on an international scale is rarely found not only in developing but also in developed countries. So far even bilateral or multilateral treaties in developing countries have considered water quality and water pollution problems only marginally. A few examples can be given:

The agreement between Burundi, Tanzania and Rwanda, on the management and development of the Kagera basin, made in 1977, is concerned with the impacts of mining, control of waterborne diseases, development of fisheries and protection of the environment in general. Even if the water pollution is not specified, any of the above aspects are closely related to potential pollutional hazards.

Similarly, the convention relating to the status of the river Gambia, signed in 1978 by Senegal, Gambia and Guinea, is concerned indirectly with the pollutional aspects when demanding that "....no project is likely to bring about serious modifications on the sanitary state of waters ...".

In the African Convention on the African countries at Algiers in 1968, the article 7 says that the contracting parties shall all take appropriate measures to prevent, reduce, combat and control pollution caused by discharge from river, estuaries, coastal establishments and outfalls, coastal dumping or emanating from any other sources on their territories.

The obviously limited number of examples which can be traced in the water treaties indicates how much effort needs to be given to the problem in the future. At present, only a few governments of the developing countries can report research work, investigation and inquiries carried out with a view to reformulating their water policies, perhaps with the exception of biological pollutants and relevant waterborne diseases. At this stage, there is an urgent need for the international organisations to take the inititative in the integration of the pollutional aspects in the international water development programs. In principle, two problems need to be tackled:

prevention of damage by water,
prevention of damage to water,

Damageby polluted water is often through the eradication of natural or induced fish, damage through water used for irrigation and last but not least damage to water supply schemes. Often, particularly in Asia, siltation causes serious damages.

Damage to water in developing countries mainly develops because of a lack of effective control, which allows uncontrolled dumping on land and water. In addition, the number of farms using excessive amounts of fertilisers and pesticides is increasing. A damage of the wetlands by pesticides is reported from the ASEAN region. On the other hand, pollution by heavy toxic metals from the mines, such as that experienced from the Zambian Copperbelt, is still rather exceptional. Lack of legislative measures and public awareness are other negative factors.

As can be seen in various reports delivered to UNEP, uncontrolled pollution is reported from many parts of the world, particularly from Asia and Latin America, where it occurs due to rapid industrialisation, spontaneous urbanisaiton and concentration of the population in shanty towns without adequate sanitary facilities. Intensified agriculture contributes by pesticides and fertilisers. Mnay water supply schemes traditionally used water without any treatment. Nowadays water sources have become seriously polluted and an increase of contamination is accompanied by the spread of waterborne diseases across the borders. Such problems have been incorporated into the programme of UNEP.

Role of UNEP in the water pollution control

Under the EMINWA Programme UNEP attempts to:

assist Governments to develop, approve and implement environmentally sound water management programmes for inland water systems.
train experts and establish training networks,
prepare manuals and guidelines for the environmentally sound management of freshwater systems,
made regular worldwide assessments of the state of the environment,
inform mass media on the achievement and activities of the programme.

Several examples can be given on how these principles are applied in the field of pollution control in international rivers.

In co-operation with the World Resources Institute and the International Institute for Environment and Development, an annual assessment of the resource base that supports the global economy, is regularly published. An important chapter of the book is concerned with quantitative and qualitative assessment of world fresh water. For instance, aspects of global freshwater availability, non-point sources of pollution, global pollution assessment, sediment loads in major world streams and recent relevant literature are found in the volume published in 1988-89. For analytical work, it is important that features of all natural resources are discussed in other chapters, which makes comparative analysis of the potential interactions more feasible.

In co-operation with the World Health Organization environmental pollution levels have been monitored in more than 60 countries for 15 years. Substantive inputs into the establishment and expanding of national and international river basin water quality monitoring networks have been supported through methodology development, network design, analytical quality control and training. The GEMS/WATER programme of UNEP has been concerned with the above activities. Water quality data are regularly published and served as an efficient tool in transboundary pollution assessment.

For the period of 1990-2000 the GEMS/WATER programme will be considered to correspond more effectively to global requirements and to improve data quality in accordance with recent scientific achievements. While in general the monitoring network has been improved, particularly in Latin America and Asia/Pacific, the project needs to be reviewed with respect to overall geographic coverage, measurement of toxic metals and usefulness of collected data for global assessment.

When the first Water Action Plan for the Zambezi was accomplished, components for the prevention of transboundary pollution became significant parts of the Plan. Under the so-called ZACPRO 5, development of a basin-wide unified monitoring system related to water quality and quantity was proposed for implementation. Emphasis was given to the promotion of existing mechanisms for water-related environmental data information between the basin countries, to a minimum augmentation of the present networks and to the strengthening of manpower and facilities of some national data centres. Under ZACPRO 6, the development of the integrated management plan recommends the development of safe drinking water supply and sanitation conditions including water pollution and accidental pollution control. Finally, under ZACPRO 14, prevention and control of water-related and waterborne diseases should be established.

In another project, attention has been given to the pollution problems of Lake Victoria. While the project itself (convened by the lake authorities in Kenya) supplied only limited results, for future work it has to be taken into account that Lake Victoria itself is a transboundary water body shared by Kenya, Tanzania and Uganda and international activities need to be strengthened.

More projects can be identified of such a type, which in principle are national, but the results of which may become significant in the international scale. For instance, at present a project on the environmental protection of the lake Xolotlan (formerly Managua) in Nacaragua has been finalized. The state of the lake has been considered critical, and improvement of the present situation will not be easy. In addition, the lake pollution may have negative impacts on the environment of neighbouring Costa Rica. Among other outputs, it is expected that effective control of the polluted waters may serve as an example in a regional scale.

More attention has to be paid to groundwater resources. A proposal concerned with the protection of the groundwater resources under the Arab states in the Gulf regions, has been submitted to the Governments concerned for further consideration.

Strategies for water pollution control in the humid tropics have been set up at the Colloquium on Water Management of the Humid Tropics, organised in July 1989 in Townsville, Australia. Special features of water pollution were identified in the region and recommendations prepared which, as a joint document of UNESCO and UNEP, will be presented to the Governments of the countries in the humid tropical belt.

Significant achievements have been made in the field of methodology and training. UNEP jointly with UNESCO has recently published 'Methodological guidelines for the integrated environmental evaluation of water resources projects", followed by "Training guidelines" written for a similar purpose.

Hygienic criteria for drinking water supply have been published jointly with WHO and CIP Moscow in 1987.

Problems relevant to the pollution of international waters are discussed in a publication "Large scale water transfers" published by UNEP in 1985.

Expression of the environmental impacts related to the pollution of the rivers and quantified in monetary terms and concentration units in a multiobjective planning approach, is found in a publication of UN and UNEP called "Assessment of mulitple objective water resources projects" and published in 1988.

Jointly with UNESCO, a need was identified to incorporate environmental aspects into the education of water engineers. A recommended syllabus for such a type of education is presented in the publication "Integration of environmental aspects in water resources engineering education". Fifty per cent of the total time assigned for environmental education is recommended to be spent on problems relevant to water pollution.

As has been mentioned at the beginning, "Draft code of conduct on accidental pollution of transboundary inland waters" is prepared by senior advisers to ECE Governments on environmental and water problems". Again, this project is supported by UNEP. The Code of Conduct, the first of its kind, may serve as an example to other continents and developing countries for preparing similar types of documents reflecting actual situations and conditions on a regional and perhaps continental scale.

In the attempt to set up general strategies for the effective pollution control of the lakes, a series of guidelines on lake management is under preparation - this time in co-operation with ILEC. The first volume has recently become available.

A series of guidelines on effective protection of groundwater resources has been prepared jointly with CIP and UNESCO. It is expected that the guidelines will be applied in the developing countries in the next biennium 1990 - 1991.

The program for effective water pollution control will never be fully accomplished, but, for the next biennium, most serious problems elsewhere in the world have been already identified. For instance, a project on the protection of the ASEAN wetlands with a strong water quality component is under preparation and another project on the development of human resouces for effective pollution control has been prepared for Asia and the Pacific. Already this year, a symposium "Wastewater Nairobi", supported by UNEP will discuss the increasing rate of pollution of African waters.

Conclusion

As a conclusion generalised outlines can be given of the program set up by UNEP at the time when the Zambezi Action Plan, first of its kind, was prepared. Attention was paid particularly to the environmental legislation leading not only to the protection of the waters but to the protection of the whole basin. Under such a policy a need was identified to develop, review and when necessary expand, update and strengthen national laws and regulations pertaining to the protection and development of the river and lake basin. This concerns, among others, laws related to deforestation, soil and water conservation, rural and urban health and development, planning, mining and industrial activities and prevention of pollution of the riverine and marine environment.

National laws and regualtions for the protection of river basins should be harmonized to meeting the objectives of overall legislation. Only then can a regional international convention for the protection, management and development of river basin resources be developed and adopted. Such a convention has to be supplemented by protocols prescribing agreed measures, procedures and standards to prevent, reduce and control pollution from all sources and to promote stated environmental objectives.

Fourth African Water Technology Exhibition and Conference Nairobi, Kenya
19-23 February 1990

Synopsis of proposed paper by M. P. Upstone

Subject: Water Pollution Control and Trade Effluent Policies in Urban Areas.

Establishment and maintenance of official water supply and sewage systems capable of providing good quality water fit for domestic, industrial and commercial use and the safe disposal of waste water is essential for the health of a community and the development of any country. The major risk to public health derives from water borne diseases but good planning, constant vigilance and awareness of sources of water pollution is imperative to protect the environment and the quality of public water supplies.

The expansion of urban areas through population growth and migration coupled with the expansion of industrial development inevitably leads to an increase in the risk of pollution. It is necessary to achieve a balance between the economic disposal of the waste products generated and the protection of water supplies against pollution and environmental pollution in general.

The paper discusses the following.

1. Sources of Pollution including unsewered areas/properties, discharges from sewage works, flood water and storm drains, industrial effluent, solid waste disposal and domestic animals.

2. The various elements needed to implement pollution control measures.

3. Practical examples of the work that has been undertaken by Severn Trent Water notably in:

   — River Tame in Birmingham UK - an industrial area with 2 million population.

   — preparation of a programme for reducing water pollution in a major city in India.

Please turn to Page 142 for paper on Water Quality Control In Kenya.

WATER POLLUTION CONTROL AND TRADE EFFLUENT POLICIES IN URBAN AREAS

Presented by Michael P. Upstone B.Sc MICE
General Manager, Severn Trent Water, Birmingham, U.K.

INTRODUCTION

The explosive growth in aspirations and demands of a community calls for the application of technology to cater for mass demands. An uncaring application of technology is likely to result in the exploitation of natural resources beyond the limits of prudence. Conservation of the environment is an integral part of the development process because sustainable and sustained economic development will only be possible if there is a rational use of resources.

The adverse impact on the environment of uncontrolled development has caused policy makers and Governments to bring in regulatory measures to prevent further degradation of the environment. However, enactment of such regulatory requirements is not of itself of real benefit unless an organisation, with the responsibility, authority and resources to monitor, control and apply sanctions to transgressors, is established.

All development activities have an impact on the environment; improved agriculture involves the use of potentially toxic materials, industrialisation results in the generation and discharge of polluting effluents, urbanisation contributes to congestion and growth of slums. It is an inevitable consequence of this desire that installation of measures to prevent pollution of the environment is an afterthought. Pollution control expenditure draws from the pool of capital funds available for production facilities. In the long term the cost of pollution control measures is significantly higher when they are retrofitted to existing plant and it is also difficult to change attitudes and established practices without the provision of comprehensive technical education and training. Briefly, ill planned development activity engenders costs which often later negate the benefits which were sought. The two major components for sustainable development are equity and environmental harmony and the mandate for environmental action should permeate all sectors of the economy through the establishment of organisational structures and a rational deployment of resources to produce a harmonious plan.

WATER AND WASTEWATER QUALITY

Quality control of potable water and sewage is essential in the effective management of the water cycle to provide a safe supply for consumption and to conserve the maximum amount for subsequent reuse whether it be for domestic industrial, commercial or recreational purposes. The controls which need to be applied will be more or less stringent dependent upon the availability of fresh water from rainfall, either directly or as a result of conservation schemes. In order to protect sewage treatment processes trade effluent discharges to sewer need to be subjected to controls on quality and flow. More stringent controls on discharges to watercourse are essential. A number of general principles are relevant in any consideration of water quality, amongst the foremost of these are:

1. Modern technology can produce water of any quality at a cost.

2. Each time water quality is improved by treatment a residue is produced.

3. The quality of the raw water, the subsequent uses of the treated water and the residue, will primarily influence the choice of treatment process.

4. Effluents and residues can either be a resource or a hazard, dependent on objectives and controls.

5. Treatment processes are most effective when the raw water quality is consistent.

6. Treatment processes are generally more efficient with stronger wastes.

7. Various water using processes within the same industrial plant have different minimum quality requirements, sequential use of the same water is possible and should be considered.

8. Both water and money will be saved by good quality control.

The protection of public health by control of water related disease transmission is of paramount importance. Good quality water for drinking must be protected from contamination by persistent organic substances, heavy metals having toxic properties, and high levels of mineral substances. In countries having extreme water shortages it has been demonstrated that sewage effluents can be directly reclaimed to provide water which complies with conventionally accepted quality criteria. The religious aspects of reuse of wastewaters as well as public attitudes in general may inhibit the introduction of such schemes. The River Rhine in its lower reaches provides a source of drinking water for some 6 million people and may contain up to 40%treated sewage effluent rising to almost 100%at times of low flow. (ref 1) In all cases of reuse it is essential that strict monitoring programmes are implemented to ensure the maintenance of a satisfactory quality.

Ref 1 WHO Reuse of effluents: Methods of wastewater treatment and health safeguards. WHO Tech Rep Ser No 517 (1973).

SOURCES OF POLLUTION

Aquatic ecosystems are intermittently subjected to pollution by natural phenomena such as floods and decaying flora but by far the greater risk is to mankind. When the assimilative capacity of a system is exceeded pollution is caused.

The sewering of towns and draining of houses is as ancient as civilisation. Within this timescale progress in pollution control is a recent phenomenon. In the UK it dates its origin in the early part of the nineteenth century although instances of water closets designed in 1596, 1775 and 1778 have been recorded.

The introduction of the water closet transferred the filth in the streets to the rivers, converting them into open sewers. In the 1850's the River Thames was so heavily polluted by the sewage from 3 million people that it was necessary to hang blinds soaked in bleaching powder to make it tolerable for Parliamentary Committees to proceed and, on occasions, the Law Courts were suspended because of the stench from the fermenting excrement in the river.

Industrialisation in the nineteenth century generated large volumes of polluted water and also encouraged more people to move from the rural to the urban environment with a further increase in the pollution of rivers. Cholera epidemics provoked Government action in the 1890's and early 1900's which lead to the introduction and development of accelerated natural processes for the treatment of sewage and industrial wastes which reduced the impact of urbanisation on rivers.

Currently 96% of the UK population has the benefit of a sewer connection with 6000 sewage treatment plants serving a population of 60 million.

In addition to human excreta and industrial effluents, farming activities pose a significant threat to the quality of water resources. In many parts of the world water bodies are also convenient recipients of the uncontrolled disposal of solid wastes.

The performance of sewage treatment plants in the UK is monitored by the National Rivers Authority and each individual plant is required to achieve a quality of treated effluent appropriate to the needs of the receiving watercourse. The quality conditions are calculated on the basis of maintaining a specified quality for the river taking into account the extent to which the effluent will be diluted by the base flow in the river. The conditions specified in consent documents invariably include flow, biochemical oxygen demand and suspended solids limits. Additionally, where circumstances require, limits may be applied for ammonia, heavy metals and specific compounds known to be harmful. The imposition of limits for many such materials is brought about by the need to conform to the requirements laid down in Directives emanating from the European Community relating to Dangerous Substances. Exceedance of the conditions specified in the consent to discharge makes the discharger liable to prosecution - a major incentive for good management of the sewage treatment works. The main source of heavy metals and dangerous substances in sewage is from the discharge of industrial wastes. The need to control the quality of these wastes is to:

1. Protect the sewerage system, the sewage treatment works and the personnel employed therein.

2. Ensure that the mixed sewage can be effectively and economically treated by the processes employed at the sewage works.

3. Ensure that the products of treatment, in the form of effluents or residues, have no unacceptable effects on the environment.

4. Ensure that if, in times of storm, storm sewage reaches a river via a storm overflow, its quality will be acceptable under those conditions.

5. Provide data upon which the design of future sewage treatment works can be based.

6. Ensure that the trader pays a fair charge for the reception, conveyance, treatment and disposal of his effluent.

7. Encourage conservation and recycling of water where appropriate.

8. Ensure that no clean water (e.g., cooling water or uncontaminated ground or surface water) is discharged unnecessarily to the public foul sewer.

Achievement of the first 4 objectives may require the trader to undertake pretreatment of the effluent, before discharge to the public sewer, to reduce the concentration of certain substances.

National guidelines for the control and charging for trade effluents discharged to sewer were first agreed between the Water Industry and the Confederation of British Industry in 1976. These guidelines were updated and revised in 1986.

Table 1 indicates the potential adverse effects of various substances which may be discharged to sewers and Table 2 shows typical limits which may be applied to control particular substances.

CLEANUP OF THE RIVER TAME UK

The River Tame drains the extensive industrial conurbations of Birmingham and the Black Country and about a century ago was little more than an open sewer being black smelly and devoid of any pleasing features.

In the early part of the 1900's a number of local sewage collection and disposal facilities were constructed. Much of the development of methods of treatment took place in the area and in particular development of the activated sludge process was carried out at Minworth which is now the largest sewage treatment works in the Severn Trent region.

The rationalisation of water supply and sewage treatment provisions, which occurred in 1974 on the formation of Severn Trent Water Authority, continued the developments initiated by the Upper Tame Main Drainage Authority. At the heart of the rebirth of the Tame has been the ambitious Tame Basin Reclamation Scheme which has involved the closure of many old and inefficient sewage works and the diversion of their flow to Minworth. This has taken huge volumes of often poorly treated sewage effluent out of the upper reaches of the river. These works are capable of fully treating the flow from a population of 2 million in addition to trade effluent flows from a diversity of industrial processes. These industrial discharges number around 1500 and generate an income for Severn Trent of 4.3 million.

Another key weapon in the cleanup of the Tame has been the construction of purification lakes downstream of Minworth at Lea Marston which are unique in this country. These lakes assist in the natural purification processes of the river. The first lake functions as a large sedimentation basin which effectively removes some 18000 tonnes of silt per year, washed down the river by storm runoff from the heavily urbanised catchment. This lake is desilted by floating suction dredgers. Further improvements will arise because of the continuing investment in sewage works.

The whole of this work has contributed to a dramatic improvement in the quality of the River Trent of which the River Tame is a large tributary. Downstream of the confluence, the Trent now supports a good coarse fishery, and in its tidal reaches, the regular return of small numbers of salmon are observed. Salmon are an indicator of a high quality water.

ENVIRONMENTAL IMPROVEMENT TO THE WATERWAYS OF MADRAS

Madras, capital of the State of Tamil Nadu is situated on the Bay of Bengal on the east coast of South India and is the fourth largest city in India covering an area of 173 square kilometres.

The 1981 census data estimated the population to be 3.3 million with a forecast of 5.2 million for 2001. Development of the sewerage system began in 1890 when open drains were first connected to pumping stations. At that time water was obtained from open wells. In 1907, J. Madeley formulated a plan to improve the sewerage system, and work commenced in 1910 and continued into the 1920's. The problems he faced still exist today; the need to provide efficient sewage collection for a flat, crowded, rapidly growing city without interrupting existing services. He introduced a system of gravity sewers draining to local pumping stations which discharged to the sea. It was designed for a projected 1961 population of 650,000 on the basis of 114 litres per head per day and consisted of a network of forcemains and gravity sewers served by three main pumping stations which are still in use today, though refurbished. The collected sewage was discharged to a sewage farm at Kasimode on the northern city boundary, excess flow being diverted to the sea. The farm was closed in the 1930's and all the flow was diverted to the sea. Extensions of the sewer system continued as the population and city area expanded. The sewerage system relies on pumping. The sewage is strong and flows are lower than predicted. Grit and solids collect in the lowest points and the system is difficult to maintain due to surcharge problems.

At the present time four sewage treatment sites exist with a total design capacity of 262 Ml/day. A treatment works is located at the headwaters of each of the two main waterways, the Rivers Cooum and Adayar, and they receive the discharges from these works. Both rivers have sandbars at their mouths, caused by littoral drift, but are kept open to a limited extent by dredging. Figure 1 shows the city limits, waterways and sewage treatment plants. The Buckingham Canal is a 400 kilometre system originally constructed for navigation. The major sources of pollution affecting these waterways are inadequate treatment of domestic waste and industrial discharges, sullage unsewered areas, cattle waste, slum settlements on the banks of the waterways and inadequate garbage disposal.

Other than during the monsoon period the River Cooum, which has a catchment of 287 square kilometres, has no base flow within the city boundary; whilst the Adayar, with a catchment area of 847 square kilometres, has only a very small base flow. However, both rivers carry high flood discharges during the three month monsoon period from September to November. The Otteri Nullah is a small watercourse arising wholly within the city boundary. There is no natural base flow and it is heavily polluted prior to its discharge into the Buckingham Canal.

A major programme of environment improvements to the waterways is planned. Severn Trent International is assisting relevant departments of Government of Tamil Nadu in identifying, monitoring and regulating the sources of pollution and drawing up a Master Plan for the programme of improvements. A Task Force and Project Implementation Group will be established with a mandate to:

1. Establish long term river quality objectives
2. Agree and control the capital investment programme
3. Determine priorities
4. Ensure adequate capital and revenue funding is made available to all relevant departments
5. Monitor the programmes and performance of all relevant departments.

INSTITUTIONAL RESPONSIBILITY AND ACCOUNTABILITY

In order to ensure the ability of sewage treatment works to treat flows to required effluent standards, thereby protecting the quality of water in the receiving water course, it is necessary to:

a) Design and construct the works to meet projected pollution trends taking into account the planned domestic and industrial pollution load.

b) Ensure the satisfactory operation of the works at all times to meet the discharge standards required.

c) Ensure that adequate maintenance of the plant and equipment is carried out on a regular basis.

d) Ensure that proper control is exercised in the trade effluent discharges to the works by issuing appropriate permits to discharge and policing these to ensure compliance.

Each of these functions can only succeed if adequate resources are provided by the appropriate institutional body at the correct time. All too often, and the UK was no different in previous generations, industrial and domestic development has taken place in urban areas in advance of the provision of sewerage and sewage treatment facilities leading to gross pollution of receiving water courses. To recover from this position, once established, requires major programmes of investment coupled with rapid increase in charges to industry and domestic users. Imposition of controls onto industrial discharges, once established, is also likely to be achieved only with great difficulty.

Governments are increasingly recognising the need to improve the quality of the water courses in urban areas with consequent environmental and public health benefits. In many cases this is being achieved by major capital investment aimed at construction of new sewage treatment works or refurbishment of existing works. Whilst this investment is clearly helpful and desirable, it can only achieve the desired objectives if coupled with attention to the regulatory framework and with training and development of those concerned with operation and maintenance of existing and new treatment plants.

It is essential that the appropriate framework of legislation is provided to ensure that control can be exercised on discharges to sewerage systems, since without basic controls, achievement of satisfactory effluents to receiving water sources in the longer term is unlikely. Whilst this legislation exists already in many cases, again, unless the manpower resources are provided to monitor and control discharges, particularly from industry, it is unlikely that the required objectives will be achieved.

A clear and well understood framework of consents to discharge, coupled with a charging system to ensure that industrial dischargers pay the costs of treatment of their effluent, will ensure that the financial resources are available for the long term operation and maintenance of the sewerage system and treatment works. Whilst the difficulties of achieving these objectives in the real world are fully recognized, particularly in areas where industry has traditionally been ill-controlled, it is considered that only by the gradual and sustained imposition of controls of this kind will long term environmental improvements be achieved.

Properly planned training and development of staff responsible for operation and maintenance of sewage treatment works is the other key factor in the equation and is one which can only be addressed by the responsible institutions. All too often in the past, sewage treatment has been a function which has been deprived of adequate resources and in which the staff have received little if any training in the required skills. Staff, properly trained in process skills and the operation and maintenance of plant and equipment, are essential if the effective operation of treatment works is to be sustained in the long term. Training plans involving the use of an on-site training or properly developed training programmes elsewhere should be seen as an important part of a programme for improvement of effluent and water quality standards in an urban area.

TABLE 1

CRITICAL ASPECTS OF THE VARIOUS STAGES OF SEWAGE TREATMENT WITH RESPECT TO INJURIOUS SUBSTANCES

Stage	Critical Aspects	Examples of Substances Which May Be Injurious
Sewerage	a) Fabric of sewer b) Atmosphere in sewer and pumping stations	acids; sulphate
Preliminary and primary treatment	a) Plant b) Settlement of solids	grease oil; surface active substances
Aerobic biological treatment	a) Activated sludge or biological filter micro and macro organisms b) Oxygen transfer rates	metal; general poisons e.g., phenols, specific substances e.g., thiourea surface active substances
Sludge treatment	a) Anaerobic microbial digestion	organo chlorine compounds
River receiving effluent	a) River flora and fauna b) Abstraction for irrigation c) Abstraction for public supply	metals; toxic organics, pesticide residues organic residues; chloride, nitrates
Sludge disposal	a) Leachate from tips b) Suitability for agriculture (soil structure, yield and quality of farm produce) c) Suitability for sea disposal	metals; ammonia metals; grease; infectious or infesting organisms metals; persistent bioaccumulated organics e.g., PCB's

TABLE 2

TYPICAL DISCHARGE LIMITS TO SEWERS FOR PARTICULAR SUBSTANCES

Substance	Mg/1
Sulphide	1-10
Cyanide	1-10
Phenol	5-20
Ammonia	250
Heavy metals	2-10 total in solution 5-30 total in solution and suspension
Cadmium Arsenic Mercury Selenium Silver	1
Lead Chromium Nickel Tin Copper	2-5
Zinc	5-10
Chlorinated Hydrocarbons	0-1
Sulphate	300-1000 as SO3
Oil	shall not contain physically separable, dispersed or emulsified oil.

TRAINING PROGRAMS FOR ENVIRONMENTAL PROJECTS IN DEVELOPING NATIONS

by

Joseph F. Selann, M.Sc.

and

Nizar A. Ahmed, P.Eng.

Edmonton, Alberta

CANADA

1.0 INTRODUCTION

There are approximately two billion people in the developing world who rely daily on risky water supplies. Water borne diseases take a heavy toll especially among the very young and the old. For this reason the UN General Assembly in 1980, proclaimed 1981-1990 as the "International Drinking Water Supply and Sanitation Decade".

The dreaded Guinea worm disease is just an example of the many illnesses that can be spread by inadequate water supplies. According to the World Health Organization, this disease afflicts some 20 million people, mainly in Africa. There are no known cures for this disease and no vaccine for immunization exists and the only prevention against this disease is through well controlled water supplies and treatment plant facilities. It should be noted that water borne diseases are not only present in areas where there are no water treatment facilities, but are also present in places served by water treatment plants. The operators charged with the responsibility of operating and maintaining these facilities therefore should carry a very heavy responsibility since they are the first line of defense against the spread of these water borne diseases.

Unfortunately, a large number of treatment plants either do not work at all or do not work well, not because they are ill conceived, poorly designed or constructed, but because they are not properly maintained. Poor maintenance is not necessarily attibutabble to operator attitude or lack of diligence; albeit it is a result of inefficient and poor maintenance programs. The World Health Organization 1986 program report identified the lack of appropriate personnel together with operation and maintenance deficiencies as the second ranked constraint (after funding shortage) in realizing the goals of the Decade.

Why should someone take the time and expense of building water supply or treatment plants and not ensure that the operators will be able to keep it in operation and to ensure that the product quality will meet expectations? In many cases, this isn't the problem either. The funding agencies almost invariably include training programs for the operators. The problem is that many of these training programs have been ill conceived, poorly thought out and poorly organized. Consequently, the proper operation of these water supplies and treatment facilities is often not a question of additional funding. It is a question of being able to determine which training and education programs work and which don't. In many instances well meaning training and education program organizers have implemented programs which are completely incompatible with the local conditions and, in some cases, create more problems than they were intended to solve. Even where there has been a great deal of goodwill or desire to benefit the recipients, the lack of appropriate organization and content has resulted in ineffective programs.

2.0 TRAINING AND EDUCATION (T AND E) OBJECTIVES

The long term goal of any training and education program has to be the development of national and collective self reliance.

The above statement encompasses a large variety of political, social and technical issues that must be addressed in detail before self sufficiency can be realized. Some of these are:

1) The political will must exist before such a program can be implemented. Political leadership will go a long way in ensuring that participants in training programs are sufficiently motivated and prepared to undertake the training. This type of training programs do not mean simply presenting information to the operators and then hoping that their job performance will improve. It is a systematic application and implementation of programs which involves the cross-section of a community and must be a part of any public health program or national health plan. It also means that appointment to these jobs can no longer be made on political patronage basis but only trained people, as they become available, will be able to operate public water and wastewater systems.

2) Social implications of undertaking a T and E program must also be considered. Our experience has indicated that participants have used environmental programs as a stepping stone to obtaining better paying jobs in other public or private sectors. Attrition rates have been so high that vacant positions were created at a faster rate than operators could be trained to fill them. These high attrition rates often resulted in labelling these programs unattractive and therefore ineffective.

   Out-of-country training and education programs have a particularly bad track record for compatibility.

3) From a technical standpoint, there are a number of considerations:

   1) A "threshold number" of people from a given area must be trained; these people will then be able to support one another.

   2) Candidates must be carefully selected to ensure success of the program.

   3) Training must be relevant to the participants' day to day activities; it is recognized that developing nations do in fact possess a wide variety of technologies - technologies that differ in urban and rural areas. In the case of the latter, training must be specific for the water supply or wastewater systems in operation.

   4) Develop programs to evaluate the performance of the individuals completing the training.

3.0 ALTERNATIVES TO EXISTING T AND E PROGRAMS

There are lessons to be learnt from unsuccessful training and education projects. The T and E programs which are funded by foreign agencies must be principally managed and controlled by the recipient countries involved. We cannot assume that the developing world is a technological desert entirely depending on transfer of technology from the West.

The success of donor countries which are now providing T and E programs for developing nations will be measured by how efficiently they can work themselves out of a job. Recipient countries must be in charge of their own T and E programs. This is true self reliance.

For alternative programs, the following options may be considered:

1) Develop indigenous, in-county programs which are modelled primarily along the lines of out-of-country programs. This approach cannot be considered to be the long term solution to T and E requirements. It relies largely on donor supplied instruction materials and methods and therefore relevance to actual conditions existing in the recipient country will always be a concern. Nevertheless, this approach is a step in the right direction and can often serve as the basis for developing future in-country programs.

2) Develop indigenous, in-country programs which are not based upon out-of-country materials or methods. This approach usually requires a "train the trainers" phase.

   During this phase a pool of local instructors/tutors is established. These trainers in turn will be responsible to develop and deliver relevant technical training courses and programs.

   These local trainers occupy a key role in the success of the programs. They have a full understanding of the social and cultural aspects involved in dealing effectively with the problems and needs which are difficult to define. They also understand the political sensitivities and the available technology in the country.

3) Develop out-reach/on-the-job training programs.

   This approach to operator training replaces a large portion of in-class training programs; instructional materials are developed to the extent that self-learning now becomes possible. In this case, the role of the trainer becomes that of a tutor. Ideally, individuals selected for the instructor/tutor training will already have experience in the field of water/wastewater operations in the country. This will make it possible for them to share and communicate their knowledge and experience more effectively.

The advantage of outreach training programs are numerous. Probably the most important of these is the fact that they impact the least on day-to-day work activities of the participants. Since training is provided "on the job", it makes it possible for them to carry out their duties, thereby removing one of the most significant objections to training: "who will look after the system while the people attend training programs". The Rajarthan, India experience is an excellent example where out-reach programs work. The project involved the training of rural youth for the maintenance of simple water supplies and pumping units under the Indian Government's "Training of Rural Youth for Self Employment". This program de-mystified the technology of what goes into the maintenance and operation of simple water systems. Training is provided "on-the-job" and is practical. Between 1981 and 1984, 113 people were trained. As of the latest reports, training is progressing well and the trainees are holding their own.

In our experience, outreach programs failed in situations where the training material was designed for more traditional, in-class situations, and was instead used in an "on-the-job" training environment. It must be recognized that in an outreach program, the training material becomes the instructor. Therefore, the material must be developed to a much higher level so it, in fact, can perform this function. It must also be recognized that to a large degree, the level of contact between the trainer and trainee is reduced. While tutors assist and monitor the progress of trainees, participants rely greatly on instructional material. Therefore, the material must be prepared to be relevant, comprehensive and self-guiding, considering the background, previous training and education levels of the trainees.

4.0 BLUEPRINT FOR FAILURE

In reviewing the causes of poor outcome of training and education programs that failed to deliver, it is found that blame can be shared equally between the donor and recipient country.

Bilateral and multilateral agencies almost invariably incorporate T and E components into their projects with the agreement of the donor, contractor and recipient country, only to find that, as the project proceeds, these aspects are given less and less prominence or often completely eliminated during the project implementation stage.

Normally, technical experts are hired to train, and after they are gone, it is business as usual. The objectives of the training program are short lived.

Furthermore, there is a clear reticence on the part of donor countries or agencies to engage in substantial funding of in-country T and E projects. The traditional pattern of funding is based on a high level of involvement by the donor country or agency in the project. The funding of programs, in which the donor is not directly involved in the long run is a difficult concept for them to accept. For this reason, most of the T and E projects are based on out-of-country training. Their limitations are numerous. For example:

1) It is extremely difficult to design relevant, site specific T and E programs in a foreign environment. Often their programs depend upon state-of-the-art practices or techniques. Unfortunately, most of what is "new" in engineering has little value for developing nations in the context of the water and sanitation decade.

2) There are no built-in mechanisms in out-of-country T and E projects that will lead to the development of long term self sufficiency by the recipient country.

3) Out-of-country programs are not cost effective in the training of "threshold number" of operators.

4) Out-of-country training disrupts the day-to-day work activities of the trainees and this creates the operation of the facility a difficult problem.

5) There is still confusion among many donor countries on how to get involved in indigenous, in country T and E programs.

To meet the objectives of effective T and E programs, donor countries have to realize that an increasing level of funding must be provided for indigenous, in-country T and E programs in which they do not have any long term involvement. This is not easy for donors to accept because they do not see any direct payback in terms of supplying materials and services from the donor country to the training process. The donor countries, in this respect, are part of the problem. There still is a traditional donor mentality which comes from perceptions that will take time to overcome.

5.0 ORGANIZATION OF SUCCESSFUL T AND E PROGRAMS

Some of the pre-requisites of successful training programs have been discussed earlier. In addition, the following points must also be considered.

5.1 Funding Requirements

As was stated earlier, effective T and E programs are often not a question of additional funding requirements; they are a function of effective utilitization assigned funding component in capital projects in a more efficient manner.

It is important to recognize that changes in the philosophy and method of T and E delivery does not change the need for funding by donor countries and agencies. The traditional sources of funding can, however, be enhanced by including special funding provisions. Such special provisions include UN's DTCD (Department of Technical Cooperation for Development) emphasis on the development of the role of women, as an example. The UN DP has recognized that training is an effective way of promoting the role of women. Therefore, funding options for T and E projects can be substantially enhanced by increasing the number of women participating in these projects.

5.2 Trainee Selection Criteria

It is important to select candidates for training and education programs who will be able to succeed.

For the above reason, some pre-qualification criteria must be established. These criteria must be set with a great deal of care to ensure that they are realistic and specific to the type of training programs. The pre-qualification criteria, on the other hand, should never be used as the reason for exclusion of a potential candidate from a program. This statement may appear, on the surface, to be contradictory to the pre-qualification criteria mentioned above. This is not the case. If, during the pre-assessment of an individual, major deficiencies in skills or previous training are identified, this information should be used to recommend specific remedial action to ensure that the candidate will be able to successfully complete the training program.

Obviously, different training programs will be required for various job descritions, hence different qualification criteria. For example, the individual who would be responsible for the electrical maintenance of a municipal distribution system will require a background in electrical work, while an individual responsible for the maintenance of hand pumps would require some mechanical aptitude.

Our experience has shown that the remedial program cannot be undertaken on an outreach basis. To be able to successfully undertake an outreach study program, a level of motivation is essential. This is usually not an unreasonable expectation because of the high level of relevance of the material to the individuals day-to-day activities. The same level of motivation, on the other hand, cannot be attained during a remedial program where the immediate applicability of newly acquired skills is not realized.

6.0 DEVELOPING AN INDIGENOUS T AND E PROGRAM

6.1 Objectives

Proper installation, inspection, operation, maintenance, repair and management of water supply and wastewater systems have a significant impact on the operation and maintenance costs and effectiveness of the system. The objective of the T and E program is to provide operators with the knowledge and skills required to operate and maintain water supply systems effectively, thus eliminating or reducing the following problems:

1. Health hazards created by the delivery of unsafe water to consumers.

2. System failures that result from lack of proper installation, inspection, preventative maintenance, surveillance and repair programs designed to protect the public investment in the facilities.

3. Additional labour and capital costs.

Scope of the T and E Program

Operators with the responsibility for wells, pumps, small water and wastewater treatment plants, disinfection and distribution systems will require the following information to be incorporated in the program.

1. General description of the responsibilities of water supply operators.

2. Sources and uses of water and disposal of wastewater.

3. How to operate and maintain wells and pumps.

4. Operation and maintenance of small treatment facilities.

5. Procedures for operating and maintaining storage systems.

6. Characteristics of distribution and collection system facilities.

7. How to operate and maintain distribution and collection systems.

8. Disinfection of new and repaired facilities.

9. Techniques for recognizing hazards and developing safety procedures.

Information in the program must be very specific to the situations encountered by the operators. The material must provide them with an understanding of the basic operational and maintenance concepts of water supply and wastewater systems with an aptitude to analyze and solve problems when they occur. Operation and maintenance programs for the two systems will vary with age of the systems, the extent and effectiveness of previous programs and local conditions.

Technology is advancing very rapidly in the field of operation and maintenance of water supply and wastewater systems. To keep pace with advances, even in the simplest of systems, training programs must be revised and updated periodically. This means that the instructors/tutors must be aware of new advances and recognize the need for continued personal training reaching beyond the scope of the program.

7.0 EVALUATION

To ensure the long term success of the T and E program, ongoing evaluation of the progress of each participant's achievement is essential.

Objectives are set in areas of knowledge, skills and attitudes. The instructor's/tutor's repertoire of evaluation techniques must include procedures for formative and summative evaluations and must permit diagnosis and judgement of learning outcomes. Trainers will also be taught how to evaluate their own performance as instructors and the programs they design and teach.

There are high expectations from the participants and they must be aware of these expectations.

To achieve these expectations, the instructor/tutor process must be clear and focused. The personal interaction between tutor and participant must be positive. The responsibility for success as well as for failure must be shared equally by the tutor and the participant.

Incentives and rewards should be included in the program to promote excellence. The most elementary incentive is giving the opportunity in which to use the newly learned skills. A certification program designed to acknowledge the progress of the participants goes a long way in motivating them. Financial renumeration that reflects increased ability can also be justified by reducing the tendency for certified people to drift away to other jobs.

8.0 THE ROLE OF THE CONSULTANT

The technical assistance from donor countries should be carried out in close cooperation with the recipient country.

The consultant must realize that his involvement in the project is limited and that training systems generally cannot be transplanted from one country to another.

While the consultant can have a significant input during the initial organization of programs and during the training of the trainers/tutors phase, he must be willing to step back and allow the recipient country to gain progressively larger autonomy over the development of the training material and particularly over the delivery of the program.

There are some specific areas where the consultant can provide valuable input into the development of in-country T and E projects. Possibly the most notable of these is in the area of funding. Consultants are experts in identifying funding options. Since funding for T and E projects are usually from the same agency or NGO that provides funding for capital projects, consultants are generally familiar with potential sources. Furthermore, their line of communication with funding agencies is usually much more direct and well developed than those of the recipient country.

Consultants can have a valuable input during the development of the out-reach training material although ultimately it should be the responsibility of the recipient country. teaching methods may also be required. The consultant can also be of assistance in these areas if he has adequate background and experience in the social and cultural make-up of the recipient country.

As was outlined earlier, the instructor/tutor would be expected to keep pace with technological development in the industry over and beyond the initial T and E program scope. It is the consultant's role to provide the periodic review and assessment of the trainer/tutor program and to provide whatever assistance is required in technical and pedagogical areas.

CONCLUSIONS

Most of the goals of the decade, in areas of capital projects, have now been completed. In many areas of the developing world the decade had a significant impact although the magnitude of the impact varied from country to country and among WHO regions.

The overwhelming challenge of the 1990's is to ensure the continued effective operation of the systems large and small. The most important constraint to the long-lasting benefit of these projects is the availability of trained people to operate and maintain them. Most T and E project organizers agree that they operate on a shoestring budget. This is unlikely to change significantly. So the challenge is to utilize available funds in the most effective and efficient manner. Projects funded by the Canadian International Development Agency (CIDA) in Belize City, Belize, Central America, Tanzania (Dar es Salaam water supply) and the Ethiopia rural water project underlined the inadequacy of traditional T and E approaches. There is sufficient evidence, however, that CIDA supported micro-realization projects have had long-lasting benefits. In Burkina Faso 16 micro-projects, costing $4,000,000, were undertaken. In addition, T and E projects were funded in Mali, Zaire, Cameroon and Haiti. All these projects were designed on out-reach basis with the objective to train completely self-sustaining maintenance crews.

The lessons learned from these T and E projects is that the principal responsibility for training must be taken by the beneficiaries. This means that the community must be involved in all stages of project planning and implementation, in a meaningful way so that a sense of ownership is instilled. Donor countries must regard the beneficiaries as partners in projects and not as recipients of technologies.

HYDRAULIC POWER FOR RURAL ENERGY DEVELOPMENT

ABSTRACT

The scope of this paper is to discuss and promote the utilization of renewable energy sources in remote areas of developing countries, with particular reference to the East African context.

The paper focuses on the potential of micro-hydraulic and micro-hydroelectric energy for rural development as compared to other sources such as the conventional diesel-powered generator sets and solar photovoltaic energy. Some considerations on the connection of rural centres to electrical grids are included too.

The paper briefly points out the importance and end-uses of rural energy; a pre-selection of the alternative energy sources available is made and a description is given of the main features of the three selected energy generation systems which could be considered; a qualitative assessment is made of the advantages and disadvantages of the mentioned source exploitation systems.

A brief case study, in the East African context, is presented and a cost effectiveness evaluation is given.

HYDRAULIC POWER FOR RURAL ENERGY DEVELOPMENT

1. Energy for African rural development.

African countries are generally defined as developing countries: this definition implies that their economies are growing, some at a slower pace, some at a faster one. A growing economy, and this applies even more to developed countries, needs increasing energy inputs: if energy is lacking, insufficient or unreliable, economic growth is respectively stopped, slowered or intermittent. Energy is therefore the "prime mover" of the economy.

A first consideration has to be made: only 5% of Africa's hydropower potential has been tapped and therefore most of the energy consumed is supplied by thermal sources relying on oil imports. The bill of these imports, which is subject to international market price fluctuations and in the exchange power of currencies, subtracts valuable foreign exchange to the respective economies; these resources could otherwise be allocated by the african nations for the development of infrastructure and economic activities, both in the urban and rural areas. From this consideration stems out the necessity for the countries to develop and exploit as much as possible their indigenous energy sources both at large, medium and small-scale in order to reduce their (raising rate of) oil dependence and, therefore, increase their wealth.

A second consideration which has to be made concerns the fact that since large-scale (thermal and hydroelectric) energy production, transmission and distribution is a very costly venture in terms of capital investment and operating costs, only medium-to-big urban and/or industrial centers are privileged users of such energy.

This is a quite understandable consequence of economic planning policies which allocate the scarce and costly energy resource to the most important, strategic and remunerative areas of utilization.

These policies, which have also characterized the developed economies in the past, and the long timespan required for the planning and implementation of energy transmission and distribution power lines, lead to the fact that small rural centres are the last ones to be reached by electrification. As a consequence rural development, (here considered in the broad sense including economic, socio-cultural and quality of life parameters of the rural people) is seriously hampered by lack of energy.

2. Demand for rural energy

The demand for rural energy is however steadily growing in Africa, and is potentially enormous (if cumulated at regional level); unfortunately it is localized in minor demand centers dispersed over vast geographical surfaces.

The rural demand for energy is related to activities that require energy such as productive and commercial ones (agricultural production and processing, small scale industries, businesses), and social and domestic activities. Three forms of energy are used which are electricity, work and heat.

Productive and commercial activities utilize energy for stores, small scale industries and food processing activities (milling, sawing, cold storage, ginning, lighting, ice making, etc.). Social service purposes include schools, hospitals, public administration offices, community facilities such as potable water supply, pumping for irrigation, lighting, etc. Domestic uses are related mainly for lighting, water supply and where applicable, to domestic appliances.

The range of power requirements for each such activities rarely exceeds 100 kW. Rural power consumption is low, being the maximum per capita demand often less than 100 W per capita.

Therefore the demand for rural energy is likely to remain unfulfilled for a long time if only conventional large-scale centralized power generating plants are favoured by policy planners.

As a matter of fact the use of grid extension (related to a large power plants) for rural electrification is generally rare (except for areas in the immediate surroundings of cities and of power plants) due to the following reasons:

- economic cost-benefit and financial evaluation ratios are negative or unfavourable, and therefore transmission and distribution to rural end users is cut out at the financing stage;

- the rural electrification systems operate at low loads which do not generally justify the collection of revenues, and if carried out, tariffs are maintained at such a low level ("willingness" or "ability" to pay) that they do not cover operation and maintenance costs of the system.

- grid electricity is not very reliable energy source in the rural setting because of frequent interruptions at the supply source and in the trasmission and distribution power lines.

Being the electrification also a means to contribute towards the coping of alarming phenomenons such the depopulation of rural areas, the demand of energy for rural centers has to be met, at least in the short-medium term, with decentralized energy generation installations.

As a general rule, decentralized energy generation plants fueled by diesel have been and are still today favoured thanks to the versatility and relatively low capital investment costs.

However, particularily in remote rural areas of developing countries, the use of the conventional diesel-powered engines for the production of electric or mechanic power finds some difficulties, including the high costs in securing regular supplies of fuel, lubricants and spareparts, adequately skilled manpower for the operation and maintenance of the plants and the necessary infrastructure (workshops, warehouses) and equipment (repair tools, machinery and vehicles).

As a result, increasing attention is directed towards the exploitation of alternative and renewable energy sources in order to meet the growing demand for energy, both electrical and mechanic, in the rural areas. These systems are generally more expensive as initial capital outlay, but, if carefully planned and installed, have operation and maintenance expenses which are negligible and generally useful life-time duration which is about four times the conventional motors.

3. <u>Selection of possible renewable energy sources</u>

The renewable electricity and work energy sources which could be considered for application in this context are mainly solar (photovoltaic and termodinamic) energy, micro-hydroelectric and microhydraulic, wind electrogenerators and wind mechanic energy.

Wind driven electro-generators and windmills have been excluded because they are only attractive in areas of sufficient wind and suitable wind regime, situations which are not common also considering the required topographic conditions (absence of mountains, trees and other obstacles which lower the performance). The electric or mechanic energy they supply is therefore considered unreliable and not sufficient to cover rural energy demand except for particular uses such as the pumping of water, which can be stored for windless periods.

Solar thermodinamic systems, besides having a limited range of application (mainly waterpumping) are complicated and low efficiency systems which have performed poorly in trials.

Therefore in the context of this paper only the solar photovoltaic and micro-hydroelectric (and hydraulic) are considered for comparison with the conventional diesel powered electrogenerator.

4. Main features of the systems

In this chapter the main features and ancillary works of the microhydroelectric, solar photovoltaic and diesel powered electrogenerators are briefly described.

A qualitative assessment with advantages and disadvantages of the three systems is given.

4.1. Micro-hydroelectric system

A micro-hydroelectric system converts the kinetic energy of flowing water into alternating current (ac) electrical energy. A micro-hydroelectric system is composed of the following main components:

- a small weir which diverts the water from the river or stream into a conveyance canal which leads to a regulation intake, with sedimentation pond and filtering device;

- a plastic or steel penstock;

- a powerhouse which includes the turbine-generator group, the water offtake and discharge canal;

- the transmission electric powerline and distribution lines.

- the automatic power regulator. This can be of two types: mechanic or electronic.

The mechanic power regulator automatically regulates directly the input flow of water into the turbine and therefore is located in the powerhouse.

The electronic device regulates the water inflow in the turbine through a feedback line which is connected to a hydraulic flow regulator. Another type of electronic regulator, called "constant load type", does not regulate the input waterflow in the turbine but converts the excess electrical energy output into thermal energy. The electronic power regulator can be located at the powerhouse or at the end of the transmission line.

4.2. Solar photovoltaic

The solar photovoltaic system converts the solar radiation energy into direct current (dc) electrical energy. A solar photovoltaic system is composed of the following main components:

- an array which is composed of interconnected photovoltaic modules each one of which includes a number of solar cells.

- a powerhouse which includes an electronic power regulator which controls the conveyance of energy into the battery system; the battery system which accumulates the electrical energy; and the dc/ac inverter, wich converts the direct current into alternating current.

- the transmission electric powerline and distribution lines.

4.3. Diesel-powered electrogenerator set.

The diesel powered electrogenerator set converts the energy produced by the combustion of diesel fuel into alternating current (ac) electrical energy.

The components of this system are:

- a power house which includes a low-speed diesel engine coupled to an electrical generator set (power regulation is automatic in function of the demand and operates on the input flow of fuel by means of the butterfly valve in the carburator);

- a storage tank for diesel fuel, filters and related connection tubes;

- the transmission electric powerline and distribution lines.

4.4. Qualitative assessment

The following Table 1. evidences the advantages and disadvantages of the microhydroelectric, solar photovoltaic and diesel powered electrogenerator systems.

Table 1. Qualitative assessment

PARAMETERS	Hydro	Solar	Diesel
Energy source			
Renewable and at no cost	X	X	
Conventional (imported)			X
Efficiency			
High (40-70%)	X		
Medium (15-30%)			X
Low (8-12%)		X	
Lifetime			
High (>15 years)	X	X	
Medium-Low (<15 years)			X
Frequency of maintenance Interventions (1)			
High			X
Low	X	X	
Technical skills (2)			
High		X	
Medium	X		X
Initial Investment Cost			
High		X	
Medium	X		
Low			X
Operation and Maintenance costs (3)			
High			X
Low	X	X	
Production of Polluting effluents			
Yes			X
No	X	X	
Physical constraints			
Locational	X		
Transport			X
Sunshine		X	

(1) Maintenance includes checking, cleaning, filling, lubricating etc. High = once a week; Medium = once a month.
(2) High = qualified technicians; Medium = trained operators.
(3) O&M include costs of wearing parts, consumables (fuel and lubricants), manpower.

5. <u>A case study in East Africa</u>

5.1. Project description

The case study refers to a project implemented in 1989 in Lukanga Location, North Kivu Region, Zaire. The project area is at about 2000 metres a.s.l. and night temperatures drop to 10 degrees Celsius.

The project objectives aimed at providing the electrification of an area for the following purposes:

on the 24 hours:

- maternity (50 beds) and sanitary dispensary (electricity and heat);
- Catholic mission facilities (domestic appliances, lighting);

daytime:

- small mechanic workshop;
- sawmill;
- cereals milling unit composed of a hammermill driven by a 4 kW three phase motor, output 300 kg per hour, operating ten hours a day;

nightime:

- villages facilities lighting (social and recreational centers);
- road and marketplace lighting.

Approximately 4000 people of 16 villages benefit of the nightime lighting.

Peak load amounts to 10 kW.

5.2. Basic technical assumptions

Owing to the relatively high peak load, the nearly continuous load demand on the 24 hours, and the necessity to feed energy for the operation of large motors (about 4 kW), the alternative of installing a solar photovoltaic power generating system was rejected.

This was due to the fact that in order to have a sufficient supply of energy both in the needed quantity and over the 24 hours the system would have required, under the prevailing local solar radiation, a very important solar array with a sophisticated control system (including a complementary diesel backup power source) and a set of batteries to accumulate energy for nightime use.

The cost of such solar powered system amounted to several hundred thousand US$ and therefore it was incompatible with the available funds.

Therefore a comparison was performed between the micro-hydroelectric and the diesel generation systems, which were both applicable in the area due to the availability of suitable water flow (for the micro-hydro) and fuel oil (for the diesel engine).

Below are reported the basic technical features of the two alternatives. The distribution lines have not been included since they are equivalent for the two systems.

5.2.1 Micro-hydroelectric system

The design data for this scheme are:

- gross head : 45 m;
- net head : 43 m;
- maximum flow : 50 l/s;
- max generation capacity : 12 kW at 380 V, three phase 50 Hz, as a continuous output.

The civil works (materials+labour) are:

- intake and settling tank: in brickwork, 2.5x1x1 m
- head race: length 1800 m, depth 0.5 m;
- penstock: underground PVC pipe, phi 225 mm, length 150 m;
- powerhouse: in brickwork, 3x3x2.5 m, corrugated sheet roof;
- tailrace: length 120 m;
- main transmission line: underground PVC sheated cable, length 750 m.

The hydropower generating set consists of:

- a Pelton turbine with 6 nozzles;
- a 3-phase 4-pole syncronous brushless generator;
- a control board and a "constant load" type electronic regulator system with 6 heat elements: 2 for water heating and 4 for air heating;

The IREM-ECOWATT system was selected due to its capacity to automatically generate both electric and thermal energies, the latter type being important for the maternity and nursery facilities.

5.2.2. The diesel powered system

The design data for this scheme are:

- max generation capacity : 12 kW at 380 V, three phase 50 Hz;

The civil works (materials+labour) are:

- Housing shed for generator set: in brickwork, 3 x 4 x 1 m, corrugated iron sheet roof;
- 4000 liters tank: in metal and brickwork;
- main transmission line: underground PVC sheated cable, length 50 m.

The diesel generating set is:

- Deutz diesel engine (F21 912), 15 KW, 1500 rpm;
- Leroy generator 15 kVA;
- a control board;
- load factor 0.25 (26,250 kWh/year)
- specific consumption 0.4 l/kWh

In the diesel option two generating sets, one in standby, are to be provided to guarantee reliability in power generation.

5.3. Basic financial assumptions

Both power generating sets are available in the country through importation. Local labour cost has been valued 2 US$/day. Investments are assumed to be completed in one year (1989).

In Table 2. are reported the investment costs in US$ (1989) for the two options, and, in Table 3. the annual operation and maintenance costs.

Table 2. Investment costs in US$ (1989)

	Hydropower	Diesel
<u>Civil Works (labour+materials)</u>		
- intake/settling	600	
- head race	1200	
- penstock	1900	
- powerhouse	1000	1100
- fuel tank		1900
- tailrace	100	
- transmission line and earthing	6400	900
Subtotal (1)	11200	3900
<u>Equipment</u>		
- Microhydroelectric	32000	
- 2 Diesel generator sets		14800
Subtotal (2)	32000	14800
Grand Total (1)+(2)	43200	18700

Table 3. Annual Operation and Maintenance costs (incl. spares)

	Hydropower	Diesel
<u>Microhydroelectric</u>:		
Maintenance Civil works (0.5%)	60	
O&M costs (2% of equipment)	640	
<u>Diesel generator sets</u>:		
Maintenance Civil Works (0.2%)		10
O&M costs (5% of equipment excl. fuel)		740
Fuel (10500l/year*0.6 US$/l)		6300
Total annual O&M costs	700	7050

5.4. Comparative cost analysis and conclusions

The purpose of the comparative cost analysis is to assess the cost-effectiveness of the two generation systems, namely the micro-hydroelectric and the diesel powered.

Even though comparative studies on alternative energy sources must be carried out on a case-to-case basis, it is believed that the presented case can fairly represent a common situation to cope with in similar environments.

The analysis has been carried out utilising the "net present value" of a stream of costs using varying discounting rates. The analysis has been carried out in constant prices.

The results of the calculations are presented in Table 4. and in the Graph n. 5.

From the analysis it appears that the micro-hydroelectric, although costlier in terms of initial investment, results to be substantially more convenient than the diesel powered system as to operation, the main reason relying in the high costs of fuel oil, and maintenance.

Already after five years of operation the micro-hydroelectric system is more convenient at a discount rate of 9.3% and increases to 22.5% after ten years and at 25.6% after 20 years.

Therefore the micro-hydroelectric system was selected, also because it offered the additional advantage of making energy available all around the clock and enabled to utilize nearly 100% of the energy produced, both in electricity and thermal forms.

The micro-hydroelectric scheme of Lukanga was implemented and its operating results are very successful; as a matter of fact the construction costs have been much lower than what was planned since the population provided labour at no cost, having been made aware of the benefits that would accrue to them as a community.

Table 4. Net Present Values of 12 kWh diesel and microhydroelectric generation plants (in US$)

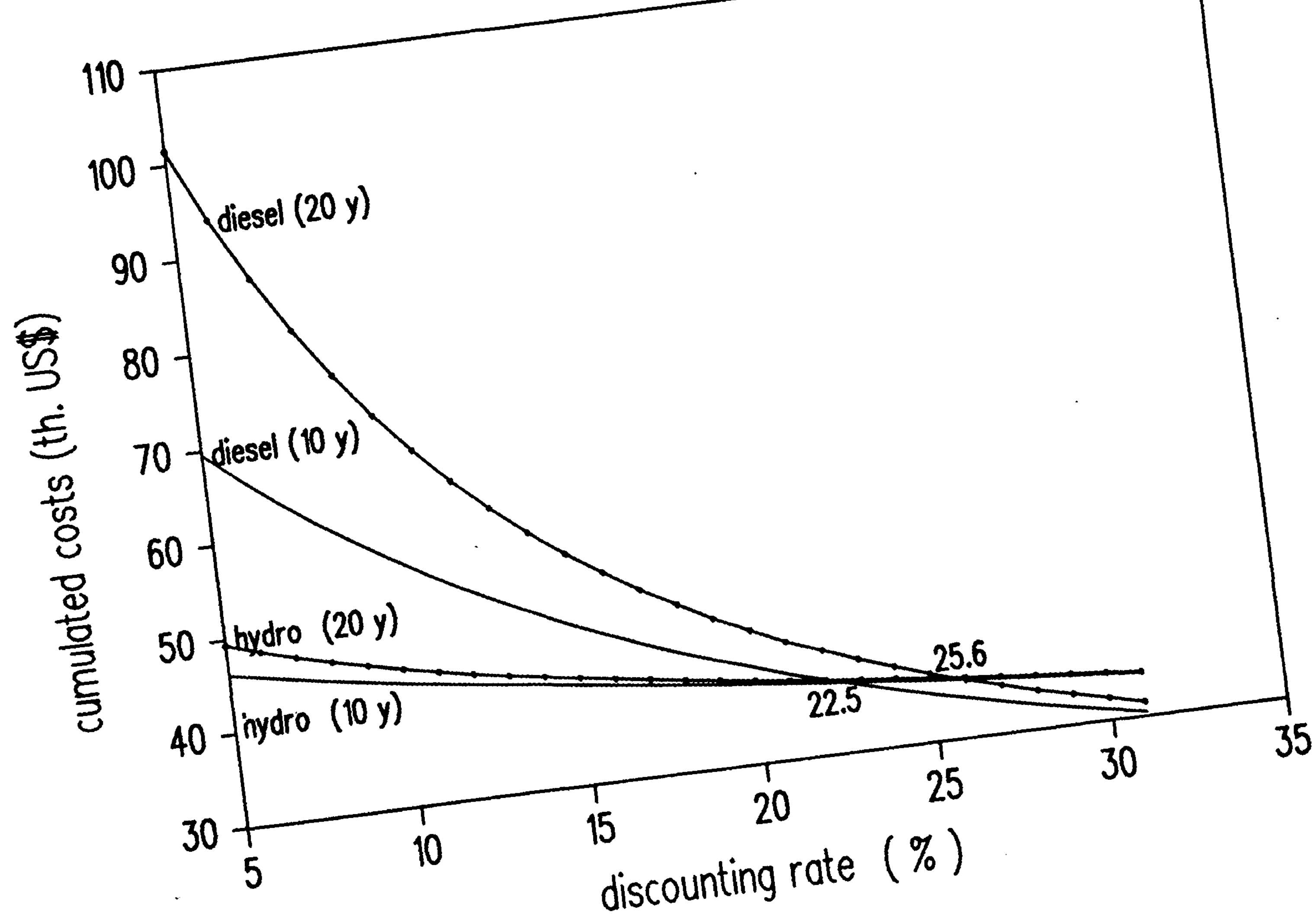
Years >	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
DIESEL POWERED																					
Investment																					
civil works	3900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
equipment	14800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total investment	18700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operation & Maintenance																					
Maintenance C.Works (1)	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Equipm. O&M costs (2)	0	740	740	740	740	740	740	740	740	740	740	740	740	740	740	740	740	740	740	740	740
Fuel (3)	0	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300
Total O&M costs	0	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050
Total costs	18700	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050	7050
MICRO-HYDROELECTRIC																					
Investment																					
civil works	11200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
equipment	32000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total investment	43200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operation & Maintenance																					
Maintenance C.Works (4)	0	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Equipm. O&M costs (5)	0	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640
Total O&M costs	0	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700
Total costs	43200	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700

		20 years			10 years			5 years	
		Diesel	Micro-hydro		Diesel	Micro-hydro		Diesel	Micro-hydro
NPVcosts	10%	71564	44690	5%	69655	46291	5%	46879	44029
NPVcosts	15%	54633	41375	10%	56381	43183	10%	41295	41685
NPVcosts	20%	44192	38841	15%	47028	40620	15%	36811	39606
NPVcosts	25%	37260	36774	20%	40214	38446	20%	33153	37745
NPVcosts	30%	32366	35016	25%	35098	36559	25%	30128	36066

Notes:

1)Set at 0,2% of investment per year
2)Set at 5% of investment per year
3)Assuming the annual production of 26250 kWh, cost of fuel set at 0,6 US$/liter
4)Set at 0,5% of investment per year
5)Set at 2% of investment per year

Graph 5 - Net Present Value Analysis



This paper comes after page No. 106

WATER QUALITY CONTROL IN KENYA

JOHN M. OMWENGA

WATER QUALITY AND POLLUTION CONTROL LABORATORY
MINISTRY OF WATER DEVELOPMENT,
P.O. BOX 30521, NAIROBI, KENYA

ABSTRACT

The distribution of water resources in Kenya varies greatly. From the standpoint of water quality there are also many variations. There are waters with extremely low concentrations of a few ions and others which have high concentrations of various ions. Urbanisation, industrialisation and modern agriculture have affected the natural quality of water. These have rendered water bodies to become unsuitable for many beneficial uses for which they were utilised earlier. The demand for good quality water continues to rise thus making it imperative to conserve and protect the national water resources for both present and future uses. This paper looks at the present water quality control practices in Kenya, as well as the envisaged trends in this decade. The current water quality monitoring programmes are discussed. The existing laboratory facilities are looked into and the problems affecting effective water quality control high lighted. A brief description of surface and groundwater quality is presented with special emphasis on the water quality problems of certain areas.

KEYWORDS

Water Analysis, parameters, pollution, water quality, standards,

INTRODUCTION

The Republic of Kenya lies between latitudes 4° 21' N and 4' 28'S and between longitudes 34° and 42°E.

The country has a great diversity of land forms ranging from snow-covered mountain peaks through a flight of plateaux to the coastal plain.

The climate of Kenya is largely influenced by its equatorial position and the wind systems which are controlled by the pressure systems of the Western Indian Ocean and adjoining continents.

The population of Kenya is currently estimated at slightly over 20 million, and the economy of the country has been growing steadily since independence in 1963.

WATER RESOURCES

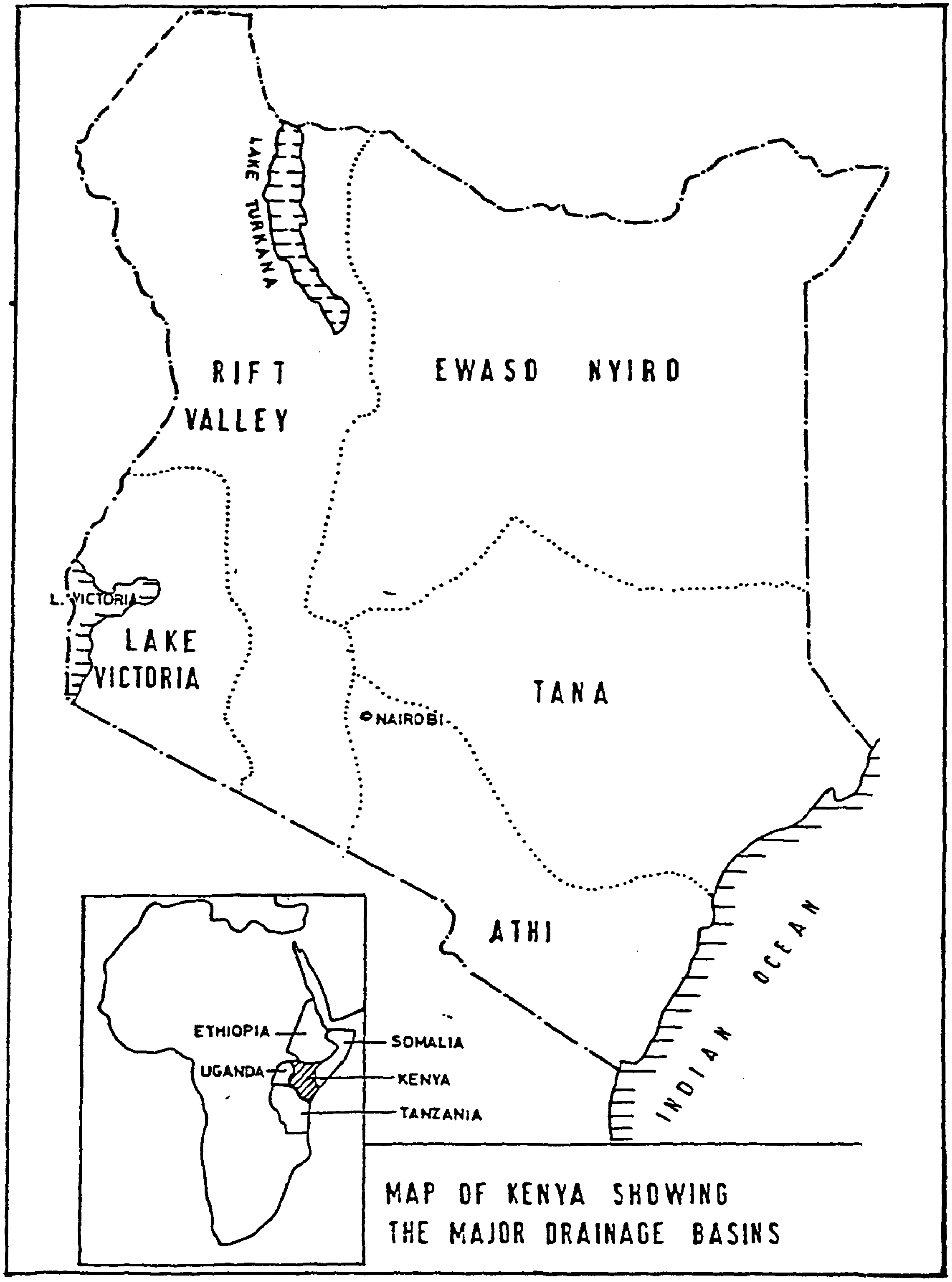
Kenya covers a total of 583,370 km^2 of which only 11,230 km^2 are water. The country's water resources are divided into five drainage basins. These are:-

1. Lake Victoria Basin

2. Rift valley Basin
3. Tana River Basin
4. Athi River Basin
5. Ewaso Ngiro Basin

The details of each basin are as shown in figure 1 and Table 1.

FIG. 1. MAJOR DRAINAGE BASINS



MAP OF KENYA SHOWING THE MAJOR DRAINAGE BASINS

Table 1. Major Drainage Basins in Kenya

No.	Drainage Basin	Area Km2	Mean Annual Rainfall, mm	Mean Annual Run off Million m3
1	L. Victoria	49,000	1245	7,292
2	Rift valley	127,000	535	810
3	Athi River	70,000	585	1,295
4	Tana River	132,000	535	4,700
5	Ewaso Nyiro	205,000	255	739
	KENYA	583,000	510	14,836

Rivers

The country has numerous permanent and seasonal rivers. Only eight are large and permanent viz:- Tana, Athi, Nzoia, Yala, Nyando, Miriu, Kerio, Turkwell. Table 2 gives some characteristics of these rivers. The water in these rivers is non-saline.

Table 2. Characteristics of major Rivers in Kenya

River	Length(km)	Station	Width (m)	Depth(m)	Flow(m^3/sec)
Tana	725	Kiganjo	12.00	0.36	0.35
		Tharaka	43.28	3.68	63.59
		Garsen	63.00	3.45	61.99
Athi	591	Thika	26.00	0.10	1.50
		New Kibwezi	5.70	0.48	0.38
		Lugard Falls	102.58	0.30	4.88
Kerio	320	Tambach	2.30	0.34	13.00
		Tot	0.70	0.10	0.01
		New Lokori	14.10	0.18	0.30
Turkwel	305	Turkwel Gorge	20.50	0.29	1.84
Nzoia	240	Webuye	28.69	1.77	10.14
		Moiben	4.70	0.31	0.44
		Nambale Market	26.00	1.86	23.30
Miriu	150	Matunda	1.60	0.11	0.01
		Sondu	35.00	0.72	4.73
		L. Victoria	17.00	0.83	5.74
Nyando	125	Ahero	16.00	0.50	1.88
		Muhoroni	10.48	0.40	1.14
		Lodiani	3.50	0.38	0.08

Lakes

A number of lakes exist in Kenya. The most important ones are given in Table 3. Nearly all the major lakes are found in the Rift Valley. The Water quality of the lakes varies from fresh (L. Victoria) through brackish (L. Turkana) to saline (L. Magadi).

Table:3 Characteristics of Inland Lakes in Kenya

Lake	Area (KM^2)	Depth (m)
1. FRESH WATER:		
Naivasha	115	6.5
Victoria (Kenya side)	3785	43.0
Baringo	130	10.0
11. BRACKISH:		
Turkana	6405	120.0
111. SALINE :		
Elementaita	18	1.1
Nakuru	5-30	Seasonal
Magadi	100	Not Determined
Bogoria	34	10

Groundwater

No sufficient data exists at the moment concerning the extent of the aquifers, their structure and the volume of groundwater. However between 6000-7000 boreholes have been drilled in Kenya, as many of the dry areas depend on ground water. The annual withdrawals from the aquifers have been estimated at about 17 million m^3. The quality of groundwater varies greatly depending on the local geology.

WATER QUALITY MONITORING NETWORK

The Ministry of Water Development operates a National Water Quality Monitoring Network which covers all the major rivers, lakes and aquifers. The monitoring programme is important in that it enables the ministry to generate and store useful water quality data. This data enables decisions to be made on the Pol[illegible] state of the rivers, general water development planning, assess impact of dev[illegible] ment activities, and on the suitability of the waters for drinking or any ot[illegible] use in their raw state.

Criteria used in the establishment of Network sampling stations

(1) Most of the stations are chosen such that they correspond with the [illegible] logical monitoring stations, thus enabling calculation of mass loadings to be made. These enable theestablishment of pollutant loads and asse[illegible]ent of the impact of water resources development activities to be estimated.

(2) Acquisition of reference baseline data at the upper reaches of river systems, both for national and global impact assessment purposes. Represantativeness is also an important factor especially when considering lake systems.

(3) Assisting in the monitoring of the efficiency of effluent treatment systems in relation to the waste assimilation capacity of the receiving water body, thereby relating system performance to the design characteristics of the treatment system, as well as keeping under observation the possible pathways of specified pollutants.

(4) The immediate use or users of a particular water resource; its importance as an economic water resource to the community.

(5) Accessibility and safety at the time of sampling to ensure continuity in sampling and data generation.

The frequency of sampling at the regular water quality monitoring stations is normally 4 times a year (Jan-Feb, April-May, June-July and Oct-Nov). Apart from these regular stations, samples are also submitted from other water bodies for routine water quality analysis and assessment of suitability for use. The following sampling schedule is adopted for water supplies:

Large supplies greater than 10,000 persons) once daily.

Medium large (5,000 - 10,000 persons) once weekly

Medium minor (1,000 - 5,000 persons) monthly

Minor W/S (50 -100 persons) every six months

The water quality information obtained from the monitoring programme is normally used in:-

- Planning and design of water supplies
- Deciding on the suitable siting of particular industries
- Establishment of stream and effluent discharge standards
- Protection of fisheries and other aquatic ecosystems
- Advising on suitability for various uses
- General planning and water resources management
- Stimulating water research programmes
- Identifying those industries causing water pollution

The Water quality monitoring programme is expensive to operate as it requires Field transport, sampling equipment, sample storage failities, well equiped laboratories and well trained, qualified and dedicated personnel inorder to succed.

Most developmental activities such as farming, industrialisation and urbanization have beenidentifiedashaving seriously contributed to the deterioration of water quality in this country. The following sources have been identified as major factors affecting water quality:-

(1) Liquid and solid wastes from industries

(2) Fertiliser nutrients as leacheates and run off from agricultural lands.

(3) Pesticides and pesticide residues as leacheates and run off from agricultural farms

(4) Domestic liquid and solid wastes from urban centres

(5) Accidental chemical spills

(6) Leacheates from natural causes.

WATER QUALITY STANDARDS

Water quality criteria for various water uses have been adopted. Besides criteria for irrigation waters livestock watering and other common uses, the most utilised water quality criteria are those for raw water sources for public water supplies and treated water. Effluent discharge standards are also applied on all effluent discharges into streams and other water bodies.

Dringking Water Quality Criteria.

In determing the suitability of water for drinking purposes, especially for large community water supplies, reference is made to the World Health Organisation's Guidelines for Drinking Water Quality. A draft Kenya Standard for Drinking water is also now available. Table 4 and 5 give the WHO guideline values for aesthic water quality and bacteriological quality, respectively.

Table 4. WHO Guidelines for Aesthetic Quality

Parameter	Concentration mg/l
Aluminium	0.2
Chloride	250
Copper	1.0
Hardness as $CaCo_3$	500
Iron	0.3
Manganese	0.1
Sodium	200
Sulphate	400
Fluoride	1.5
TDS	1000
Zinc	5
Colour	15TCU
Taste and Odour	Not offensive for most consumers
Turbidity	5 NTU
pH	6.5 - 8.5

Table 5 WHO Guidelines for Bacteriological Quality

Piped Supplies		Number per 100 ml
(i)	Treated water entering distribution system	Feacal coliforms 0 Coliform organisms 0
(ii)	Untreated water entering distribution system	Feacal coliforms 0 Coliform organisms 3 in anyone 0 in 2 consecutive samples. 0 in 98% of yearly samples.
(iii)	Water in distribution system	Feacal coliforms 0 3 coliform organisms in anyone or 0 in 2 consecutive samples. 0 in 95% of yearly samples.
Unpiped supplies		Feacal coliforms 0 coliform organisms 10.
Bottled drinking water		Feacal coliforms 0, coliforms organisms 0
Emergecy supplies of Drinking Water		Feacal coliforms 0, Coliform organisms 0

Effluent Discharge Standards.

Effluent discharge standards have been formulated and are enforced by the Pollution Control Unit of the Ministry of Water Development. The Standards are derived from the generalised effluent discharge guidelines (Table 6) and are specific for each industry. The standards are based on the nature and volume of effluent discharged, the dilution capacity of the receiving water body and the subsequent use of the water downstream of the discharge point. Table 6 gives the generalised effluent discharge guidelines. However, separate discharge limits exist for, heavy metals, pesticides and other toxic materials.

Table 6 Generalized Effluent Discharge Guidelines

Assume a dilution of 1:10 in receiving stream /body of Water

Parameter	Maximum permitted in effluent discharged
BOD_5 (5 days at 20°C)	20 mg/l
Suspended Solids	30 mg/l
Cyanide (as HCN)	0.1 mg/l
Sulphide (as $S^=$)	0.1 mg/l
Oil and Grease	Nil
Phenols	0.5 mg/l
Total toxic metals (alone or in combination)	0.5 mg/l
pH	6.5 - 9.0
Temperature	± 3°C of recipient

THE NATIONAL WATER POLICY

The national water policy broadly defines those water resources to be protected (surface, ground, inland and coastal waters) and allocates responsibilities for protection of the water resources to the Ministry of Water Development and other authorised water undertakers such as local authorities. The policy also determines the priorities to be given to the water use among the competing users such as domestic, industrial, and agricultural, and strikes a balance between existing private rights and governmental intervention in the Public interest.

These policy principles derive from the Water Act Cap. 372 of the laws of Kenya which also ensures that the water policy is properly interpreted and implemented.

POLLUTION CONTROL ACTIVITIES

There is an established pollution Control unit in the Ministry of Water Development. This unit works very closely with the Water Laboratory to ensure continuous monitoring and protection of the water resources. The unit ensures that samples are regularly taken from the established national water quality monitoring station for analysis. It also carries out inspections on exisiting industries and proposed sites for new industries and advises on good industrial practices. It also samples industrial effluents and institutes legal action against those industries that contravene the law on water pollution. Over the past years, the activities of this unit have ensured continued protection of our water resources from pollution, by setting up effluent discharge standards for industry and ensuring that industries abide by the same.

LABORATORY FACILITIES

In order to ensure the success of the water quality monitoring programme and to ensure continued monitoring and safety of water supplies a number of water Laboratories have been set up in the country to carry out water analysis. A central water laboratory exists in Nairobi while a number of smaller laboratories have been established in each of the provinces.

The Central Water Laboratory.

Set up in Nairobi, the laboratory acts as a water quality reference centre. It undertakes both routine and specialised water quality and wastes water analysis. It also co-ordinates the analytical work done by other laboratories. It is equipped with a wide range of modern instruments and is capable of carrying out more advanced water analysis such as the detection of toxic pollutants like pesticided residues, trace elements and heavy metals. It advises on suitability of water for use and provides useful information to the hydrology, geology, drilling and Pollution control units of the Ministry. The scope of analysis carried out in the central laboratory is shown on table 7.

The Provincial Laboratories.

There are five fully operational laboratories at Nyeri, Kisumu, Nakuru Mombasa and Kakamega. Fully equipped laboratories have yet to be established at Garissa and Embu. The laboratories only carry out simple physico-chemical and micro-biological analysis. The scope of analysis of these laboratories is mainly to cope with routine water and waste water analysis. These laboratories handle water samples from their immediate surrounding areas and only thoses samples that require more advanced analysis such as heavy metals and pesticide residues are sent to the central laboratory in Nairobi. The laboratories also provide advice on suitability of water for use.

Other Laboratories.

In areas where alot of industrial or agricultural activities are going on smaller (district laboratories) laboratories have been set up to facilitate the determination of some basic water quality parameters. Field testing and sampling is also carried out. All major wate supplies have equipped laboratories at the treatment works where such tests as microbiological analysis, residue chlorine pH, colour and turbidity can be carried out to ensure that the water supplied is safe for drinking. In some cases these laboratories have been equipped to carry out full chemical analysis.

Table 7 = Parameters analysed for in the Central Water Laboratory

PARAMETERS	UNIT
pH	pH Scale
Colour	mg pt/l
Turbidity	N.T.U.
Permanganate No. (20min. boiling)	mgO_2/l
Conductivity (25°C)	uS/CM
Iron	mgFe/l
Manganese	MgMn/l
Calcium	mgCa/l
Magnesium	mgMg/l
Sodium	mg/Na/l
Potassium	mgK/l
Aluminium	mgAl/l
Total Hardness	$mgCaCO_3/l$
Total Alkalinity	$mgCaCO_3/l$
Chloride	mgCl/l
Flouride	mgF/l
Nitrate	mgN/l
Nitrite	mgN/I
Ammonia	mgN/I
Total Nitrogen	mgN/I
Sulphate	$mgSO_4/l$
Orthophosphate	mgP/I
Total Suspended Solids	mg/l
Free Carbon Dioxide	mg/l
Dissolved Oxygen	mg/l
TDS	mg/l
Heavy metals(Zn, Cd, Pb, Cu)	mg/l
Pesticide Residues	mg/l
Phenols	mg/l
Sulphides	mg S^-/l
MBAS	mg/l
Bacteriological Analysis	-

Contraints

Most laboratories lack modern instrumentation. This limits the scope of analysis. Where instruments have been supplied; sometimes there is no back up service and equipment may lie unused for lack of simple spare parts. Unscrupulous businessmen are also a major problem, as sometimes unserviceable equipment are marketed. Sometimes chemicals and glassware of the right quality are not readily available. Equipment especially for field use is often too expensive.

CURRENT WATER QUALITY TRENDS

Surface waters - Rivers and Streams

Water quality data generated over ten years from many of our rivers and streams indicates that the waters are fresh with conductivities rarely exceeding 1000 us/cm and moderate pH values (6.0 - 8.5). The waters are soft and have low concentrations of metal ions. However few rivers have fluoride content levels in excess of 1.5 mgF/l and iron and manganese levels in excess of 0.1mg/l. In generally most of the waters also tend to have high levels of colour and turbidity and high bacterial counts. The waters can generally be treated using partial or full conventional water treatment to render them suitable for drinking.

Surface waters - lakes

As mentioned earlier water quality of our inland lakes varies from fresh to saline. (Refer to table 3). Only the fresh water lakes are being utilized as sources of water supplies.

Groundwaters

No general statement can be made on ground water quality as it depends on the geology and hydrogeology of an area as well as on the depth of the well or borehole. However most waters are clear and colourless and free from bacterial contamination.

The following water quality characteristics have been observed:-

Most waters in Nyanza and Western Provinces are mainly fresh and soft and only a few boreholes near L. Victoria have been found to be saline and hard. Waters from Coast Province tend to be saline and hard due to sea water intrusion. About one third of Borehole waters from the Rift Valley, Nairobi and Central Provinces tend to have high levels of fluoride and total hardness; factors which limit their usefulness. On the other hand, about 50% of waters from the Eastern and North-Eastern Provinces tend to be hard and saline with occasional high levels of iron and manganese. Shallow wells in these areas tend to have poor bacterial quality due to poor sanitation practices and poor drainage.

WATER TREATMENT

Most surface waters are used as sources of water supplies. Conventional treatment is used in most of our water supplies. In some cases, only partial treatment is necessary e.g. sedimentation and disinfection. Aluminium sulphate is used as the main coagulant, although several polyelectrolytes have been tried as coagulation aids. Tropical chloride of lime (calcium hypochlorite) and chlorine gas are used for disinfection. Although fluoride is a water quality problem in Kenya groundwaters no defluoridation has been tried beyond laboratory trials.

FUTURE ROLE OF WATER QUALITY CONTROL

In the current decade 1990-1999, it is anticipated that pollution causing activities will be on the increase. Pollution Control and Water Quality Monitoring activities will have to be intensified. Laboratory fac facilities will also have to be expanded by opening up new laboratories as well as equiping and purchasing more modern equipment. The exisitng water quality monitoring stations will have to be reviewed and more new stations opened. More personnel will also be trained in laboratory technology. and water and environmental sciences.

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INSTITUTIONAL APPROACH TO WATER MANAGEMENT IN SEVERAL COUNTRIES

by

C. LEFROU

(HYDROPLAN)

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The organization of water management in the countries of the world is the result of gradual adaptation to the situations created by changing needs considering the social, economic and political context specific to each country.

1

RESPONSIBILITIES

1.1 POTABLE WATER AND SEWAGE SYSTEMS

In France, as is the case in most developed countries, it is the townships that are responsible for potable water distribution and sewage systems. The townships can group together in inter-township councils and contract the management of potable water and sewage systems to private companies. Until a few months ago, when Great Britain completely privatized waterway authorities, France was the country where private management of potable water was the most developed in the world.

A few major companies share this market and are at the head of powerful industrial groups acting in all areas of service to local and regional governments. These companies have acquired knowhow which is unique in the world, as regards both technical matters and administrative and financial management of these services.

Other countries also have recourse to private companies, but to a lesser extent than in Great Britain and France. This is the case in particular for the United States, Spain and Italy.

Elsewhere, potable water and sewage systems are managed by municipal technical boards or specialized government agencies. In Abidjan (Ivory Coast) and Conakry (Guinea), this management is insured by joint public-private companies.

In certain developing countries, these systems are directly managed by the government, in particular in rural areas.

Contracting of public services to private companies is developing throughout the world. This evolution has two major causes:

- the search for greater efficiency,
- the recourse to private funding for public systems in order to lighten the burden on government finances.

The choice between public and private companies is a fundamental political option which is the responsibility of each nation. However, a few essential principles based on experience are commonly accepted:

- Decentralized management allows more involvement by the population and its elected representatives,
- The technical management units must be of sufficient size to reach a satisfactory level of technicity,
- Efficiency requires creating financially independent organizations specialized in water management.

1.2 IRRIGATION

In France, as is many other countries, it is the farmers who build and operate the irrigation systems. This is in particular the case for irrigation by underground water or small surface structures used to locally collect rainwater.

Where medium-sized collective equipment is required for irrigation, it is generally built by groups of farmers. In certain countries, the equipment can be built by private companies. They are generally structures for monocultures associated with agrifood industries.

However, in all countries, where major structures are required, they are built under the responsibility of local or regional governments or by a special agency. For instance, in France, development agencies such as LA SOCIETE DU CANAL DE PROVENCE, LA COMPAGNIE NATIONALE DU BAS RHONE ET DU LANGUEDOC, etc. were created. The main purpose of the structures built by these organizations is irrigation, but they actually have multiple aims. The government contributed a large share to the funding of these structures. The remaining investment costs as well as maintenance and operating costs are borne by the users. The price structure adopted allows the costs to be covered while giving the users the incentive to make optimum use of the water.

Similar organizations exist in many countries, in particular in the United States, Spain, Morocco, India and several African countries.

1.3 NAVIGATION

The development and operation of the waterways are almost always the responsibility of the national government, which passes part of the corresponding costs to the users through taxes. In certain countries, harbor facilities are managed by public port authorities which collect fees from the users for the services rendered.

1.4 HYDROELECTRICITY

Hydroelectric power generation is generally contracted to a national, regional or local utility which is state-owned in certain countries and private in others. In all cases, the power generated is sold either to the users or to another utility which handles power distribution. The legal status of small hydroelectric power stations varies from one country to another.

1.5 INDUSTRIES

Industries, both state-owned and private,

- build their own water supply structures and waste water purification and disposal structures,

- or are connected to the public water mains and sewage systems, in which case they pay the corresponding fees, benefiting, in certain cases, from special rates,

2

WATER REGULATION

In many countries, water use is subjected to the right of ownership or to government authorization.

In France, the right of ownership applies to underground water with the exception of certain intensely used aquifers for which government authorization has been established. On the contrary, the use of and discharge to surface water are subjected to government authorization except for a few rights which have come down from the 18th century. These authorizations are granted and monitored by government agencies and are the subject of prior public inquiries.

In countries where there is a long hydraulic tradition, a government authorization system often coexists with a system of ancestral rights. This is for instance the case of Morocco. Elsewhere, only the government authorization system exists. In certain countries of the first category, where the competition for the use of water resources is very strong, the system of ancestral rights must be called into question. For this reason, Spain recently placed all its surface and underground water under government authority.

It is generally the public authorities who are responsible for water administration. In nations with a federal structure, this responsibility generally lies with the states, not with the federal government, which often gives rise to conflicts between states which cannot be settled by the federal government. For example, the United States had to renounce the implementation of a policy of river quality objectives and has a policy of uniform emission standards. The same problems arise concerning the quantitative and qualitative aspects of water resource management in the Federal Republic of Germany, Belgium, Brazil, Argentina and India.

3

INTEGRATED WATER RESOURCE MANAGEMENT

Where water use is small compared to the available resources, water use conflicts have a local dimension and the institutions established are those best suited to their arbitration. For instance, in France, in the 19th century, the responsibility for water administration was devolved to the Ministry of Transportation for navigable waterways, the Ministry of Public Works for urban areas and the Ministry of Agriculture for rural areas, the Ministry of Industry being made responsible for the administration of deep underground water at the same time as for mining policy. The decentralized agencies of these ministries were made responsible for exercicing these competences.

When it appeared necessary, around 1930, to organize administration on a larger scale, specialized organizations were created, such as the Compagnie Nationale du Rhône or la Société du Canal de Provence.

In the 1950s, the need for a more coherent approach appeared and organizations for coordination between government agencies were set up on a regional scale but had no real power except for studies.

It was not until the beginning of the 1960s that it appeared obvious that the problems of resource development and pollution had taken on a dimension such that it became necessary to adapt a joint, coherent approach for the drainage basins. France then set up an administration system on this scale consisting of three elements:

- A "Basin Committee" including civil servants representing the government, elected representives of the local and regional governments and representives of the various categories of users. This parliament of water is responsible for defining water policy on the scale of the drainage basin and in particular of approving the water development plans and monitoring the coherence of river quality objectives,

- a financially independent "basin financial agency" which makes the studies relative to the knowledge available on the resources and needs and proposes joint development projects and actions directed at the users, in particular the polluters. It contributes to funding the costs of these developments and actions and collects fees from water users based on the amount of water they use and the amount of pollution they discharge. The rate of these fees is voted by the basin committee.

- a "basin delegation mission" which coordinates the government agencies concerned by water administration.

The establishment of organizations responsible for implementing integrated administration at basin or subbasin level is not new nor is it specific to France. At the turn of the century, in a highly industrialized region of Germany, the local governments and users created such organizations for administration of the water of three tributaries of the Rhine: the Ruhr, the Emscher and the Lippe.

Similarly, in the United States, the Tenessee Valley Authority with mainly a development vocation was created around 1930 and the Delaware River Association, to which the riparian states delegated their powers of water administration and management, was created around 1960.

Although France was the first country in which such a system was generalized to the entire country, it was soon followed by Great Britain and the Netherlands and, more recently, by Spain.

It is without a doubt Great Britain which went farthest in delegation of competences to basin organizations, since the British river authorities were responsible for water administration, potable water distribution and sewage systems, navigation, flood prevention and development of the river beds. Potable water distribution and sewage systems were recently privatized.

Integrated river basin management has become a necessity in many countries and is now often necessary for international waterways. But in the latter case, the problems are much more difficult to solve since they involve the sovereignty of each riparian nation.

International commissions are then created, generally with a limited objective: navigation, flood anouncement and prevention, hydroelectric equipment, hydraulic development or pollution prevention. The commissions are generally provided with funding for study, they organize discussion meetings and they can prepare development plans but have no regulatory or financial powers.

When the constraints imposed by coherent management are not too strong and do not result in a financial imbalance between the riparian nations, the studies conducted jointly and discussions can allow them to harmonize their water management policies. But if a structure with a common interest must be built by one country but requires a financial contribution from the other countries which benefit from it or if the regulatory constraints that must be imposed by the governments on the users are very severe, it is necessary to establish international agreements between states which must be ratified by the parliaments.

International commissions for hydraulic development and flood prediction and prevention exist for most of the major international waterways of Europe, South America, Africa and Asia. Concerning pollution, the International Rhine Commission is the most active. The acute water quality problem in this highly industrialized basin led to organizing regular meetings at ministerial level and establishing international conventions concerning salt pollution and toxic pollution.

4

CONCLUSION

Water is vital for life and health. Each and every human being should receive a sufficient quantity and quality of water.

Water is also an important factor in economic development, in particular in the areas of farming, industry and power generation. The growth in needs due to population growth and economic development as regards a constant resource irregularly distributed in space and time increases the conflicts between the users of a given drainage basin or aquifer.

The establishment of institutions adapted to the physical dimension of the problems as well as to the economic, social and political context has become necessary.