The countries of Africa have seen growing pressure on water resources, with increasing demand and costs, for agricultural, domestic and industrial consumption. This has brought about the need to maximize and augment the use of existing or unexploited sources of freshwater. There are many modern and traditional alternative technologies for improving the utility and augmenting the supply of water being employed in various countries, but with limited application elsewhere due to the lack of information transfer among water resources managers and planners.

The "Source Book of Alternative Technologies for Freshwater Augmentation in Africa" was prepared by the Institute of Water and Sanitation Development (IWSD) in collaboration with the Centre Regional pour L'Eau Potable et l'Assainissement a Faible Cout (CREPA), the Network for Water and Sanitation International (NETWAS) and the Training, Research and Network for Development (TREND) as part of the joint United Nations Environment Programme (UNEP) Water Branch and International Environmental Technology Centre (IETC) initiative to provide water resource managers and planners, especially in developing countries and in countries with economies in transition, with information on the range of technologies that have been developed and used in the various countries throughout the world. UNEP wish to thank the Institute of Water Supply and Sanitation and those individuals involved in the preparation of the Source Book. This Source Book was edited by Dr. J. Thornton and page set by N. Aron. The final revision of the Source Book was assisted by V. Santiago, C. Strohmann and E. Khaka from UNEP IETC and Water Branch, respectively. This information was gathered through surveys carried out on a regional basis--in Africa, Western Asia, East and Central Europe, Latin America and the Caribbean, and Small
Island Developing States. The results, including this Source Book, will be compiled into a Global Source Book on Alternative Technologies for Freshwater Augmentation to be used throughout the countries of the world.

It is hoped that the technologies summarized here will be useful in the sustainable development of the countries of Africa and other regions.
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1. BACKGROUND

Freshwater is a finite and limited resource upon which health and development depend. Given its limited availability and importance, efficient and effective use of water resources is necessary for sustainable economic and social development. Such use should be predicated upon protecting and improving the environment to the maximum possible extent (DANIDA, 1991).

Increased international concern about water resources management has recognised two underlying principles; firstly, that water should be managed at the lowest appropriate level, and, secondly, that water should be considered as an economic good (UNDP, 1990; ICWE, 1992).

Notwithstanding the need for national policies on social and developmental priorities, it has been recognised that centralised and sectoral approaches to water resources development and management have often proved insufficient to address local water management problems. Management at appropriate lower levels allows a greater opportunity to ensure sustainable development of resources; increase awareness, involvement and responsibility amongst users; and, recognise local interests and mobilise local resources, while allowing central government agencies to concentrate on essential national functions.

Access to water of adequate quality and quantity is a fundamental human need and recognised as a basic human right. However efficient allocation of water beyond these basic needs can only come from a full recognition of the costs and benefits associated with various alternative uses, taking into account future needs. This does not prevent or argue against the use of targeted government support to assist social and developmental priorities.

Water and water development are irretrievably connected with land use management, and urban and industrial development. The necessity to integrate water management with these sectors in ways which are in the best interests of a nation are most readily achieved by recognising the efficiency of management at the lowest appropriate level, and that water development decisions are best made in acknowledgement of the real value of the
Freshwater resources have been dwindling over the years, both in terms of quality and quantity, while the demand for high quality water has been steadily increasing. Studies carried out on a global basis indicate that only a small percentage of the available water is of good enough quality for human use. As an element of social and industrial development, water use has increased dramatically in importance. So, not only do we have increased water use due to population increases, but also an increased importance of water as a key determinant of development. In the fifty years, to 1990, the world's population doubled, as did the per capita water consumption rate (from about 400 m³/year to about 800 m³/year (Engelman and Le Roy, 1993).

Falkenmark, *et al.* (1990) have proposed a water scarcity index based on an approximate minimum level of water required per capita to maintain an adequate quality of life in a moderately developed country. One hundred litres per person per day is considered to be the minimum for basic household needs to maintain good health in this index. The experience of moderately developed and water efficient countries shows that roughly 5 to 20 times this amount tends to be needed to satisfy the requirements of agriculture, industry and energy production. On the basis of these premises, a country whose renewable freshwater resource availability on an annual per capita basis exceeds 1,700 m³ will suffer only occasional or local water shortages. When freshwater availability falls below 1,000 m³/person/year, countries will be likely to experience a chronic water scarcity in which the lack of water begins to hamper economic development and human health and well being. When renewable water supplies fall below 500 m³/person/year, countries will be likely to experience absolute scarcity. (Engelman and Le Roy, 1993), although there are arguments which suggest that there are many market adjustment mechanisms which would allow societies to cope below this level.

In Africa, 88% of stored water is consumed by agriculture, mainly in irrigation. Domestic water consumption is very small (30 to 40 litres/day), especially when compared to the 700 litres/day consumed in the United States. As Africa increasingly develops, however, it may be anticipated that development will be paralleled by an increasing demand for water, both for food production and for domestic use, as well as for industrial development. The proportion of water used in industry is often seen as an indicator of
economic development.
The situation in African countries with regard to water scarcity is shown in the following
table. Using Falkenmark's definition of water scarcity, six African countries were in a
position of water scarcity or water stress in 1990. This will increase to 16 by 2025. South
Africa will move into the category of water scarcity by 2025 and, depending on the
population projections used, Zimbabwe and Tanzania may also do so by that time. Of 20
African countries that have faced food emergencies in recent years, half are either
stressed by water shortages or are projected to fall into the stress category by 2025
(Engelman and Le Roy).
The cost of exploiting water resources for what ever purpose has been increasing over the
years thereby pushing the unit cost of water beyond the means of the poor. Further,
urbanization in a number of developing countries has resulted in the generation of large
volumes of solid and liquid wastes which have contributed to an increase in the pollution
of the limited available water resources. Also, in the last decade, the global weather
patterns have changed, resulting in heavy floods or severe droughts throughout the
continent. Africa has been plagued especially by periods of severe drought which have
resulted in serious water shortages. Thus, the need for proper management of the scarce
water resources of Africa, as well as elsewhere, has become critical.

**TABLE 1. POPULATION AND ANNUAL RENEWABLE FRESHWATER
AVAILABILITY IN AFRICA**

Traditionally, African communities have applied many methods to augment their water
supplies. While these methods have changed and developed with time, relatively few
attempts to learn about and share experiences between communities, countries and
regions have been made. There are undoubted benefits to be gained from the transfer of
technologies, especially since the relatively recent upsurge in appreciation of the
importance of community inputs to the process of water resource development has
resulted in an increased focus on the approaches that have been used in the past. Some of
the reasons why traditional methods have either not been widely adopted to date and/or
why they have failed in the past have been summarised in a recent review of water
harvesting and soil and water conservation practices by Lee and Visscher (1990):

- Conflict of objectives. Historically, colonial systems in Africa attempted to impose land management programmes, such as promotion of contouring for the purpose of erosion control, in a top-down manner. This resulted in a lack of understanding, and often of acceptance, of the programmes by the local people. Thus, whilst there may have been real concerns within governmental and other agencies about soil conservation, the people often were not aware of these concerns or they had other priorities, such as agricultural production. In many countries, this policy of top-down resource management continued after independence. Centrally-directed programmes, whether implemented by governmental agencies or by nongovernmental organisations (NGOs) and external aid agencies, without the full involvement, and indeed control, of the community have almost invariably failed. Measures that were implemented through these programmes have been disregarded and have fallen into disuse and disrepair. Similar examples exist in domestic water supply.

- Technology. Water augmentation systems introduced from outside the community have often used methods and machinery which the communities are unwilling or unable to maintain for various reasons, including the amount of labour required or the difficulties in maintaining and repairing machinery. Further, not enough attention has been given to indigenous irrigation and water conservation technologies. In fact, it is often difficult to identify and describe these technologies. Indigenous water harvesting systems and associated conservation methods are infinitely varied and often highly location specific. It is essential to take this into account when transferring freshwater augmentation technology from one area to another (Critchley, et al., 1992). For this reason, local people must be allowed to make their own decisions with regard to which technologies are appropriate, given that only techniques fitted or adapted to local social and environmental conditions are likely to succeed (UNSO, 1992).

- Community contribution. The main concern of communities in the drier areas of Africa is harvesting enough water to ensure the production of a crop or enough grazing to sustain the communities. Thus, in order to succeed under these
conditions, water conservation programmes must win the respect and cooperation of these local communities. Increasing pressures on the land are beginning to convince some communities of the need for land rehabilitation and soil conservation. Only through this awareness, and the resultant sense of personal benefit from improved access to water and consequent improvement in productivity and food security, will communities be convinced of the need to adopt new practices. Water conservation strategies introduced by agencies have rarely built on the experience and traditional practices of the people. Similarly, such strategies have rarely used the community organisational structures to prepare or manage the project.

- Monitoring and Reporting. Of the many water augmentation projects carried out in Africa, few, if any, have they been properly monitored so as to be able to develop an assessment of the successes, failures and lessons to be learned. As a result, many of the mistakes made are destined to be repeated in other projects. Given the issues identified above, and the increased need for improved water management in the light of decreased availability, it is clear that communities themselves need to be central to the planning and decision-making process with regard to development projects, including selection and implementation of freshwater augmentation technologies. Further, augmentation of freshwater resources should build on those practices already in use within the communities or neighbouring communities, and should employ those methods and technologies which the communities, themselves, consider to be sustainable. Contrary to popular belief, freshwater augmentation technologies are applicable in all areas of Africa regardless of the amount of rainfall. Application of the most appropriate technologies may assist communities to postpone investment of scarce financial resources in new development projects, rehabilitate degraded lands, improve water quality, and alleviate water shortages.

2. PURPOSE OF THE SOURCE BOOK
The main purpose of this book is to provide information on technologies for the augmentation of fresh water resources. It is expected to benefit especially water resources managers and planners in Africa, and enable them make informed choices, thereby optimizing the use of available freshwater resources and augmenting these resources
using technologies appropriate to Africa. This book is also intended for sectoral training institutions, researchers, private developers and donors. The Source Book is intended to be part of a global source book on alternative technologies for freshwater augmentation, to be compiled by UNEP.

3. ORGANIZATION OF THE SOURCE BOOK
This Source Book is in three major parts. Part A presents an introduction to the Source Book and gives a background to freshwater augmentation and the reasons it is necessary. It outlines the purpose of the Source Book and its use. The methodologies used to obtain the information reported in the Book are outlined, and a summary of the different technologies for freshwater augmentation in Africa are summarised in a spreadsheet. The introduction also includes other relevant observations, conclusions and recommendations.

Part B, Chapters 1 through 3, deals specifically with the alternative technologies. This section describes the technologies in use to maximise water use efficiency and to augment freshwater supplies. The technological profiles provided include a technical description; an assessment of the extent of use; a review of operation and maintenance needs, costs, and suitability; and, appropriate references and sources of information. Technologies are categorised by sector (Agriculture, domestic and Mining/Industry) and by application (water harvesting, water quality upgrading, water conservation and wastewater recycling and reuse). Part C, Chapter 4, presents case studies of selected technologies. These studies are based on field surveys, and highlight especially innovative, cost effective technologies that have been successfully applied.

4. HOW TO USE THE SOURCE BOOK
This Source Book is a quick reference for water resources managers and planners. Because these users work in specific sectors, the manual is structured by sector. To best use this Book, the sector of interest must be identified, and the relevant field of application selected. For the purposes of this Book, there are three primary (economic) sectors: agriculture, mining and industry, and domestic supply. Within each of these sectors are four applications: water harvesting, upgrading of water quality, wastewater
treatment and reuse, and water conservation. A summary spreadsheet is provided for quick reference.

The descriptions of the technologies are not meant to be exhaustive, but, rather, are intended to give an overview of what the technology is all about. Detailed information on each technology can be obtained by referring to the references and sources of information provided at the end of each description.

5. SURVEY METHODOLOGY

For the purpose of developing this Source Book, Africa was divided into 5 regions, notably:

- Southern Africa, comprising Angola, Botswana, Lesotho, Malawi, Mozambique, Madagascar, Namibia, South Africa, Swaziland, Zambia, Zimbabwe
- East Africa, comprising Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, Uganda
- Anglophone West Africa, comprising The Gambia, Ghana, Liberia, Nigeria, Senegal, and portions of Central Africa (i.e., parts of Cameroon, Congo, Equatorial Guinea, Zaire)
- Francophone West Africa, comprising Burkina Faso, Cote de Ivoire, Guinea Conakry, Guinea Bissau, Mali, Niger, Mauritania, Togo and portions of Central Africa (i.e., parts of Cameroon, Congo, Equatorial Guinea, Zaire)
- North Africa, comprising Algeria, Egypt, Libya, Mauritania, Morocco, Tunisia

Four institutions carried out the study in their respective regions: the Centre Regional pour l'Eau Potable et l'Assainissement a Faible Cout (CREPA), based in Ouagadougou, Burkina Faso, was responsible for Francophone West Africa and North Africa; the Network for Water and Sanitation International (NETWAS), based in Nairobi, Kenya, was responsible for East Africa; the Training, Research and Network for Development (TREND) Group, based in Kumasi, Ghana, was responsible for Anglophone West Africa; and, the Institute of Water and Sanitation Development, based in Harare, Zimbabwe, was responsible Southern Africa. These four institutions comprise part of the International Training Network for Water and Waste Management (ITN), a UNDP-World Bank
initiated programme for capacity building in the water supply and sanitation sectors. The institutional members of the ITN operate independently, but meet annually to share experiences from their respective regions.

The Institute of Water and Sanitation Development coordinated the project, prepared the final report, and compiled the literature review. The final report was based upon regional reports prepared by the participating institutions. Each institution recruited consultants from their respective regions to assist with data collection and regional report compilation.

A workshop was convened by the Institute to discuss the results of the literature search and field survey. This workshop was attended by experts from throughout Africa and a representative from UNEP.

6. SUMMARY OF THE SURVEY RESULTS

Table 2 summarizes the technologies described in this Source Book.

TABLE 2: SUMMERY EVALUATION OF ALTERNATIVE TECHNOLOGIES FOR FRESHWATER AUGMENTATION IN AFRICA

AGRICULTURE (WATER HARVESTING)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Extent of use</th>
<th>O &amp; M Level of involvement</th>
<th>Costs Effectiveness</th>
<th>Suitability</th>
<th>Advantage(s)</th>
<th>Disadvantages</th>
<th>Cultural Acceptability</th>
<th>Comments and Recommendations</th>
<th>Environmental Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting Pits ZAY/ZAI</td>
<td>Moderate</td>
<td>Low</td>
<td>Community</td>
<td>Low</td>
<td>High</td>
<td>Semi-arid</td>
<td>Moderate</td>
<td>Low Community</td>
<td>Low High Semi-arid</td>
</tr>
</tbody>
</table>
degraded land
Simple
Higher
yields
Highly
acceptable
Requires more
promotion
Demi- Widely in Low Community & Low High 200 - 800 mm Cheap Takes time, In highest Further Increases
Lunes or
semicircular
hoop
Kenya and
Niger
Extension
workers
rainfall Easy
Improved
vegetation
not suitable
for
mechanisati
on Can
break with
high runoff
population
densities but
low in
pastoralists
research in
yield
Labour inputs
on rainfall
vegetation
cover on
degraded lands
Katumani
pitting Kenya Low Community Moderate Very
high
Grazing lands-
500-800 mm of
rainfall
Improved
grazing and
crops
Labour
intensive
No cultural problems
Needs wider promotion
Rehabilitation effect on river course and water quality
Permeable rock dams Burkina Faso No Data
Community, NGOs, Government
High Very high
Less than 700 mm of rain
Local supply of stones
Valley bottoms
slope <2%
Increased crop production
Erosion control
Improves soils
Controls gulley formation
Cost of transport (stones)
Large quantities of stone required
Acceptable
Requires technical advice
Positive effect on river course and water quality
Contour
stone bunding Burkina Faso, Mali Low Community Low if stones are readily available High Semi arid 700-800 mm of rainfall Stone available Wetter areas to prevent overgrazing Simple Increased inland use Leads to shortage of stones High cost transport of stones Highly acceptable Extension support required Research in eventual silting required Rehabilitation of degraded land and reduction of soil erosion Tied contour ridge Moderate Low Government, NGO, Community Low High Variety of
climatic and soil conditions
Water shortage and severely degraded areas
Low cost
Both mechanical or labour possible
Labour intensive
Low planting density
Acceptable Required effective promotion
Land rehabilitation and reduces soil erosion
"Fanya-juu" terracing
Morocco, Kenya Moderate Community Moderate Very high
>700 mm if rainfall
Deep soils slopes < 5%-50%
Traditional method
Increase in crop yields
Labour costs high
Highly acceptable
Promotion in other areas required
Effective control of erosion
Flood harvesting using bunds
Somalia Low Community No data
Low High
150-300 mm of rainfall
Clay soils
Simple
Improved food
security
Results in occasional water logging and bund breakage
Highly acceptable
Introduces contour surveying and research in optimum spacing of bunds and positioning of spill ways
Poor management of flows can lead to erosion
Earth bunds
"Teras" Sudan Low Community No data
Low High 150–400 mm of rainfall
Farmer managed
Soil and water conservation
Lack of spill ways Acceptable
Develop spillways to
improve efficiency and reduce operations & maintenance
Reduces degradation
External catchments using contour ridging
Niger, Kenya, Egypt, High Community, NGO, Government
Moderate Very high
350-650 mm of rainfall
Reclamation of degraded land
Increased More reliable crop
Labour intensive
Community not fully involved
Not fully assessed
Need demonstration and promotion involving the community
Reduction of soil erosion
Sand abstraction
Zimbabwe, Botswana, Libya,
Algeria
Private sector, Government, Communities
High High
Sandy river beds, usually seasonally dry
Reliable source of water
Ranges from small to large
Capital cost high
sand can shorten life span of equipment
Highly acceptable
Research relating various productivity parameters required
Over abstraction may reduce downstream flows
scale Lagoon front hand dug well
irritation
Ghana Low Community Low
Locally appropriate and effective
Good shallow groundwater
Local materials
Local skills
Income generating
Shallow wells may dry up
Acceptable
Studies needed on saline intrusion
None expected
Sub-surface dams, small dams, sand dams
Kenya, Zimbabwe, Egypt, Libya, Tunisia, Algeria
Low Local agencies High High
Sandy seasonal rivers prone to siltation
Good quality water
Encourage silt deposition and water filtering
Crop production made possible
Mainly limited to drinking water augmentation
Acceptable
Need to
promote the technology more
Reduction of erosion, silt deposition and increased moisture infiltration
Cloud seeding Zimbabwe Very High Government Community Very high Limited rainfall Agriculture a major commercial activity No long term effect on weather Politically attractive Equipment can be put to other use Depends on weather High expertise required A belief that rain would have fallen anyway No cultural problems Better indicators of impact of cloud seeding No expected environmental effects Tidal
irrigation Gambia Low Government
Community Very high
Very successful
Where river is in relatively flat basin with high tide intrusion
Low operation and maintenance
Income generating for community
Unavailability of spare parts
Acceptable
No further development foreseen

AGRICULTURE (WATER QUALITY UPGRADING)

Technology
Extent of use
O & M
Level of involvement Costs Effectiveness Suitability Advantages Disadvantages Cultural
Acceptability
Comments and Recommendations
Environmental
Impact
Utilisation of artificial wetland for wastewater treatment
East and
Southern Africa
Low Community Government Low High Small communities up to 5000 people
Treatment of waste water from towns, mine drainage, livestock, production, paper mills, tanneries, food processing plants, etc
Not dependent on external energy or chemicals
Low operations and maintenance
Effluent can be used for irrigation
Possibility of increased salinity
Acceptable Important to ensure acceptability before promoting the technology
More research in design and operation required
Aesthetically pleasing on the type of plants chosen
Wetland can be a
home for a wide range of birds and plants
Can be used for recreation

AGRICULTURE (WATER CONSERVATION)

Technology
Extent of O & M Level of involvement Costs Effective ness Suitability Advantages Disadvantages Cultural Acceptability Comments and Environment al Impact use ity Recommendations

Conservation tillage
Eastern and Southern Africa
Low
Government, community, NGOs
Low High
Most soils and slopes-strip cropping well drained soils and slopes of 6-15%
Contour farming, slopes of 3-8%
Soil erosion and runoff control
Conserves moisture
Mulch and strip improve soils
Strip and mulch can harbour pests
Special skills may be needed for contour. Cost of chemicals can be high. Require use in combination. No cultural norms against Promotion required. Conserves soil moisture and reduces soil erosion. Chemical use under zero tillage can be harmful to environment. Deficit irrigation in Zimbabwe and South Africa. Low Government Community. Inadequate data. Where water is limited. Conserves water. There will be some harvest. The yield depend on percentage deficit and will always be less than optimal. Further research on how this could be combined with water harvesting required.
Conserves water and enables plants/crops to be grown.
Savanna wetland cultivation in Zimbabwe and Tanzania.

Moderate Community Low High
Shallow seasonally water logged depressions
Small scale approach most suitable
Provides food security, and drinking water in the dry season
Acceptable

There is high potential for expansion in Africa.
The impact on the environment should be further investigated.

Plans for water conservation gardening Household level
Africa wide
Low Community Low High Urban water conservation
External water supply
Simple
Knowledge of plants required Acceptable
Promotion of appropriate plants needed
Promotes use of indigenous plants
Porous clay pots and pipes
Zimbabwe Low Community Government Low High <500 mm of rainfall
Cost pf pipes low
Reduces weed problems
Can be used for several seasons
Initial high labour input Porosity of pots decreases with time
Need to market this strategy
Conserves water

AGRICULTURE (WASTEWATER TREATMENT AND REUSE)
Technology
Extent of use
O & M Level of involvement Costs Effectiveness Suitability Advantages Disadvantages
Cultural Acceptability
Comments and Recommendations
Environmental Impact
Wastewater
reuse
Widely used Moderate Local authority Government Farmers Low to the farmer High Cultivation of fish Irrigation Agriculture Reduces amount and use of other artificial fertilizers Polishing ground for the removal of nutrients Low cost nutrient water to farmers Can use pollution Effluent contains pathogens Significant mechanisation required General social aversion to close association with excreta There is need for further promotion of the technology Reduces further exploitation of fresh water Pollution of
environment
possible
especially if
waste water is
not properly
managed

DOMESTIC WATER SUPPLY (WATER HARVESTING)

Technology
Extent of
use
O & M Level of
involvement Costs Effective
ness Suitability Environmental
Implication Advantages Disadvantages
Cultural
Acceptability
Comments
and
Recommendations
Protected
springs
Extensively
used Low
Community
Government,
NGOs
Low capital
and
recurrent
High Areas with
springs
Prevention of
soil erosion
Low cost
Appropriate
Low
services
level
Highly
acceptable
High potential
and should be
promoted
Rock and
roof catchment systems Extensively used Low Community Government NGO Moderate Moderate Suitable in arid and semiarid areas Minimizes soil erosion Good water quality Ease of operations and maintenance Low level of services Acceptable Should be promoted for adaption Fog harvesting Rarely used Low Government High capital investment Limited Suitable for areas with scarce water resources Low operations and maintenance costs Limited production Acceptable To be used where other technologies and limited Ground water abstraction- Handpump
equipped
wells
Extensively
used Low
Community
Government
NGO
Low in
capital and
recurrent
High
Suitable
where ground
water is
available
within
reasonable
depth
Point sources can
cause
degradation of
environment
Low costs
Good
quality
water
Ease of
community
management
Low level
of services
Moderately
acceptable
Should be
promoted and
community
participation
intensified
Rope
washer
pumps
Moderately
used Low
Community
Government,
NGOs
Low Low Shallow wells
<table>
<thead>
<tr>
<th>Water Source</th>
<th>Cost</th>
<th>Use</th>
<th>Acceptability</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water</td>
<td>Low</td>
<td>Limited</td>
<td>Acceptable</td>
<td>To be adapted whenever feasible</td>
</tr>
<tr>
<td>Artificial Recharge</td>
<td>Low</td>
<td>Government</td>
<td>NGOs High Moderate</td>
<td>Regions lacking alternative water sources Can cause water/aquifer pollution</td>
</tr>
<tr>
<td>Water conservation</td>
<td>High</td>
<td>Moderate</td>
<td>Achieved</td>
<td>Need for abstraction systems to reuse it Acceptable To be used if other methods are not feasible</td>
</tr>
<tr>
<td>Well tank / borehole</td>
<td>High</td>
<td>Low</td>
<td>Acceptable</td>
<td>Should be adapted in areas with very deep water tables</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High capital and low recurrent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High capital costs Acceptable</td>
</tr>
</tbody>
</table>
regions where water is found in great depths

DOMESTIC WATER SUPPLY (WATER QUALITY UPGRADING)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Extent of use</th>
<th>O &amp; M Level of involvement</th>
<th>Costs</th>
<th>Suitability</th>
<th>Environmental Implication</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Cultural Acceptability</th>
<th>Comments and Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denitrification of groundwater</td>
<td>Low</td>
<td>Moderate</td>
<td>Community NGOs</td>
<td>Community</td>
<td>Low in capital and recurrent</td>
<td>Moderate</td>
<td>In regions with high level of nitrate concentration</td>
<td>Low in operations and maintenance</td>
<td>High capital costs Acceptable Should be adapted in</td>
</tr>
</tbody>
</table>
quality
Seeds not available throughout the year
Acceptable
Should be promoted for adaption
Central Africa
In stream water quality upgrading
Ghana Low Community Government NGOs
Low capital and recurrent Moderate
In rural areas with surface water
Low costs No chemical required
Good quality water
Low level services Lifting mechanism required
Acceptable To be adapted whenever possible

DOMESTIC WATER SUPPLY (WATER CONSERVATION)
Technology
Extent of use
<table>
<thead>
<tr>
<th>Technology</th>
<th>Extent of use</th>
<th>O &amp; M Level of involvement</th>
<th>Costs</th>
<th>Effectiveness</th>
<th>Suitability</th>
<th>Environmental Implication</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Cultural Acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOMESTIC WATER SUPPLY (WASTEWATER TREATMENT AND REUSE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Direct reuse of treated municipal wastewater</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>Urban areas</td>
<td>Water is conserved</td>
<td>Saving resources</td>
<td>High costs</td>
</tr>
</tbody>
</table>

**Comments and Recommendations**

Urban water conservation High High

Government Water supply agencies

High High Urban areas

Water is conserved

Saving resources

High costs

Acceptable

Application should be intensified
Can cause health problems
Augmentation of water
High costs
Possible health hazards
Low
To be considered for used in the absence of alternative sources of water
Indirect reuse
Regeneration of water Zimbabwe Moderate Government Farmers
High capital and moderate recurrent
Moderate
In regions with limited water resources
Augmentation of volume of water achieved
High costs
Saline water Acceptable
To be used in areas of scarce water resources

MINING AND INDUSTRY (WATER QUALITY UPGRADEING)

Technology
Extent of use
O & M
Level of involvement
Costs Effectiveness
Suitability
Advantages Disadvantages
Cultural Acceptability
Comments and Recommendations
Environmental Impact
Electrodialysis
Mining operation in South Africa
Requires skilled labour, close monitoring
Established mining or industrial concerns
High investment and running costs
80% removal of salts
Industrial and mining
Effective method of removal of salts from brackish water
Reduces
corrosion
Water is reused
Not suitable for
small scale
application
High capital and
operational costs
Highly skilled
manpower
Further treatment
of product
required to make it
portable
No cultural
concern
Analysis
was based
on trial test
report
Proper disposal
of liquid and
gaseous by
products
required

MINING AND INDUSTRY (WASTEWATER TREATMENT AND REUSE)

Technology
Extent of
use
O & M Level of
involvement Costs Effectiveness
Suitability Advantages Disadvantages
Cultural Acceptability
Comments and
Recommendations
Environmental Impact
Industrial
water reuse
Eastern and
Southern
Africa
Industry specific
Skilled manpower
Enforcement of regulations
Industry specific
Significant reduction in water demand
Urban water conservation
Reduce water demand
Investment in technology
No cultural barriers
Requires guidelines for other countries and industries
Minimizes pollution
Water conservation
Recycled water used for blending freshwater
Brewery and bottling industry-Achimota, Ghana
Regular maintenance of mechanical
system
Skilled manpower
High initial capital costs
Reasonably low operating costs
Significant reduction in raw water demand
Industry that demands a lot of boiler water
Saving on water demands and industry
Can be modified to include other sources of water such as groundwater
Only applicable where there are heat exchanges
Impure water could result in scaling of boilers
No cultural barriers
No adverse environmental impact
Water recycling in Gold Mines
Underground gold mines
Extensive application in Ghana
Pumps operate 10 hours a day
Regular maintenance of pumps and reservoir required
Trained personnel needed to manager pumping system
Regular maintenance of pumps and reservoir
High capital and mining costs
Ensure adequate primary treatment of waste water from mining operations
Ensure year round supply of water for mining operation
Applicable in subsurface mining systems
Limits pollution load on surface
augmentation
Required
fuel/energy
for pumping
Further
treatment of
reservoir
water might
be required
to meet
effluent
standards
No cultural
concerns
Technology
specifically
relevant
to case at
Tankwe
Golden
Mines in
Ghana
Technology
minimizes
direct
pollution of
surface water
Proper
disposal of
waste products
is reservoir is
required to
minimize
environmental
pollution

MINING AND INDUSTRY (WASTEWATER TREATMENT AND REUSE)

Technology
Extent of
use
O & M
Level of
involvement

Costs Effectiveness Suitability Advantages Disadvantages Cultural
Acceptability

Comment

s and

Recomme
n-dations

Environmenta
l Impact

Dry cooling at power station
Available in South Africa
Skilled manpower
Power utilities
Integral part of costs and generating stations
Water consumption for cooling is less than 20% of west cooling draft towers
Suitable for areas prone to water shortage with utilizes thermal power stations for power
Power production not influenced by drought
Station siting not limited by proximity to river
Higher capital
costs
Less efficient than wet cooled systems
Requires higher quality of groundwater that wet cooled system
No cultural problems
Utilisation of seawater for cooling South Africa
Skilled labour
Power facilities
High capital costs
Avoids use of freshwater resources
Coastline situations
Alternative freshwater uses
Limited applicability
No cultural problems Localised marine impact

MINING AND INDUSTRY (WATER HARVESTING)

Technology
Extent of use
O & M Level of involvement Costs Effectiveness
Suitability Advantages Disadvantages
Cultural Acceptability Comments and
7. RECOMMENDATIONS

The workshop of experts on freshwater augmentation technologies from Africa, who finalized this report in Harare, made the following recommendations:

1. UNEP should facilitate the distribution of the Source Book(s) for use by planners, water resource managers, extension workers, researchers and educators worldwide.

2. Institutions (governmental and private, NGOs and donors), both local and international, should strengthen the development and adoption of favourable policies for the use of freshwater augmentation techniques; wherever practicable, they should sponsor local entrepreneurs to further develop some of these techniques.

3. UNEP, in collaboration with other multilateral and bilateral agencies and programmes, should facilitate, through appropriate institutions, the regular updating of the Source Book(s). Users of the Source Book(s) should promote the Source Book(s) by documenting further development of existing technologies and by providing information on new technologies.

4. Local training institutions should support applied research programmes aimed at improving the performance of existing freshwater augmentation techniques and
the development of new ones. The collection of new, and the updating of existing, information should be made an ongoing activity of the participating institutions.

5. Implementing agencies should, insofar as is practicable, build on local experiences and structures, giving due consideration to cultural practices and emphasizing partnerships with beneficiary communities. A community-centred decision-making process, especially one that builds on women's capacities, should be adopted for successful promotion of many of these technologies.

6. Implementing agencies and beneficiary communities should endeavour to better document alternative technologies and their experiences, especially with regard to costs and benefits, in order to ascertain the effectiveness and efficiency of the technologies.

7. The recipients of the book should endeavour to promote its use and to circulate the information.

8. REFERENCES


PART B - TECHNOLOGY PROFILES
Technologies for freshwater augmentation are wide and varied making it impossible for this source book to cover them all. This Source Book attempts to cover those technologies that are African, traditional and unique. Periodic reviews of the included technologies will be necessary. Part B covers these technologies in three sectors: agriculture, domestic water supply, and mining and industry. Each technology is classified according to its application within that sector. Four key areas of application have been used for this classification: water harvesting; water quality upgrading; water conservation; wastewater recycling and reuse. Some technologies may be used in more than one sector and this will be indicated accordingly.

1. AGRICULTURAL TECHNOLOGIES
Technologies classified for agricultural use are primarily for crop and/or livestock production. For some of these, it is not possible to separate those that directly benefit soil conservation, as water and soil conservation in the agricultural sector are often closely related.

1.1 FRESH WATER AUGMENTATION
Water augmentation technologies have traditionally been practised in the dry regions of Africa, but with little transfer of information on these technologies to other areas of the continent. Methods of water harvesting for agricultural production usually have the dual
function of water supply and soil conservation, and it is often difficult to separate these two functions into their components. It is probably true to generalise that, in the past, governments have been more concerned about soil conservation, whereas communities have been more concerned about water conservation.

It has become evident over the last decade that all areas of Africa are prone to periodic water shortages, whether caused by drought, increased demand or mismanagement. Increased population densities also accelerate land degradation and result in inappropriate settlements in dry regions, thereby further extending the population at risk from low rainfall events. Water shortages, whatever the cause, have a serious effect on livestock survival in the agricultural sector, reducing food production and exacerbating malnutrition, starvation and poverty. A major objective of governments in Africa has been to increase food security and alleviate poverty - difficult objectives to achieve but ones which depend to a great extent upon the more efficient and effective use of water in the agricultural sector.

Experience has shown that the technologies exist in Africa to harvest crops in low rainfall areas, to rehabilitate degraded land, and to protect and increase land productivity through effective water and soil management. The technologies described below provide an introduction to the range of approaches used throughout Africa.

1.1.1 Planting Pits (Zai)

Technical Description

The Zay is made on land which is not very permeable so that runoff can be collected. Zai are holes dug approximately 80 cm apart to a depth of 5 to 15 cm, with a diameter of between 15 and 50 cm (Figure 1). Zai improve infiltration of the captured runoff. The holes are deepened each winter. Improvements in the traditional pits by the addition of fertilizer and organic matter (compost) have resulted in dramatic improvements in yield. Figure 1. Planting pits, or Zai (Lee and Visscher, 1990).

Extent of Use

The Zay technique is used in Mali, and in Burkina Faso in the Yatenga and Niger provinces where locally it is called Tassa. It can be used in all Sahelian countries, especially in Sudan.

Operation and Maintenance
The holes, filled with runoff water, extend favourable conditions for infiltration for as long as possible after runoff events. In case of too much water, such as during a storm, the debris placed in the pits as compost soaks up the excess water easily, effectively storing the water and creating a damp environment around the plants. The pits are easy to manage. However, it is important to make sure that the holes are correctly dug and that the debris is evenly placed in each hole. The holes must be checked each winter to make sure that they are in good conditions, and they must be filled with organic matter as required.

**Level of Involvement**

This is a very simple technique which needs no other equipment than what is usually already available. It is necessary is to inform the public and to carry out awareness campaigns so that the zay is accepted. However, after a few pilot projects, experience has shown that acceptance of the technique spreads quickly, thanks to its simplicity and effectiveness. Farmers notice after each rainfall that the earth around the plants remains damp for a considerable length of time.

**Costs**

The cost of the zay is considered in terms of the time which it takes the farmer to dig the holes and fill them with organic matter. Depending on the hardness of the ground, the input required is between 30 and 70 person days per hectare for the digging of the holes and 20 person days per hectare for fertilisation with manure and composting. Taking into account the wear and tear cost of materials used by the farmers, the cost may be estimated at approximately $8/ha.

**Effectiveness of the Technology**

In the regions where zay are used, zai are usually constructed on abandoned or unused ground. Thus, crop yields resulting from this practise bring a benefit of 100%. Yields range between 0.7 and 1.0 t/ha for sorghum.

**Suitability**

The planting pits meet the criteria for three types of conservation practises at the same time (soil conservation, water conservation, and erosion protection) on encrusted and filled soils. Although the technique can be adopted for use on degraded canals and encrusted surfaces, it generally is applied on silt and clay soils.
Environmental Benefits

Zai improve groundwater recharge. Zai also limit the volume of runoff and, hence, the extent of soil erosion. Advantages Zai increase infiltration into the ground. After several years of employing this practice, the soils may re-acquire its porosity and permeability. For this reason, zai are often used for cultivation and regeneration of the soil.

Disadvantages

The major disadvantage of this technology is the demand for supplementary efforts from the farmer who has to watch over the state of the holes, deepen them and refill them with manure before each wet season. Zai may also be subject to waterlogging in very wet years.

Cultural Acceptability

The zai has met with no reservations in the countries where it has been introduced. The technology has been expressed in such a manner so as not to be contrary to any sociocultural practices.

Further Development of the Technology

It is commonly adopted by communities in low rainfall regions in West Africa, but requires promotion for the technique to extend beyond Burkina Faso and Mali.

Information Sources


1.1.2 Demi-lunes or Semi-circular Hoops.

Technical Description

This is a short slope, micro-catchment technique, although the size of the semi-circle and its catchment may be varied considerably according to the rainfall of the region and the preference of the community. Generally, the catchment to cultivation ratio varies from 10:1 to 3:1, and the size of the lunes or circles varies from a radius of 2 to 15 m (Figures 2 and 3). Demi-lunes are constructed by hand labour with an emphasis on rehabilitation of degraded land.

Figure 2. Demi-lunes from Niger (Critchley et al., 1992).

Bund height varies from 15 to 25 cm. The demi-lunes are laid out along a contour and
staggered in successive lines. Some sites are protected from external runoff by diversion ditches. Soil for the bund is either drawn from within the hoop thus levelling the land, or by creating a furrow inside or outside the hoop.

Figure 3. Dimensions as used in Kenya. A cut off drain may be cut along the contour (Critchley et al., 1992).

**Extent of Use**
While widely promoted in Niger (where several thousand hectares are cultivated using this technology) and demonstrated in several areas of Kenya, neither country reports the spontaneous adoption by the technique by the community. It has been adopted by Niger as a recommended measure for moisture conservation.

**Operation and Maintenance**
The operation and maintenance requirements are within the means of the individual farmer to undertake, and involve the regular upkeep of the embankment.

**Level of Involvement**
Entirely developed by community labour once adopted, the initiative to create demi-lunes is often external to the community. As a result, the technique has not been spontaneously adopted.

**Costs**
The cost of this technology can be approximated as $150/ha for labour or about 10 person days/ha.

**Effectiveness of the Technology**
The demi-lunes or hoops are used mainly for increasing pasture production and rehabilitation of degraded lands. This technique is used only rarely for crop production. The demi-lunes have resulted in dramatically improved vegetation growth within the hoops, but, in most cases, production has not been measured.

**Suitability**
This technology is currently being used in a wide range of land types and rainfall regions (in areas with rainfalls ranging from 200 to 800 mm annually). It would appear to be adaptable to different conditions by adjusting the catchment to cultivation ratio.

**Environmental Benefits**
The technology results in increased vegetation cover on degraded lands.
Advantages
Some dramatic improvements in vegetation within the semi-circular hoops have been reported. It is cheap and easy to implement this technology with available manual labour.

Disadvantages
It is not a technology that has been taken up by the people - possibly because of a reluctance to invest much time in improving grazing lands. Also, the structures are vulnerable to breakages when subjected to high volumes of runoff, but this is generally a function of the diversion ditches rather than the technology itself. When breakages due to overloading by runoff occur, operators should reduce the catchment to cultivation ratio. This technology is not suitable for use with mechanisation and in areas where cattle are the primary product, given the propensity of cattle to trample the lunes.

Cultural Acceptability
The demi-lunes or hoops have been most successful where there was a high population density. It has been least successful when applied by pastoralists.

Further Development of the Technology
Little has been done to monitor systematically parameters such as yield, labour input requirements, or rainfall effects. This information is needed before further widespread promotion or adaptation of this approach is undertaken.

Information Sources

1.1.3 Katumani Pitting
Technical Description
Terracing of grazing land is generally considered to be too expensive and labour intensive in relation to the expected returns. However, eroded grazing lands may be revegetated economically by building small, interlocking mini-catchments using a pitting and ridging technique coupled with reseeding with native grasses and legumes.
Pitting should start at the top of an eroded slope below a cutoff drain which will intercept runoff from above. Pits should be dug to form interlocking catchments, each about 2 m² in area, varying in shape with the micro topography. Pitting can be extended down the slope as convenient and necessary. Final embankments should be about 30 cm high, around crescent-shaped trenches, 15 cm deep and 20 cm wide. Cow peas, or other ground cover crop, should be sown on the ridges, and cattle excluded, during the first growing season to allow vegetation cover to establish and soil to compact (Figure 4).

Figure 4. Stylised representation of Katumani pits in plan (a and b) and cross sectional views (c) (Simiyu et al., 1992).

**Extent of Use**
Crescent-shaped pits have been used to restore eroded lands in Kenya.

**Operation and Maintenance**
There are limited operation and maintenance requirements. In particular, over-grazing should be avoided so as not to cause a return to a previously denuded condition. Cutoff drains also are to be maintained.

**Level of Involvement**
Local community inputs or hired labour is generally used to construct the pits and cutoff trench.

**Costs**
Costs are primarily related to labour costs of about $100 to $150/ha. To establish a ground cover crop, fertilisers may be needed, especially where severe loss of topsoil has occurred. However, these costs can be offset, in part, by growing a cash crop during the first year after construction. For example, a first year cow pea cash crop can offset the cost of construction and fertiliser.

**Effectiveness of the Technology**
Surface runoff is reduced with the result that soil moisture content is greatly increased and available for use in growing both grain and forage legumes. Cow peas, grown during the first season, have been reported to yield 750 to 900 kg /ha. Notwithstanding, weeds and grasses tend to dominate in the second season, unless additional management
practices are adopted. Pasture yields of 3 to 4 t/ha/season are achievable, with a legume content up to 50%. Total dry matter production on Katumani-treated land increased by a factor of 5 to 10 compared to untreated land.

Suitability
This technology is appropriate for the rehabilitation or conservation of grazing lands in regions with 500 to 800 mm rainfall.

Environmental Benefits
Positive benefits are the rehabilitation of degraded lands, and stabilisation of soils. Use of native vegetation can also contribute to the maintenance of biodiversity.

Advantages
Improved fodder production and grazing capacity, and agricultural products from a planted tree crop (e.g., fruits, nuts or firewood), are likely outcomes of adopting this technology.

Disadvantages
Adopting this technology is labour-intensive.

Cultural Acceptability
No adverse cultural problems have been recorded.

Further Development of the Technology
The challenge is to extend the Katumani pitting technique to a larger group of farmers, soil types and environments in the region.

Information Sources

1.1.4 Permeable Rock Dams
Technical Description.
Permeable rock dams are long, low structures across valley floors which have the simultaneous effect of controlling gulley erosion while causing deposition of silt, and spreading and retaining runoff for improved plant growth (Figure 5). This is a floodwater harvesting technique.
Permeable rock dams are usually constructed across relatively wide and shallow valleys. Some dams may require central spillways, especially where the water course is incised, but the majority of permeable rock dams will consist of long, low rock walls with level crests along the full length. This causes runoff to spread laterally from the stream course, and, if the dam is overtopped, results in water being distributed evenly along the length of the crest. Wing walls or spreading bunds on the dam should follow the contours away from the centerline of the valley or gully. In addition, contour stone bunds are sometimes used in association with rock dams, especially when the dams are widely spaced. Stone bunds are placed to prevent the overflow from the dam creating a gully downstream of the structure, which could erode back to, and undercut, the dam wall. In general, poor siting of dams, such as at the head of gullies, leads to their failure. Each dam is usually between 50 and 300 m in length. The dam wall is usually 1 m in height within a gully, and between 80 and 150 cm in height elsewhere. The dam wall is also flatter (2:1) on the downslope side than on the upslope side (1:2), to give better stability to the structure when it is full. A shallow trench for the foundation improves stability and reduces the risk of undermining. Large stones are used on the outer wall and smaller stones internally.

**Extent of Use**
Several hundred permeable rock dams have been constructed on the central plateau of Burkina Faso.

**Operation and Maintenance**
No data are available on the operational and maintenance costs associated with this technology.

**Level of Involvement**
Several organisations have been involved in the promotion of this technology in Burkina Faso. The structures are labour-intensive and require provision of mechanised transport for moving the quantities of stone required. Villages that request application of this technology usually pay half of the transportation costs, contribute all of the labour, and manage the dam. Where rock dams have been installed, a spill over into the construction of smaller rock dams by individual land owners has been seen.
Governmental or agency involvement is comprised primarily of provision of technical advice needed during the construction stage. More recently, villages have been asked to form a land resource management committee to serve as a focal point for coordination of land and water resource management activities with extension agents. This committee draws up a land use management plan that provides the planning context for dam construction and other environmental protection projects.

**Costs**

A typical rock dam providing erosion control and water supplies to plots of 2 to 2.5 ha costs about $500 to 650 for transportation of materiel and about 300 to 600 person days of labour.

**Effectiveness of the Technology**

Permeable rock dams provide a more effective and popular technique for controlling gully erosion than gabions. Permeable rock dams, in addition to the effective control of gullies, have resulted in considerable crop yield increases behind the dams. Gullies are rehabilitated by the deposition of silt behind the dams, increasing the depth and quality of the soil immediately behind the dam as a result of the deposition of fertile silt. They have also improved the amount of moisture available for crops. Yields of sorghum from land restored with permeable rock dams range up to 1.9 t/ha compared with a yield of 1 t/ha from equivalent, untreated land. Other crops planted behind permeable rock dams include rice (on heavy soils), pearl millet and peanuts.

**Suitability**

This technology is appropriate for regions with less than 700 mm annual rainfall, where gullies are being formed in productive land. It is particularly suited to valley bottoms with slopes of less than 2%, and where a local supply of stones and the means to transport them is available.

**Environmental Benefits**

The control of gulley formation and the encouragement of silt deposition can have positive effects on a river course and water quality.

**Advantages**

Advantages to be obtained from employing this technology include:

- Increased crop production and erosion control as a result of the harvesting and
spreading of floodwater

- Improved land management as a result of the silting up of gullies with fertile deposits
- Enhanced groundwater recharge
- Reduced runoff velocities and erosive potentials.

**Disadvantages**
The disadvantages of using this technology include:

- High transportation costs
- Need for large quantities of stone
- Site specificity.

**Cultural Acceptability**
This technology is an acceptable technology within local communities of Burkina Faso. Different approaches by various agencies have resulted in confusion in cases where some communities have been asked to pay a proportion of the costs and others not.

**Further Development of the Technology**
Implementation of a programme of permeable rock dam construction requires technical knowledge. In addition, development of a community-centred, sustainable resource management system is required which builds upon the existing demand for implementation of resource conservation practices in villages. There is need to develop cheaper construction techniques if this technology is to be used more widely and if construction is to keep pace with demand.

**Information Sources**


**1.1.5 Contour Stone Bunding**

**Technical Description**
A single line of stones, or a stone bund, depending upon the availability of stones, is laid along a contour (Figure 6). The resulting structures are up to 25 cm high with a base
width of 35 to 40 cm (Figure 7). They are set in a trench of 5 to 10 cm depth which increases stability. The spacing between bunds varies but is usually between 15 to 30 m.

For rehabilitation of barren and crusted soils the farmers often use a combination of stone bunds and planting pits (zai; see Chapter 1.1.1 above). The contour stone bunds do not concentrate runoff but keep it spread. They also reduce the rate of runoff allowing infiltration, which is further enhanced through the use of the planting pits. Farmers often start at the lower points of a field and work upslope rather than the conventional wisdom which would suggest starting at the higher points in the catchment and working downslope. Stone bunds, however, are not easily damaged or destroyed by runoff, and, by starting lower on the slope, farmers can be certain to harvest sufficient runoff for production of a crop in a year of below average or irregular rainfall.

Extent of Use
The method was pioneered in the 1980s in Burkina Faso as a simple and effective technique for conserving water and soil resources. Since that time, it has been spreading rapidly. From 150 ha bunded by farmers in 1982-1983, the number of hectares had risen to an estimated 8 000 ha by 1989. Over 400 villages have participated in the installation of this technology. Thousands of hectares of barren land have been reclaimed by the combined use of stone bunds and planting pits.

Contour stone bunds, or simpler stone lines, are used in Mali on the Dogon Plateau.

Operation and Maintenance
There is limited, ongoing repair required as the stones are not vulnerable to erosion. However, silting behind the stone bunds requires that the stones to be relaid from time to time. Care must be taken that overtopping of the bunds does not lead to erosion on the downstream face, with subsequent gully formation and undercutting of the bund.

Level of Involvement
Beyond the initial, demonstration project in Burkina Faso, the technology has expanded in use of its own accord. Thousands of hectares outside of the project area currently use this technology. It is entirely farmer managed. In some villages, land management committees have been set up to look at a variety of activities related to improving land
utilisation in their respective areas.

**Costs**
Where stones are in short supply, there are increased costs associated with their acquisition and transport. This will be self-limiting for the technology.

**Effectiveness of the Technology**
Contour stone bunding is effective when judged by the acceptability of the technology by farmers. Farmers use stone bunds on fields currently under cultivation and to expand cultivation to new areas. Stone bunding is particularly attractive to farmers because of its ability to be implemented on fields already under cultivation. Yields in the first year have been increased by an estimated 40%. When barren fields are rehabilitated, yields of 1 200 kg/ha have been achieved in the first year. Application of fertilisers has only rarely been necessary, and the expected decline in fertility has not been observed although it is expected that, ultimately, there will be a need for a limited use of fertilisers.

**Suitability**
The technology is particularly suited to semi-arid lands, where stones are available. In the areas of application of this technology, long term average rainfalls are over 700 mm, but during the 1980s, when this technology came into widespread favour, rainfalls have been below 600 mm. The technique has also been used in wetter areas of Mali to prevent erosion due to overgrazing, and, in addition, has produced profitable cash crops.

**Environmental Benefits**
The technology has noticeable, positive environmental impacts, leading to the rehabilitation of degraded lands and reducing soil erosion.

**Advantages**
Benefits to farmers have been evident, and the technology is simple to implement at the local level. Stone bunds do not readily wash away and, therefore, the technique is not vulnerable to unusual and variable intensity rainfall events. In Burkina Faso, the project has also resulted in increased attention to land use planning and the environment by villages.

**Disadvantages**
The popularity of the technique has resulted in shortages of stones and, therefore, a higher cost for latecomers.
Cultural Acceptability

There is a long history of soil and water conservation on the Dogon Plateau. Likewise, farmers in the Yatenga Region of Burkina Faso have traditionally used stone lines on their fields. For this reason, the further development of the concept into installation of stone bunds has been readily accepted. Farmer-to-farmer extension has been shown to be an effective tool which is underrated in many projects.

Further Development of the Technology

A concern over the eventual disposition of silt-in of the bunded areas has not yet been addressed, but it has been suggested that the planting of perennial grass on the bunds will maintain their function of slowing and spreading water and help to retain deposited silt within the bund basins. Extension support is required amongst the Dogon in Mali who have not yet adopted the improved methods based on the simple stone lines they currently use.

Information Sources


1.1.6 Tied Contour Ridges

Technical Description

Contour ridges are small earthen ridges, 15 to 20 cm high, with an upslope furrow which accommodates runoff from a catchment strip between the ridges (Figure 8). The catchment strip is usually uncultivated, but, where contour ridging is used to control erosion rather than for water harvesting, the whole area may be cultivated. Ridges may be from 1.5 to 10.0 m apart, but, as this is a micro-catchment system and the catchment is a function of the distance between ridges, the precise distance should be calculated for the expected rainfall of the region (Figure 9).

Figure 8. Contour ridges as used in Kenya
Small earthen ties are made within the furrows at 4 to 5 m intervals to prevent lateral flow (Figure 10). The objective of the system is to collect local runoff and store it within the soil profile in the vicinity of the plant roots. Micro-catchment contour ridging is usually not designed to accommodate overflow, so the system should be protected with a cutoff drain.

The tied contour ridging system is used for tree planting (with a wider distance between ridges) and crop production. Crops are planted on the ridges as well as in the furrows. Figure 9. Field layout for contour ridging which varies according to the catchment to harvest area ratio (Critchley et al., 1992).

**Extent of Use**
It has been adopted in Kenya, Niger, Zimbabwe, amongst others. It does not seem to be taken up spontaneously, however, and is mainly promoted through projects and government policy. Nevertheless, tied ridges are widely used in commercial farming situations in southern Africa as a means of controlling soil erosion.

**Operation and Maintenance**
Minimal maintenance is required if the ridges are properly constructed initially. Maintenance involves reconstruction of any lines and ridges that might have collapsed.

**Level of Involvement**
While possible to prepare with hand implements, most projects have used mechanised equipment to construct the contour ridges. Farming practices thereafter are left in the hands of the community. The siting of contours can be done by the community after training.

**Costs**
With human labour, an estimated 32 person days/ha is required. Using machinery, the time requirement is reduced, but the costs are increased to an estimated $100/ha. This technology is considered low cost, although the rate of its adoption has not been high. Figure 10. Tied furrows as used in Zimbabwe (Critchley et al., 1992).

**Effectiveness of the Technology**
Data from Kenya suggest that there are considerable yield advantages in using the contour system. The data also show that, when used in combination with appropriate
crops, it has a demonstrated ability to reduce the risk of crop failure due to drought by concentrating the runoff. This technology has been used with millet, cowpeas and sorghum.

The application and effectiveness of the technology is believed to be greatest in those areas where soils have been degraded to the extent that the people cannot reverse the trend using their own resources. An external input of mechanical equipment can have a large impact in these situations.

**Suitability**

The technology is being used in a variety of climatic and soil conditions and can be adapted to rainfall by adjusting the distance between contours and also the area of cropping. Water harvesting potential is reduced or lost if the catchment area is planted. At Baringo, Kenya, where there is a mean annual rainfall of 655 mm, the project area has a catchment to cultivated area ratio of 2:1. Further, a range of slopes may be treated, though the dimensions need to be increased as slope increases. In the relatively higher rainfall area of Zimbabwe, there is only a 1.5 m spacing between the ridges, and the ridges themselves act as the catchment. Planting is carried out alongside the furrow to take advantage of the concentrated water but to avoid waterlogging.

The system is suitable for areas where cultivation is limited by water shortages and in areas where there is severe environmental degradation.

**Environmental Benefits**

Benefits of land rehabilitation and reduced soil erosion are normal results when this technology is used.

**Advantages**

This low cost technology has the potential to increase food security in below normal rainfall years. The system can be implemented using either a mechanised or manual labour approach. As with other water harvesting methods, it is more likely to be successful in areas which experience severe dry spells and/or highly variable rainfalls. The technology reduces soil erosion and increases soil moisture content.

**Disadvantages**

The unusual cropping system of planting on ridges and next to furrows, but leaving the catchment unplanted, is thought to be a disincentive for adopting this technology.
Further, the labour-intensive approach is not thought to be attractive in the areas where the technology has been tried. In Baringo, Kenya, farmers were reportedly reluctant to repair bunds after they were washed away. The relatively low planting density discourages farmers, especially in a good year, and the technique does not work well on steep slopes.

**Cultural Acceptability**

No data have been reported on this aspect of the technology.

**Further Development of the Technology**

Globally, this is a well-documented and widely-practised technology which can be adapted to a variety of conditions. However, in Africa, it requires effective extension and promotion before it is widely adopted.

**Information Sources**

**Contacts**


**Bibliography**


**1.1.7 Fanya-juu Terracing**

**Technical Description**

Based on the development of bench terraces over a period of time, and known by its Swahili name, *fanya-juu* terraces are constructed by throwing soil up slope from a ditch to form a bund along a contour (Figure 11). The trench is 60 cm wide by 60 cm deep, and the bund 50 cm high by 150 cm across at the base (Figure 12). Several of these terraces are made up the slope following the contour lines. The distance between bunds depends upon the slope and may be from 5 m apart on steeply sloping lands to 20 m apart on more gently sloping lands.

Figure 11. Initial profile and later development of fanya juu terraces (Critchley, 1991). Similar terracing systems are found in many countries where the stones from rocky slopes are used to build the bunds or terrace walls, often on very steep slopes. Contour ridges may be combined with this system.
Through gradual erosion and redistribution of soils within the enclosed fields, the terraced lands level off, forming the terraces. Soil and rainwater are conserved within the bunds, and the bunds are usually stabilised with planted fodder grasses. In addition, each farm using this technology is surveyed to see if it needs a cutoff drain to be installed in order to protect the terraces from surplus rainfall. The use of stone terrace walls allows surplus water to pass through the bunds by infiltrating between the stones and overtopping the walls.

Figure 12. Construction of the bund (Critchley, 1991).

Extent of Use

The technology is known from the Machakos District of Kenya, which is hilly and subject to widespread erosion. Since the mid 1980s, the District has achieved the installation of an average of 1 000 km of new fanya-juu terraces each year, plus several hundred km of cutoff drains; 70% of the cultivated land in the District is reported to have been terraced.

Between 1974 and 1991, the National Soil Conservation Programme in Kenya prepared and implemented conservation plans on 925 000 farms. The rate of compliance increased to 100 000 farms per year by 1991. A variety of technologies were promoted through this Programme, including fanya-juu terracing. Over 500 000 farmers were trained in conservation technologies.

Use of terracing is also reported on steeply sloping lands in Morocco.

Operation and Maintenance

Regular maintenance of the embankment is required.

Level of Involvement

In Kenya, the implementation of this technology is normally undertaken by self-help groups who work collectively on each others lands. Some richer members of the community employ others to prepare the terraces since family labour on its own is generally not adequate for constructing these features. Self-help groups in Machakos consider soil conservation to be one of their main activities.

Costs

The labour required for construction is estimated at 150 to 350 person days/ha for terraces and cutoff drains. The cost of these structures is approximately $60-460/ha.
Effectiveness of the Technology
In Machakos, crop yields have increased by 50% (or by 400 kg/ha) through the use of fanya-juu terraces.

Suitability
This technology is suitable for marginal or wetter zones of 700 mm annual rainfall or above. Soils should be deep. The technique is suitable for use on slopes of less than 5% to 50%.

Environmental Benefits
There is effective control of erosion. Where a whole catchment has been conserved there is an improvement in streamflows with consequent benefits for a village water supply.

Advantages
The technology generally results in a reliable increase in crop yields.

Disadvantages
The technology is costly in terms of labour. Unprotected bunds, which have not been planted with grass, are prone to erosion.

Cultural Acceptability
This technology has fitted well into culture of the self-help groups present in the areas of application to date, and reinforces their emphasis on full involvement of the community in freshwater augmentation efforts. The technology has already been established in the area and, therefore, there was no cultural resistance to it.

Further Development of the Technology
Application of this technology in other areas needs to be further examined as there were special conditions in the Machakos District of Kenya which enabled it to succeed.

Information Sources
1.1.8 Flood Harvesting Using Bunds

Technical Description
This system is normally used where slopes are above 0.5% and there is significant runoff to be harvested. It is a long slope catchment system where water travelling in small gulleys is diverted onto a farm plot (Figure 13). The plot has contour bunds within the fields at a typical height of 50 cm and a base width of 150 cm. These bunds commonly extend across the whole plot and excess water spills around a short arm at one end. Fields are typically 1 ha in area, and there may be a second collecting bund behind the first to collect any overflows.

An alternative overflow system is the incorporation of a 10 cm plastic pipe into the bund. In cases of excessive flooding or water logging, the bund may be breached deliberately.

Figure 13. The laag system of capturing floodwaters (Critchley et al., 1992).

Extent of Use
This technology is widely used by agro-pastoralists in Central Rangelands of Somalia where it is known as laag. There are up to 2,500 families using this system in Somalia. A common way of using flood flows in a wadi or river channel is to construct a dam or a barrage to divert the water onto cultivated lands using a water spreading technique such that water is not allowed to form ponds. Rather, water is induced to flow over the land surface at low velocities. This is particularly appropriate in grassed areas used for forage production, and has been used experimentally in West Africa and Kenya.

Operation and Maintenance
There is evidence that the laag systems have developed over several generations, and, although breaching of bunds and occasional water logging occur, the cultivators are able to design, manage and maintain the system locally.

Level of Involvement
This is a traditional technique used for generations to harvest water for crop production. Structures are normally made by hand, and the system is simple and easy to construct. Rice farmers often hire tractors for the mechanical construction of bunds and for
Costs
Costs of implementation of this technology are not known as it is a traditional technology implemented by farmers at their own expense. However, costs are believed to be less than $100/ha.

Effectiveness of the Technology
The technique is used to augment income from livestock production by crop cultivation and the simultaneous provision of fodder for the livestock. Sorghum is the usual crop of choice, although cow peas are also grown. Two crops can be grown if the rains arrive as expected. Yields are not specifically available, although, for this area, they are generally given as 415 kg/ha for sorghum and 330 to 530 kg/ha for cow peas. Local agropastoralists say that harvested runoff improves crop performance and, without it, crop failure may occur or crop production may not even be possible.

Suitability
The technology is used in Somalia in a region with an annual rainfall of between 150 to 300 mm, split between two rainy seasons. Crops are harvested in each season. Water harvesting is most common in zones of clay soils. This technique also requires an associated drainage gulley network, river system or system of road drains. Riparian situations may also be suitable.

Environmental Benefits
Limited environmental impacts are expected, although poor management of the flows can lead to erosion. Generally, this technology reduces soil erosion and improves vegetative ground cover.

Advantages
These systems are completely farmer-managed, simple to construct and allow the harvesting of floodwaters that would otherwise flow off the land surface. Provision of water to livestock and crops also contributes to improved food security.

Disadvantages
The traditional system has a problem in that contours are estimated rather than measured, resulting in occasional waterlogging and bund breakages.
Cultural Acceptability

This technology is culturally-acceptable in Somalia as an indigenous water harvesting technology.

Further Development of the Technology

Introduction of contour surveying instruments in the determination of contour lines, and completion of further work to determine the spacing between bunds and positioning of spillways, would improve the technology.

Information Sources


1.1.9 Earthen Bunds

Technical Description

Earthen bunds are essentially an external catchment, long slope technique of water harvesting. Typically a u-shaped structure of earthen bunds which farmers build on their cultivated lands to harvest runoff from adjacent upslope catchments, this technique usually collects rainwater and, sometimes, floodwaters (Figure 14).

The base bund approximately follows the contour line and impounds the runoff. Two outer arms fulfil the same function and also act as conveyance structures which direct water to the cultivated lands. Sometimes, shorter inner arms are added which divide the land into smaller basins and improve the spread of captured runoff (Figure 15). A shallow channel is left on the inside of the bund to support the conveyance and circulation of runoff.

Figure 14. Typical element of the teras water harvesting structure (van Dijk, 1995).

Excess water is normally drained along the tips of the outer arms which are reinforced
with materials such as stones, brushwood or old tyres. Bunds are usually 0.5 m high and 2 m deep at the base, but these dimensions can vary greatly depending on both the slope and the amount of runoff expected in the area. The base can be between 50 to 300 m long, while the arms are usually 20 to 100 m long. The size of the cultivated area serviced by such a structure is 0.2 to 3 ha.

Figure 15. Overview of a teras water harvesting system (van Dijk, 1995).

Extent of Use
One of the few examples of traditional water harvesting technologies where the technique is applied over a wide area. The system is called teras in Somalia, where there are reported to be "thousands" of teras plots in some regions of the Sudan. The bund system is also widely used in Ghana, Burkina Faso and Mali.

Operation and Maintenance
This is a labour-saving technique. Generally, between 3 and 18 days/ha of work is required to ensure that the system runs efficiently. However, breaches of the bunds will require additional work in order to effect repairs. The local dynamics of a drainage system may also require that the conservation structures be continuously adjusted for best performance.

Level of Involvement
Entirely traditional and farmer-managed, earthen bunds may be built by hand using simple tools, although the use of hired tractors is becoming more common.

Costs
There are no data on costs available, but they are not believed to be high when earthen bunds are constructed manually by a farmer. Mechanical construction methods increase costs.

Effectiveness of the Technology
The technique allows the production of a crop of millet or sorghum. Based on data from the Sudan, yields may reach 750 kg/ha in a good year. Quick maturing millet should be planted immediately after the water from a storm has subsided. This crop grows and matures in about 80 days.

Environmental Benefits
Use of this technology reduces land degradation.
Suitability
This technology is appropriate for areas of the Sudan where the foothills reinforce high intensity and short duration rainfall, with 150 to 400 mm rainfall, annually. Low infiltration increases the generation of runoff from teras catchments. Catchments are normally 2 to 3 times the cultivated area in regions of 150 to 400 mm annual rainfall. Teras irrigation suits the lifestyle of the Beja in the Sudan, as they are often absent from the land, and this system lends itself to small-scale private enterprise. In West Africa the technology is widely found in valley bottoms.

Advantages
The technology is entirely farmer managed and, therefore, not subject to the organisational problems of other soil and water conservation techniques. Socio economic surveys have indicated that application of soil and water conservation practises contributed about an additional 75% to the total household crop production income in the 1980s and 1990s.

Disadvantages
The lack of a spillway can result in breached bunds.

Cultural Acceptability
There are no cultural restrictions. The Muslim population of the Sudan initiated the use of this technology about 40 years ago.

Further Development of the Technology
The development of spillways may improve the efficiency and reduce maintenance costs.

Information Sources


1.1.10 External Catchments Using Contour Ridging

Technical Description
A further variation of the contour ridging technique described in Chapter 1.1.6, this technology uses an external catchment and incorporates a stone spillway into the
contour bund, providing for excess runoff to flow around the structure (Figure 16). Bunds are made of earth or, occasionally, stone, and, in Niger, they are usually covered with a layer of stone on the top and back slope (Figure 17). The area impounded by the bund is planted. The usual catchment to cultivated area ratio is 2:1 but reaches 5:1 in Kenya where off contour bunds are used as collection systems to channel runoff to cultivated plots.

Figure 16. Macro-catchment water harvesting system (Imbira, 1989).

For full utilisation of the cropping area, the spillway height should be level with the base of the spillway on the next contour uphill. Levelling of the ground between contours assists in water spreading when runoff is collected. The spillway height determines the depth of water retained and is usually about 10 cm.

Figure 17. Macro-catchment water harvesting in Niger (Critchley et al., 1992).

**Extent of Use**

Several thousand hectares are treated with a variety of bund systems, although the largest number of projects are in Niger and Kenya.

**Operation and Maintenance**

Maintenance is required to control erosion around spillways and bund wing walls. Achieving adequate compaction of bunds with manual construction methods is difficult and may result in breaches during the first year of operation. Grass planted on the bunds and spillways helps to protect these surfaces from erosion and reduces maintenance requirements, particularly since some resistance to the repair of breached bunds was reported in Kenya (Figure 18).

**Level of Involvement**

The Kenyan programme of bund construction is all done using manual construction methods, whereas, in Niger, the bunds are constructed by machine and only the stone is laid by hand. Construction of these storages has largely been done through food-for-work programmes and there is some concern about the level of true involvement of people. In at least one application, it was observed that there was little voluntary participation in the use of this technology by the community.

Figure 18. Spillway construction for bunds with external catchments (Pacey and Cullis, 1991).
Costs
In Niger, the estimated construction cost is about $500/ha for bunds, land preparation and fertiliser. In Kenya, 100 person days/ha are commonly devoted to construction, resulting in an approximate cost of between $52 to $202/ha.

Effectiveness of the Technology
This technology is effective in controlling erosion. Yield information is not available for Niger, but, in Kenya, the comparison with control plots has shown an highly significant increase in yields of sorghum and cow peas.

Suitability
This technology is suitable for low and unreliable rainfall areas, with an annual precipitation of 350 to 650 mm. It is also well-suited for use in the reclamation of degraded land.

Environmental Benefits
The technology has beneficial effects in the reduction and control of soil erosion.

Advantages
The advantages are the concentration of runoff to allow the cultivation of a crop where otherwise none would be possible. This results in increased and more reliable level of production.

Disadvantages
A high demand for labour in the construction and maintenance of these systems may partly be a reason for the low level of acceptance by the community. Approaches have not yet been found to fully involve the community.

Cultural Acceptability
These have not been fully assessed; however, there are no known limitations.

Further Development of the Technology
This technique is clearly an appropriate technology for the conservation of soils and the recovery of degraded lands. Nevertheless, the technology needs to be demonstrated as useful to the community and presented in a way that the community is willing to manage.

Information Sources
1.1.11 Sand Abstraction

**Technical Description**

Water is abstracted from sand-filled river beds during periods in which there is no surface water flowing in the river. In such situations, the sand is fairly saturated. The method involves the use of slotted cast iron or PVC pipes drilled into the sand-filled river bed, connected to a mainline or manifold, and a pumping system. The water pumped out and distributed for use in agricultural or domestic applications. In small-scale, domestic systems wells or casing sunk into the sandy river bed are fitted with simple hand pumps, or a bucket and windlass assembly.

**Extent of Use**

Freshwater abstraction from sandy river beds is widely used in Zimbabwe and Botswana for farming and domestic supply purposes. Commercial enterprises, such as ARDA and the Hippo Valley Estates in Zimbabwe, have successfully used sand abstraction for irrigation purposes. At Chisumbanje, ARDA has installed some sand abstraction units for winter irrigation of wheat and early cotton crops. Hippo Valley Estates successfully used sand abstraction during the drought of 1991-1992 for sugarcane irrigation in one of their Estate sections. Sand abstraction has great potential for freshwater augmentation in agriculture in areas where runoff is stored in surfacial aquifers such as "dry" river beds.

**Operation and Maintenance**

Adequately designed pumping units are essential for the successful operation of this technology. Care must be taken to balance the yield of the sand aquifer and the pumping rate, and also spacing of abstraction points, to minimize excessive drawdowns. Maintenance involves ensuring that well points do not collapse. This is achieved by casing the well. Further, the screening at the well-point intake has to be good to minimise the intake of sand grains which can damage pump impellers and shorten the life of pumping plant.

**Level of Involvement**
For large-scale operations, the technology has been limited to applications in the governmental and private sectors. For small-scale operations, local communities may be involved.

**Costs**

For large-scale schemes, there is a relatively high capital cost in the form of pumps and pumping accessories, and relatively moderate operating costs, primarily related to the need for fuel for the pumping equipment.

**Effectiveness of the Technology**

The technology is quite effective as has been proven by its application in Zimbabwe. As an example, the sand abstraction units at Chisumbanje (ARDA) are capable of delivering over 340 l/s, which is adequate for irrigation of up to 300 ha of summer cotton and winter wheat. The volume of water available is a function of the depth of sand in the river bed. A general guideline, based on the ARDA experience, is that 20% of the volume of sand is water.

**Suitability**

This technology is suitable for sandy river beds that are usually seasonally dry.

**Environmental Benefits**

This technology may permit maintenance of ground cover vegetation during drought periods. However, over abstraction may reduce downstream flows.

**Advantages**

Use of this technology has the advantages of:

- Lower financial requirements compared to surface water developments (e.g., dams)
- Providing a reliable source of water even during the dry season
- Requiring management and operational skills not much different from those required by borehole systems
- Being applicable over a range of operations from small scale- to large-scales.

**Disadvantages**

The technology has the disadvantages of having:

- Relatively high capital costs related to the purchase of hardware
- The potential for considerably shortened equipment lifespans, primarily arising
from the effect of sand on the pumps.

**Cultural Acceptability**

Traditionally, sand abstraction has always been practised in the whole region, albeit on a small scale, for human supply and livestock watering. Therefore, it has a high degree of acceptability.

**Further Development of the Technology**

A study for relating to the various productivity parameters (e.g., drawdown and well spacing, yield, casing and sand depths, sustainable pumping rates, etc.) is required before this technology is widely used on a large-scale. In Zimbabwe, research to answer some of these questions is already underway.

The hardware requirements necessary to implement this technology are not a problem in the region.

**Information Sources**

*Agricultural and Rural Development Authority*, Box CY 1420, Causeway, Harare, Zimbabwe.

*Department of Geology*, University of Zimbabwe, Box MP 167, Mt Pleasant, Zimbabwe.

*Departments of Water Resources Development* (Botswana, South Africa, Namibia and Swaziland).

**1.1.12 Lagoon-front Hand-dug Wells**

**Technical Description**

The land adjacent to a lagoon is called the lagoon front. This land is commonly divided into family- or individually-owned plots. Farm development starts by making row beds of approximately 1.5 m in width and 6 m in length on which vegetables are grown.

Hand-dug wells are then constructed in between the rows of beds (Figure 19). One metre diameter well rings are constructed by trained masons. The rings for the well are left for at least a week to dry.

Figure 19. Vegetable beds among a well field

In order to sink a well a suitable place is chosen among the rows of bed and a hole of about one metre diameter is dug in soil with a shovel. The first ring for the well is lowered into the hole. The well digger goes into the well and digs the soil out from under the ring with a hoe. As the soil is removed the ring moves downwards until the top edge
of the ring is flush with the ground surface. A new ring is added on top of the old one, and the well digger continues digging. New layers are added until the groundwater table is reached, at which time water flows into the bottom of the well. Usually the groundwater table on the lagoon-front is at a very shallow depth. Having struck water, digging continues for about one metre below the groundwater table. When the well reaches the desired depth, a 0.5 m ring is added at the surface so that the well stands above the ground level. A bucket with an attached rope is commonly used as the mechanism for lifting water from the hand-dug wells.

**Operation and Maintenance**

After the system has been installed, ongoing maintenance costs range from $10 to $40 annually. There is no need for power and spares.

**Level of Involvement**

This technology is traditional and farmer-managed. Construction is done by local masons and workers with simple hand tools (e.g., shovels, etc.). Because the scheme is entirely privately-owned and farmer-managed, there are fewer potential organizational problems.

**Effectiveness of the Technology**

The technology of lagoon-front hand-dug wells yields quality of water good enough quality for vegetable crop irrigation in an area filled with salty water. Without this technology, commercial farming would be impossible in the densely populated sand bar region of southeastern Ghana.

**Costs**

1995 cost of constructing a well is approximately $20. The operation and maintenance costs range from $4 to $10, annually.

**Suitability**

This type of irrigation scheme is suitable for irrigation of small rural farms, ranging in area from 0.1 ha. to 0.5 ha, in coastal areas.

**Advantages**

The materials for making the wells are obtained locally, and local skills are employed. These skills are traditionally passed on for generations. Once installed, the wells can be used for many years. Interviews with local farmers revealed that income from irrigated farming activities constitutes up to between 90% and 100% of family income. The
viability of the farming activities helps to curb the drift of youths from the rural areas to the cities. It is labour-based and provides employment for the youths, thereby providing a vibrant economic activity in an otherwise poor rural area. This technology requires no pumps or power-driven tools.

**Disadvantages**
The shallow depth of the well sometimes makes it dry up during the growing season. It also makes the well susceptible to contamination from the surface.

**Cultural Acceptability**
The rural life style of the coastal dwellers makes it easy for them to accept this technology.

**Further Development of the Technology**
Geophysical surveys to determine the freshwater - seawater interface will improve the technology. This will enable the depth of the well, the pumping rate, etc. to be determined. Such determinations will improve overall water management in the coastal zone.

**Information Sources**
*Dr C.S Kpordze*, UST, Kumasi, Ghana.

1.1.13 Sub-surface Dams, Small Dams, and Sand Dams

**Technical Description**
A sub-surface dam consists of a vertical, impermeable barrier through a cross section of a sand-filled, seasonal river bed (Figure 20). A ditch is dug at right angles across the river and into each bank, preferably where a rock dyke protrudes. This provides a solid, impermeable base onto which a simple masonry wall can be built within the trench. In some situations, the wall is raised gradually as sand from upstream accumulates behind the structure, forming a sand dam (Figure 21).

Figure 20. Subsurface dam (IRC, 1991).

The same approach may be used to control erosion in stream beds and to encourage deposition of alluvial deposits for agricultural purposes.

It is important to ensure that there is a seal between the vertical barrier and the impermeable layer beneath the sand to avoid seepage of water. Similarly, the barrier must also be extended into the banks to prevent lateral seepage and side erosion.
Water is taken out through a shallow well in the sand bed, or through a filter box, into a gravity pipe which runs through the dam to the point of use downstream. Figure 21. Construction of the dam continues in stages as silt or sand is deposited behind the wall (IRC, 1991).

In other situations, a small earth dam is built to hold back water and soil. The soil deposited is cultivable, and the water held back penetrates to the water table, providing a degree of groundwater recharge as well as increasing soil moisture. Cultivation usually starts late in the wet season and relies on the residual soil moisture in the alluvial bed. For soil conservation purposes, the dam should be built as close as possible to the head of the stream as this is where the water begins to erode the soil.

For water supply augmentation and soil conservation purposes, it is better to build a series of small dams along the same stream, rather than building one large dam. A sequence of small dams increases alluvial deposition and improves infiltration more than a single large dam.

Gabions (Figure 22) are often used as permeable rock dams, slowing down water flow and increasing infiltration, and reducing erosion and increasing silt deposition (Chleq and Dupriez, 1988)

Figure 22. A gabion is a container filled with stones, the typical dimensions of which are given (Chleq and Dupriez, 1988)

Construction of the wall requires specialist advice to ensure it will withstand the pressure of the water behind it.

**Extent of Use**

Small dams of various types are common in southern Kenya, and occasionally found in Zimbabwe.

**Operation and Maintenance**

Once constructed, recurring costs are negligible. The structures may be assumed to last for 30 years.

**Level of Involvement**

The level of involvement depends on the extent of the project. Generally, small dam design and construction is within the capacity of local agencies. Often, governmental
agencies and extension services are involved in the initial production of standardised designs for dissemination to communities.

Costs
A 3 500 m³ dam is estimated to cost approximately $8 250, resulting in an annual equivalent cost of about $0.11/m³.

Effectiveness of the Technology
This technology is an effective means of augmenting drinking water supplies, providing additional arable lands, and protecting watercourses from sedimentation.

Suitability
It is most suitable for use in sandy, seasonal rivers prone to siltation.

Environmental Benefits
Reduction of erosion, management of silt deposition within river basins, and increased moisture infiltration within the soil profile and into the groundwater are environmental benefits associated with sub-surface dams.

Advantages
Small dams store water from seasonal flows and are less vulnerable to siltation. Water is of good quality for consumption due to the filtering effect of the sand. When used for agriculture, the dams are effective in slowing down flows, and encouraging silt deposition and water infiltration, providing both soil and water conservation benefits. They allow crop production where otherwise it may not be possible, and reduce siltation in other, conventional water storage systems downstream.

Disadvantages
The use of these structures is limited to drinking water augmentation in most cases.

Cultural Acceptability
There are no significant cultural problems.

Further Development of the Technology
This technology has not been widely adopted, probably due to the lack of indigenous knowledge on the principles of small dam construction.

Information Sources
1.1.14 Cloud Seeding

Technical Description

This technique involves the beneficial modification of convective rainfall to increase rainfall production efficiency. Typically, only about 30% of the atmospheric water vapour entering Southern Africa reaches the ground as precipitation (Mather and Terblance, 1993). This approach encourages efficient raindrop formation through a collision-coalescence process which is enhanced or accelerated by the introduction of hygroscopic nuclei into a storm updraft at cloud base. Silver iodide crystals are most commonly used as nuclei for raindrop formation, and are released (by rocket or aeroplane) into an appropriate cloud formation.

The requirements for the evolution of precipitation from water vapour have been summarised as:

1. The air must be cooled, or vapour must be added, until the air becomes saturated.
2. The air must contain particulate nuclei to enable the phase transition from vapour to water or ice to occur without great supersaturation.
3. Some of the water particles formed must grow large enough to fall out of the cloud.

Extent of Use

Rainfall augmentation is extensively used in Zimbabwe, and also in Egypt.

Operation and Maintenance

This is an expensive technology to operate, requiring sophisticated equipment, control and monitoring procedures, and materials, including a cloud-seeding aeroplane, a measurement and monitoring plane, and a communications plane for experimental and monitoring purposes; aircraft maintenance and hanger facilities; meteorological radar and air sounding equipment; a computer system and data analysis software; a rain gauge network and automatic weather stations; and suitable cloud formations. Also, optionally required are structures for increased rainfall storage to make optimal use of the additional rainfall generated through this technology.
Level of Involvement
Personnel with various skills and from different disciplines (e.g., meteorological cloud physicists, radar operators and technicians, computer operators and technicians, and engineering technicians) are required to operate and maintain sophisticated measuring systems like laser imaging probes. Further, implementation of this technology involves a lot of forward planning and requires coordination and application of skills and knowledge developed over several years. Implementation of this technology is mainly by governments because of the costs and skills involved. However, beneficiaries (e.g., forestry, water and agriculture agencies) need to be involved in planning so that design, implementation and measurements associated with this technology (i.e., rain and stream gauging, radar operations, etc.) can be smoothly undertaken, and best use made of the artificial rainfall.

Costs
It is estimated that the cost of water produced is about $1.50/m³/season/ha (United Nations, 1985). This cost is made up of scientific equipment and hardware costs; flying costs for cloud seeding (capital and operational, including maintenance or hire charges); salaries for scientists and pilots; the cost of seeding agents and flares; and, software costs (for experimental and monitoring purposes).

Suitability
Cloud seeding is suitable in regions where water resources are seriously limited, and, particularly, where agriculture is a major commercial activity. Cloud seeding provides additional water to crops during periods when little or no rainfall would otherwise occur. However, cloud seeding can only be practised when weather conditions are favourable.

Advantages
The advantages of cloud seeding include:
• Few adverse environmental impacts
• Political attractiveness
• No long-term effects on weather patterns
• No physical structures to remain if programme is discontinued.

Disadvantages
The disadvantages of cloud seeding include:
• Weather-dependent success (clouds must be present)
• Lack of trained personnel (the required expertise is not available in many developing countries; adequate training may take several years to develop)
• Many benefits will accrue to all in the project area, regardless of expectations and desired participation (a lack of control over where the rain will fall)
• The belief that the rain would have fallen anyway.

Environmental Benefits
There are no expected environmental effects associated with this technique. The localised disturbances in rainfall patterns may even cause some limited harm.

Cultural Acceptability
There are no cultural problems.

Further Development of the Technology
Better indicators of impact of cloud-seeding need to be developed and implemented.

Information Sources

Contacts
G.K. Mather and D.E. Terblance, National Precipitation Research Programme, Water Research Commission, Private Bag 824, Pretoria, South Africa, Tel. +27 12 705 925, Fax +27 12 705 925

Ministry of Transport and National Supplies, Department of Meteorological Services, Post Office Box BE150, Belvedere, Zimbabwe, Reference File - National Cloud Seeding Season 1992/93.

Bibliography
1.1.15 Tidal Irrigation

Technical Description
Tidal heights of 1.3 m and 1.0 m exist in the Gambia River at Jahally and Pacharr, respectively. Special intake structures with gates were constructed, which, when opened at high tide, allow brackish tidal water to enter irrigation channels leading to the farms to be irrigated. The gates are opened for a period of between 3 and 24 hours depending on the size of the area to be irrigated. Tidal irrigation is coordinated with pumped irrigation, and is used to irrigate low lying areas along the Gambia River. Pumped irrigation systems are used for areas at higher elevations.

Extent of Use
This technology is used in an on going project in The Gambia, West Africa.

Operation and Maintenance
Once installed, this technology can be maintained by locally-trained artisans with general farm experience.

Level of Involvement
The technology is locally- or community-controlled, although some expertise is required for the design, siting, construction and maintenance of the civil structures.

Costs
The capital costs of the project, at 1983/84 prices, was $7.5 million. The current operation and maintenance cost is about $220/ha/year.

Effectiveness of the Technology
The technology has been very successful in paddy rice cultivation. Using tidal irrigation, double cropping of 167 ha and 850 ha is achieved annually at Jahally and Pacharr, respectively. Similarly, irrigation of 440 ha and 125 ha is achieved annually at Jahally and Pacharr, respectively, with pumped irrigation. The annual yield is 9 t/ha/year at an annual cost of $70/t/year.

Suitability
This technology is appropriate in areas where tidal and river conditions are similar to those at Jahally and Pacharr. Generally, the river is in a relatively flat basin with an high degree of tidal intrusion. This technology should only be used with salt-tolerant crops.

**Environmental Benefits**

There are no known environmental benefits. Drawbacks include a risk of salination and creation of a barrier to migratory fishes.

**Advantages**

The technology is very successful because, once the intake structures and irrigation channels have been constructed, the operation and maintenance costs are very low. Maintenance work on the irrigation channels, and clearing of weeds and bush from the channels and arable area, can be done by the local farmers.

**Disadvantages**

The major difficulty experienced is the lack of availability of spare parts.

**Cultural Acceptability**

It is accepted by the local community and is seen as an income generating project.

**Further Development of the Technology**

No further development of the technology is necessary.

**Information Sources**


**1.2 WATER QUALITY IMPROVEMENT TECHNOLOGIES**

**1.2.1 Artificial Wetlands for Wastewater Treatment**

**Technical Description**

Constructed wetlands are artificial, shallow excavations which are designed, built and operated to emulate the natural functions of wetlands. They contain a bed of porous soil, gravel or ash of about 0.3 to 1.0 m in depth, and are constructed with a peripheral embankment at least 0.5 m above the bed to contain storm conditions and the accumulation of vegetation and influent solids. Emergent aquatic vegetation, such as Typha, is planted within these basins to emulate the structure and functions of swamps, marshes and wetlands (Figure 23).

Water quality improvement is accomplished through physical, chemical and biological
processes operating independently, and through the interaction of the plants, media and microorganisms. The vegetation physically obstructs flow and reduces water velocity, thereby enhancing sedimentation and deposition of absorbed elements and contaminants. The root systems improve soil permeability, transfer oxygen into the surface sediments, and provide an increased surface area for aerobic decomposition of organic compounds by microorganisms and the chemical oxidation of many metal ions. An example of this interactive process is the co-precipitation of phosphate by iron, aluminium and calcium, which drastically reduces phosphate levels across the wetland profile.

Artificial wetlands may take various forms but generally include a screening stage to separate settleable solids (which are sent to a drying bed prior to land disposal), a wetland cell, and an aeration and disinfection stage as shown in the schematic layout below.

**Extent of Use**

There are projects using this technology in Zimbabwe, Zambia, Kenya, Uganda and Mozambique. Significant research on this technology has been undertaken in South Africa (Wood and Pybus, 1992).

**Operation and Maintenance**

Without separation of particulates, the subsurface flow systems experience severe clogging after two to three years of operation. When this occurs, the systems are suitable only for nutrient removal from an otherwise clear effluent. Subsurface flow systems have a further disadvantage in that they are frequently unable to maintain adequate dissolved oxygen levels to effect ammonia removal to the level necessary to satisfy most water quality standards and criteria.

During the first growing season, during the period when the wetland the vegetation is initially being established, water levels should not overtop the new growth. At a minimum, routine weekly inspections are essential to properly manage flows within the system. The following aspects require regular checking: piping, vegetation health and vigour, water levels in each component, and dykes and flow control structures. Shortcircuiting should be prevented through (re-)planting vegetation or blocking any channels.

There are no moving parts, and so the system can be managed easily with readily available tools and staff.
Figure 23. Layout and functions of a constructed wetland.

**Level of Involvement**
This is a relatively simple technology, therefore, can be constructed and maintained by untrained personnel, unlike conventional treatment plants. Initial design, however, must assure adequate capacity to prevent transmittal of disease and creation of odours.

**Costs**
Costs comprise annual and unit costs for the system components, land costs, labour costs, supervisory costs, and costs of technical training. Costs associated with the operation of conventional, mechanical-type plants in the United States, which may be considered as high relative to wetland treatment systems, have been calculated at between $0.011 to $0.057/m³/day. There are no equivalent cost estimates for Africa.

**Effectiveness of the Technology**
Wetland treatment is at least as effective as conventional treatment methods with respect to the removal of bacteria, and the reduction of common nitrogen compounds and suspended solids (Sinclair, 1995). Depending on the type of vegetative material used, wetlands may also remove toxic elements, with some types of plants removing these elements preferentially and at a much lower costs than using chemically-based techniques.

**Suitability**
Wetland treatment is ideal for small communities of up to 5 000 people, and work well in isolated settlements like rural schools, leisure resorts, housing complexes, flats and office buildings. Wetland systems are also suitable for treating wastewater from towns and small cities, mine drainage, urban stormwater runoff, runoff from livestock production facilities, landfill leachate, and wastewaters from paper mills, tanneries, food processing plants, petroleum refineries and several other industrial sources. Wetlands may also be used to replace failed septic tank fields, providing a semi-natural alternative for small institutions in areas where there is a high water table and no central sewerage system. However, these conditions can lead to a risk of groundwater contamination (Jesperson, 1995).

**Environmental Benefits**
This technology can be aesthetically pleasing, depending on the type of plants chosen.
Wetland provide a habitat for a wide range of birds, plants, reptiles, and invertebrates. Where they are properly designed, they can also be used for recreational and educational purposes. However, the environment may not be not completely free of pathogens.

**Advantages**
Wetlands utilise indigenous, microbial communities to breakdown harmful waste products. Wetland treatment systems are not dependant on external energy or chemical inputs, and require little maintenance. They therefore have low operation and maintenance costs. Wetland treatment systems offer a viable option in cases where soakaways fail due to unfavourable soils, and they can be landscaped into a feature like a water garden. Effluent from the wetland can be used for lawn or non-edible crop irrigation with or without further treatment. Most countries require some degree of posttreatment if the effluent is directly used for edible crop irrigation.

**Disadvantages**
There is a possibility of increased salinity in the water due to the discharge of leachate from the wetland and biogeochemical transformations of pollutants within the soil media. Leachate discharge may occur seasonally during periods of reduced plant growth (i.e., during winter).

**Cultural Acceptability**
There is no direct handling or reuse of the wastewater, but it is important to ensure local acceptance of this technology before promoting the technology in specific communities.

**Further Development of the Technology**
More experimental and operational systems would help in the accumulation of relevant data for use in the design and operation of future wetland treatment systems.

**Information Sources**

**Contacts**

*Clearwater Revival*, Post Office Box 413, Marondera, Zimbabwe, Tel. 263-79-23619, Fax 263-79-24279.


*University of Makerere*, Kampala Uganda.
Bibliography

1.3 WASTEWATER TREATMENT TECHNOLOGIES AND REUSE

1.3.1 Wastewater Reuse

Technical Description
Wastewater from a conventional or wastewater stabilization pond system is directed by a system of pipes or canals to a night storage reservoir from which it is used for pasture or crop irrigation. The crop will strip the wastewater of its excess nutrients (nitrates and phosphates), while many pathogens that may be in the wastewater die due to the inhospitable environment at the soil surface or are filtered out by the vegetation. Nevertheless, the ability of some pathogens to survive suggests that this technology be applied cautiously, with full knowledge of the characteristics of the wastewater source being used. Appropriate infrastructure is required to transport the effluent from wastewater treatment works to the site of use.

This technology may be combined with aquacultural operations. In which case, ponds may need to be designed for use in fish culture and additional infrastructure will be needed for this purpose. If the effluent is to be applied for irrigation of crops and the production of foodstuffs, special pre-treatment steps may need to be applied prior to the transportation of the effluent to the storage site.

Extent of Use
Wastewater reuse is practised in Tunisia, South Africa, Zimbabwe, and Burkina Faso. Over 15 schemes are operational in Tunisia. In Tunis, for example, irrigation of citrus trees with wastewater has been done since 1964. There are plans to extend the wastewater irrigation scheme to an additional 40 000 ha around Tunis.
Operation and Maintenance
The treatment system that provides the wastewater is usually maintained by the local authority. The conveyance system and wastewater distribution system may be operated by these same local authorities, but is generally operated by governmental agricultural development authorities from the point of effluent discharge to the end user. The on-farm distribution system is typically operated by the individual farmers. Maintenance of the pumping systems, delivery canals, pipes and furrows is required. It is recommended that a system for monitoring the health of workers be established to minimise the risk of spreading disease, given the nature of the raw water.

Level of Involvement
The transfer system from the treatment works to the farmer is usually managed by trained or experienced personnel from the local authority. The application of the effluent onto the lands is done by the farmer, and does not require a lot of technical know-how since it mimics traditional or conventional practises. However, additional health precautions should be used, and rural health workers should participate in training schemes established to promote this technology. It is also important for the farmers to know the application rates of the effluents to minimise the occurrence of phosphorus poisoning of grazing animals and avoid over-fertilisation. Thus, agricultural extension workers also should participate in the establishment of this technology.

In Tunisia, wastewater is distributed to farmers by the local Agricultural Development Authorities, which are responsible to the Ministry of Agriculture. These Authorities construct and maintain the wastewater distribution system. They distribute the wastewater to the farmers according to an organised delivery schedule and collect revenues from the sale of the wastewaters. The farmers are responsible for on-farm distribution.

Costs
In Tunisia, the cost to the farmer is $0.031/m3 of wastewater supplied. Costs are influenced by the necessity of pumping, provision of infrastructure for pipelines, distance from the source to point of application, and type of application.

Effectiveness of the Technology
Irrigated agriculture benefits from the high nutrient levels present in wastewater, thus
reducing the need for fertilizer applications. In aquacultural operations, reported yields of 0.8 to 4.0 tonnes/ha/year of fish have been achieved from effluent ponds.

**Suitability**
This technology is suitable wherever proximity to a wastewater disposal system coincides with a need for irrigation water or where the nutrient content can beneficially replace fertilisers or fish food. Applications of wastewater in agriculture should conform to World Health Organisation guidelines.

**Environmental Benefits**
The reuse of wastewater reduces the need to further exploit available freshwater resources which may be limited. There is, however, a danger of polluting the environment, especially the groundwater, if the wastewater is not properly treated initially.

**Advantages**
Use of wastewater for agricultural purposes does not require special skills, and can reduce the amount and use of other artificial fertilizers. Wastewater reuse serves as a polishing ground for the removal of nutrients, providing those nutrients to farmers at low cost. This technology may offer job opportunities to farmers who cannot afford conventional irrigation systems.

**Disadvantages**
Wastewater reuse can cause pollution of surface and ground waters if not properly managed. Further, the effluent may contain pathogens which can be harmful to farmers and consumers of edible crops irrigated with wastewater. Use of this technology requires significant investment in effluent transfer mechanisms such as pumps and pipes. The availability of irrigable land often limits the volume of wastewater that can be treated; however, in some cases, the volume of wastewater may limit the extent of irrigated agriculture.

**Cultural Acceptability**
A general social aversion to close association with excreta makes the use of wastewater problematic in Africa. Fish from sewage ponds are too closely associated with the excreta to be acceptable in many cultures. However, irrigated crops may be fully acceptable. Religious, especially Islamic, restrictions may also further limit the application of
wastewater reuse technologies in parts of Africa.

**Further Development of the Technology**

There is need for further promotion of this technology. However, the bacteriological quality of the crops requires further investigation to ensure the public health. The technology, although relevant and quite widespread, is now being challenged by forthcoming technologies which seek to remove nutrients from effluents and therefore recycle wastewaters directly back to receiving waterbodies.

**Information Sources**

**Contacts**

Centre Regional Pour l'Assainissement a Faible Cout (CREPA), 03 BP 7112, Ouagadougou 03, Burkina Faso, tel (226) 310359/60, fax: (226) 310361

Ecole Inter-Etats d’Ingenieurs, de l'Equipment Rural (EIER), BP 7023 Ouagadougou, Burkina Faso.

**Bibliography**


**1.4 WATER CONSERVATION**

**1.4.1 Conservation Tillage**

**Technical Description**

Conservation tillage is used to describe a number of technologies that are utilized in agriculture to conserve water and soil. Conservation tillage practices include, amongst others, strip, cropping, contour farming, zero or chemical tillage, mulch tilling, and reduced tillage.

- Strip Cropping

Strip cropping is the farming of sloping land in alternate, contoured strips of inter-tilled
row crops and close growing grasses (or other ground cover crop), aligned at right angles to the direction of natural flow of runoff. The close-growing strips slow down runoff and filter out soil washed from the land in the inter-tilled row. This control of runoff also allows increased opportunity for infiltration of the runoff and, thus, increased moisture in the soil. The strip widths can be varied depending on the soil type and slope.

- **Contour Farming**
  
  Contour farming involves aligning plant rows and tillage lines at right angles to the normal flow of runoff. It creates detention storage within the soil surface horizon and slows down the rate of runoff, thus giving the water the time to infiltrate into the soil. The contour bunds are earth banks 1.5 to 2.0 m wide, forming buffer strips at 10 to 20 m intervals, and are important for the functioning of the technology. The effectiveness of contour farming for water and soil conservation depends on the design of the systems, but also on soil, climate, slope aspect and land use of the individual fields.

- **Zero or Chemical Tillage**
  
  In this approach, the land is not tilled at all. Chemical tillage uses herbicides to control weeds, avoiding the need to till the soil. This tillage technique conserves water in the soil profile since the soil is not tilled and exposed to the drying (evaporative) elements of the atmosphere. The moisture is retained within the soil profile. The new crop is generally planted directly into the stubble of the previous crop.

- **Mulch Tillage**
  
  Mulch tilling involves covering bare soil with mulch or plant litter to prevent or reduce the evaporation of soil moisture and minimise the erosive energies of rain falling directly onto soil particles. The mulch is usually crop residue such as maize stover, sorghum trash and wheat straw. In cases where these are not available, or are eaten up by animals, gravel can be used as a mulch.

- **Reduced or Minimum Tillage**
  
  Reduced tillage is a practise in which the soil is tilled to some extent but not completely inverted. There are several ways of achieving reduced tillage. For example, the plough can be supplemented with discs or a chisel harrow, and the land ploughed in narrow strips, coinciding with the spacing of the row crops, leaving the intervening space untilled. Reduced tillage means a smaller volume of soil is exposed to erosion and
moisture loss by evaporation; hence, conserving moisture.

**Extent of Use**
Conservation tillage is widely practised in Eastern and Southern Africa (Kenya, Malawi and Zimbabwe) and has gained momentum because of the current heightened level of environmental awareness. Conservation tillage is part of extension training in most countries in these regions and is likely to remain so for some time to come.

**Operation and Maintenance**
There are limited operation and maintenance needs associated with these technologies. Maintenance involves keeping the structures in a functional state, e.g., maintaining the contour bunds to prevent erosive runoff of stormwaters, or maintaining the grass strips to retain their functionality. When mechanised ploughing is carried out, equipment maintenance is important in order to ensure the correct depth of penetration of the ploughs, seed injecting devices and other cultivating equipment. Generally, conservation farming requires equipment modifications relative to conventional farming techniques, and may require some initial capital investment to replace unsuitable machinery, although conservation tillage may be done using more traditional, manual farming methods.

**Level of Involvement**
The level of involvement includes the participation of extension workers from governmental agencies and nongovernmental organizations (NGOs) working with local communities. There is a need to build trust between these two parties for the successful implementation of these technologies. Extension agents need to run demonstration plots to prove that this suite of technologies actually works. Zero tillage, which requires the use of chemical herbicides, requires a higher level of education amongst the farmers to prevent undesirable human consequences and environmental damage.

**Costs**
For minimum tillage, labour and operation cost are about $40/ha. For zero tillage, the costs are a function of the cost of chemicals and work out at about $120/ha. (Zimbabwe). In general terms, the methods are cheaper than conventional tillage due to the reduced demand for ploughing, but are subject to some opportunity costs at the time of conversion from conventional tillage.

**Effectiveness of Technology**
These technologies are very effective in minimising soil disturbance and in controlling erosion losses. However, the different variations discussed above have varying degrees of effectiveness:

- Contour farming limits soil loss to about 18 t/ha/year, compared to 46 t/ha/year using conventional tillage (FAO, 1993)
- Zero tillage limits runoff to 3.4% and soil loss to about 2 t/ha/year
- Mulch tilling decreases erosion losses to a "trace" compared to 40 t/ha for bare check land (Finkel, 1986)
- Minimum tillage reduces soil losses to about a tenth of that of tilled lands (Finkel, 1986).

**Suitability**

The suitability of conservation tillage techniques also varies with each particular practise, although all are generally suited to agricultural operations throughout the continent.

- Strip cropping is effective on well-drained soils on slopes of 6 to 15%
- Contour farming is suitable on slopes of between 3% and 8%
- Zero tillage is suitable on most soils and slopes, and is especially suitable for use on hydromorphic soils with poor internal drainage
- Mulch tilling is also suitable under most conditions
- Reduced tillage is suitable under most conditions, provided other factors, like slope and rainfall intensity, are taken into account in the practices.

**Environmental Benefits**

These methods help to conserve soil moisture and reduce soil erosion. The grass strips and mulching also enhance soil structure and nutrient status. Unfortunately, the grass strips and mulching, if not properly applied, can harbour pests and vermin that can destroy crops; hence, conservation tillage is usually implement as part of an integrated nutrient and pest management strategy. Chemicals used under zero tillage can be harmful to the environment.

**Advantages**

The advantages of conservation farming are numerous, but varied, depending on the particular practise employed:

Strip cropping is effective for erosion and runoff control. Strip widths and spacings can
be designed to suit machinery and farm operations, while the grass strips can help provide grazing for farm animals during winter, depending on conditions. Grass strips can also enhance soil structure and nutrient status (depending on strip crop; e.g., legumes).

- **Contour farming** is effective in soil loss control, yielding up to a 50% reduction in erosion.
- **Contour farming** also conserves soil moisture.
- **Zero tillage** is saves energy and time, although the cost of herbicides may offset the savings in time and energy. Zero tillage is effective in reducing erosion and conserving moisture, compared to conventional tillage.
- **Mulch tillage** has substantial moisture conservation benefits. The mulch improves soil structure and nutrient status, especially if there is earthworm activity, which is promoted by mulching. There is reduced runoff loss and improved infiltration of runoff water into the soil. Weed growth is suppressed and accomplished in a completely environmentally-friendly manner, and the mulch can provide fodder for animals (depending on circumstances).
- **Reduced tillage** conserves soil moisture compared to conventional tillage methods. There are lower land preparation costs, soil compaction and aggregate breakdown is reduced, and less area of ploughed surface is exposed to erosive rains.

**Disadvantages**

Each conservation tillage technique also has a number of disadvantages:

- **Strip cropping** leaves grass strips which can harbour pests and vermin that can destroy crops if not managed correctly. Maintenance of the grass strips during winter can be a problem especially if the grasses are not hardy. Also, a poor choice of strip crop can lead to use of a crop that competes with the main crop.
- **Contour farming** results in less benefit to compacted or poorly permeable soils because these soils become saturated quickly. This can prove harmful to certain crops. Also, special skills may be required to construct effective contour lay outs. Ineffective lay outs can give rise to difficulties in tillage and crop management, and, on steep slopes, contouring alone can be deleterious, since water
concentrating in the furrows may breach the bunds and cause even more erosion. The effectiveness of contouring has to be enhanced by combining it with other practices such as strip cropping or terracing.

- Zero tillage requires significant inputs of chemical herbicides. The cost of these chemicals can be quite high, rendering the whole technique unviable. Further, the chemicals used can cause considerable harm the environment. Zero tillage needs to be used in rotation with other techniques, such conventional farming techniques, every so often.

- Mulch tillage, by leaving plant residues in the field, can create conditions which harbour pests and diseases (e.g., cotton stalks). In poor farming regions of the world, there are many alternative uses for the mulch (e.g., animal feed, thatching materials and fuel) which would reduce its availability for use in mulch tilling.

- Reduced tillage can result in the deterioration of soil condition over time, if the technique is not used in conjunction with other rotational practices.

**Cultural Acceptability**

There are no cultural norms against any of these conservation tillage techniques. Indeed, minimum tillage techniques mimic traditional agricultural practises in many countries.

**Further Development of the Technology**

A concerted extension programme is required to push forward the adoption of these technologies.

**Information Sources**

**Contacts**


**Bibliography**


**1.4.2 Deficit Irrigation**

**Technical Description**
Deficit or minimum irrigation is the deliberate under-irrigation of a crop. The technique is employed in areas where water is very limited. In some cases, water is only applied at the critical stages of crop growth. Applying minimum quantities of water at these critical stages sustains the crop so that it continues to develop and to yield reasonable quantities of produce - the alternative being no crop at all. For dryland farming, the technology is practised in conjunction with water harvesting. The harvested water being enough for "critical stage" applications.

**Extent of Use**

The technology is employed by large-scale commercial farmers in Zimbabwe and South Africa for growing winter wheat. It is successfully done using sprinkler and drip irrigation systems.

**Operation and Maintenance**

The operation of this technology requires minimum skills once the systems are installed. However, the installation of piping requires some training, and the maintenance of pumps requires artisans.

**Level of Involvement**

Trials are being carried out in Zimbabwe to establish the applicability of the technique for use in small rural irrigation schemes. It is usually farmer-managed with external technical advice.

**Costs**

Experiments carried out in Mutoko, Zimbabwe, show that applying 86% of the optimum irrigation water results in net returns of $100/ha. The operational cost was $130/ha.

**Effectiveness of the Technology**

The method is effective in sustaining crops with very little water. Reasonably high yields of winter crops have been recorded in Southern Africa, under conditions where there was little irrigation water available.

**Suitability**

This technology is suitable for use where water is limited (e.g., by drought) and a reduction in volume of irrigation waters is necessary.

**Environmental Benefits**

There are positive benefits to using this technique as it conserves water and enables
plants and crops to be grown under adverse conditions.

**Advantages**
The technique saves on water. Because of the limited volumes of water used, there is also a resultant saving on electricity and labour. Also, if practised where the rains have failed, farmers will at least harvest something.

**Disadvantages**
The crop yields will progressively reduce depending on the percentage deficit applied. The yield will always be less than the optimum.

**Further Development of the Technology**
There is need for further research on how this technology could best be combined with water harvesting techniques.

**Information Sources**

1.4.3 Savanna Wetland Cultivation

**Technical Description**
This technique involves the cultivation of valley wetlands found in the plateau savanna regions of Africa (called dambos in southern Africa; Figure 24). *Dambos* are a multipurpose land and water resource being used for water supply, grazing and cultivation. *Dambo* catchments were thought to act as hydrological reservoirs, storing water in the rainy season and releasing it through evapotranspiration from the dambo surface and dry season stream flow. This was used as a basis for legislative protection of wetland but has not been supported by more recent hydrological investigations (Owen *et al.*, 1995).

Figure 24. Dambo distribution in southern Africa (Bell *et al.*, 1987).

Erosion plot and gully monitoring studies suggest that garden cultivation does not appreciably increase soil losses from *dambos*.

Figure 25. *Dambo* land use recommendations (Bell *et al.*, 1987).
This technology may be called micro-scale irrigation and involves the utilisation of water around the periphery of a wetland using conventional agricultural methods (Figure 25). Garden cultivation appears best suited to the upper wet zone of the dambo and should not normally exceed 10% of the total catchment area.

**Extent of Use**

*Dambos* are used for small-scale cultivation on farms ranging in area from 15 to 20 000 ha in Zimbabwe. Discouraged by colonial legislation, they have been developed entirely through local initiatives.

**Operation and Maintenance**

Depending upon the season, raised beds may be necessary to protect crops from water logging.

**Level of Involvement**

This technology is entirely farmer-initiated and managed.

**Costs**

There are no additional costs relative to conventional cultivation techniques incurred through the use of this technology.

**Effectiveness of the Technology**

Studies have shown that the upper dambo zone, which normally remains wet throughout the year, offers an insurance against years when rain-fed crops fail. Gardens on *dambos* provide food security through the production of staple crops, dietary variety through the production of vegetables, and also cash income to farmers and their families.

**Suitability**

This technology is suitable for shallow, seasonally-waterlogged depressions at the head of a drainage network. Such depressions are quite common and therefore this method is suitable for increasing crop production in these areas.

**Environmental Benefits**

Experiments carried out jointly by the University of Loughborough and the University of Zimbabwe have shown that there are no adverse environmental consequences.

**Advantages**

The small size of *dambos* (0.1 to 1 km wide by 0.5 to 5 km long) suggests that a smallscale
approach is most suitable. It provide food security in years of poor rain-fed agricultural production and allows some dry season cultivation.

**Disadvantages**
Perceptions of environmental risk, which have not been dispelled by the limited data available, remain.

**Cultural Acceptability**
The practice has been developed by local people, who have no cultural problems with it.

**Further Development of the Technology**
There is a potential for considerable expansion of wetland cultivation in Africa which will probably require a clarification of the policy situation and removal of restrictive legislation. The impact on the environment should be investigated further.

**Information Sources**


**1.4.4 Plants for Water Conservation Gardening**

**Technical Description**
Most ornamental gardens (domestic and institutional) use a lot of water to maintain green plants and flowers in the midst of a dry environment. High water consumption then results. Water conservation gardening involves the use of indigenous plants for different climatic regions. In order to conserve water, plants with similar water requirements are grouped together. The introduction of plants indigenous to a region ensures that not much watering is required (Holland and Holland, 1994).

**Extent of Use**
The full extent of use of this technology is difficult to quantify as it is subtly practised at household level. Therefore, little information available is available. This technology is being used for landscaping in some office parks in South Africa.

**Operation and Maintenance**
Drought-resistant plants need to be watered until they are established. Often drought-resistant plants are already present in gardens, but have not been separated from those which are water-thirsty.

Level of Involvement
The level of involvement is user-dependent, but householders are thought to be the major user group. Local authorities, private companies, and other organisations can promote the technology by example through using and refining it. Water agencies can assist by disseminating information about the technology, together with lists of plants suitable for various regions within their service areas. Preparation and distribution centres, often garden supply outlets, are required to provide initial stocks. Gardeners need to be informed so that they can identify hardy plants and transplant them in groups which are determined by their water requirements. There is a need also to continually raise the awareness of householders with respect to the continued economical use of water.

Costs
The costs are negligible in the long run as these are incurred mainly at the start of the project during procurement of suitable plant varieties. In general, these costs are no more than the start-up cost of landscaping with non-native plant species. On a national basis the major costs involve the identification of the plant species and the suitable agroecological regions.

Effectiveness of the Technology
The technology is potentially very effective in conserving water, given that approximately 30% of the total quantity of water drawn by urban households from municipal connections is used for garden watering. Hence, even if a small percentage of urban dwellers start using the technology, the impact could be significant and lasting. In Israel, the use of more efficient garden watering practises resulted in individual savings of over 50%. These savings were achieved by supplying only enough water to maintain adequate plant and soil moisture levels.

Suitability
This technology is suitable in all urban situations as a water conservation strategy.
Environmental Benefits
These are positive as the technology conserves water and promotes use of indigenous plants.

Advantages
It is a simple technology to implement. The technology can effectively extend the design life of the water sources supplying a municipal area. The resultant water savings also have labour and financial savings.

Disadvantages
The initial plant identification and grouping phase can be time consuming and costly. The use of local/regional and indigenous plants might become a national requirement, in which case the classification could be done on a provincial basis. However, groupings made in one region may not be transferable. Further, recent research in the United States suggests that care must be exercised so as not to contaminate the gene pool by moving native plant materials between ecological genomes, even if the plants are visually identical. Likewise, care must be taken to avoid introducing nuisance species.

Cultural Acceptability
The technology is culturally acceptable. However, acceptance of some native plant over non-native species may be limited since water conserving flora rarely exhibit the diversity of flowers that are found amongst plants from more water-rich regions.

Further Development of the Technology
Further development of this concept is required to identify locally appropriate plants for each region.

Information Sources

Contacts
D.M.C. Fourie, Department of Agriculture and Water Supply, Post Office Box X388, Pretoria, South Africa, tel +27 12 3197165, fax: +27 12 3262817.

Bibliography
Eiovson, S., 1955. South African Flowers for the Garden, Department of Agriculture and Water Supply, Pretoria..
1.4.5 Porous Clay Pots and Pipes for Small-scale Irrigation

Technical Description

Porous clay pots and pipes are a means of water application that conserve water by applying water directly to the roots of plants, thereby limiting evaporation losses (Figure 26).

Both clay pipes and clay pots can be homemade; most are installed by individual householders. The pipes are joined to form tubes of 250 mm in length with an inside diameter of 75 mm. The pipes are placed along the entire length of the beds by laying them end-to-end in a levelled trench. At one end, a right angle fitting is attached and an upright section of pipe installed. The trench is then backfilled with soil to a depth of 100 to 200 mm, depending upon the soil type. Water is poured into the porous pipe through the upright pipe. Each plant bed is about 3 to 6 m in length. The water seeps into the root zones through the joints between the individual pipes, or through the pipe walls if unglazed clay pipes are used.

Alternatively, porous pots (made of unglazed clay) are buried in the soil up to their necks next to the plants or between plant rows at intervals of 300 mm. Water seeps from each pot through the pores and forms a wetted zone. Varying the frequency of filling, the size of the pots and the spacing between pots affects the watering process. Selection of the most suitable size of pot and its placement is governed by the type of crop.

Figure 26. Clay pipes and clay pots.

Extent of Use

Adoption is fairly limited, possibly due to the fact that the initial stages are very labourintensive.

Trials in the dry areas of Chiredzi, Zimbabwe, have shown that communities are interested in this technology.

Operation and Maintenance
Once the systems are installed, there is very little maintenance required. Operation is quite simple.

**Level of Involvement**
Farmers, researchers and extension workers must work together to implement this technology. Communities can construct and operate the system. However, government officials and/or NGOs may have to work with pipe/pot manufacturers to ensure availability of supplies of suitable pots and pipes. Extension workers can assist farmers in pipe/pot placement for best effect and at depths/densities best suited for various types of crop.

**Effectiveness of the Technology**
It was found, during the replicated trials, that water savings varied from 11 to 28% of the water used with traditional irrigation.

**Costs**
Since this technology uses clay pots and clay pipes that are locally manufactured, the costs are normally low. The major cost is the cost of labour, which is estimated at approximately $40/ha in Zimbabwe.

**Suitability**
This technology is most suitable for dry areas with less than 500 mm rainfall/year. With this technology, it becomes possible to save water and irrigate small vegetable gardens in rural areas. Communal farmers, especially women, can manufacture the pots/pipes without having to develop special skills.

**Environmental Benefits**
Porous clay pots and pipes conserve water and enable crops to grow in areas where they otherwise could not grow.

**Advantages**
Material for clay pipes and pots, and local skills for pot-making, are readily available at negligible cost. This method provides a uniformly-wetted area, and, because water is applied at depth, often helps to reduce any weed problems - weeds generally have shallow root systems that are not well-served by this technology. Also, pots can be placed next to individual plants. Once the technology is installed the system can be used for several seasons.
Disadvantages
The initial labour required to manufacture the pots/pipes and install this technology is very high. The use of clay pots can be more labour intensive than traditional methods of watering crops, and may have difficulty in coping with providing adequate water for crops with high water requirements. Also, the porosity of pots decreases with time, and they have to be replaced at intervals. Pot lifespans are greatly reduced by the use of turbid water with a high silt and clay content. The silt accumulates in the pores, effectively sealing the pipes/pots.

Cultural Acceptability
The technology is culturally acceptable.

Further Development of the Technology
There is need to market this technology, especially in areas of low rainfall (less than 500 mm/year).

Information Sources
Contacts
Lowveld Research Station, Post Office Box 97, Chiredzi, Zimbabwe.

2. DOMESTIC WATER SUPPLY
Technologies for the augmentation of domestic water supply systems are varied, starting with simple ones at the household level and ranging to more complex ones at the municipal level. Despite the existence of these technologies, access to domestic water supplies remains a problem for a majority of communities in Africa. The major reasons for this situation are the scarcity of water sources which can be attributed to a number of factors including population and industrial growth, increased agricultural activity, the destruction of catchment areas, the deterioration of the socio-economic and political environment, and changes in global climatic conditions, among others. All these factors have created a situation of water limitation. As a remedy to this situation, there is need to maximize the efficiency of use of existing freshwater resources, and to augment existing supplies, by using appropriate, cost effective and environmentally-friendly technologies. These technologies are classified in the broad categories of water harvesting, water quality upgrading, water conservation and water recycling and reuse. Water conveyance technologies have not been covered in detail as these are not
considered as technologies for freshwater augmentation, but, rather, they are a necessary component in the transfer of water from areas of water abundance to areas of water shortage. Hand pumps, and, indeed, other pumping systems, are regarded as water conveyance systems and, therefore, are not discussed in detail. However, some unique, traditionally African methods of water conveyance are mentioned in this section.

2.1 FRESH WATER AUGMENTATION TECHNOLOGIES

2.1.1 Protected Springs

**Technical Description**

There are three elements which comprise a spring catchment installation (Figure 27); namely, a) the "effective" catchment, consisting of a perforated pipe within a trench or dry walled channel (stone package), b) a supply pipe leading to an inspection chamber, and c) an inspection chamber, which consists of an entry basin for receiving the spring water and an operation chamber which helps to control water quantity and quality. Sometimes it can also serve as a sedimentation basin, and, in such cases, may be called silt trap.

Figure 27. Typical spring protection box (WHO, 1992).

Construction should be done during the peak of dry season in order to identify and use the most reliable springs. Nevertheless, spring protection structures have to be designed with overflow pipes so that they can function during peak flows during the rainy season. Usually, the excavation around the spring, necessary for construction of the catchment, is started from the point where the groundwater emerges. Once that excavation is completed, the construction of the other system components starts. There are two parts; preparation of a permeable construction into which the source waters enter, and a dam which prevents the water from bypassing the catchment or reservoir. The dam, or barrage, is constructed opposite to the point of entry of the water into the catchment. It has to direct the source waters into the supply pipe, which conveys the water to the inspection chamber. The barrage has to be built into the impermeable layer, as well as into both side walls, to prevent the water from bypassing the system. The foundation of the barrage is cast into the excavation directly against the ground in order to create a tight seal with the ground. The barrage is then constructed, of either concrete or stone masonry, on top of the foundation. The height of the dam should be positioned lower than
the level of the top of the water bearing layer. Difficulties may arise when the source waters have to be bypassed during construction of the foundation. (The flow should never be obstructed!) Usually a temporary dam is constructed of clay behind the excavation, and water is diverted with a temporary pipe or syphoned by a tube.

The permeable construction consists usually of a drain in the dry-stone masonry or of perforated pipes. The cross-section of this catchment drain should be sufficient to ensure that the maximum yield of the spring can be drained off without obstructing the natural spring flow. The drain has to be sloped at 1% to 2%. In the case of a solid substrate, no flooring is normally provided, but, for sandy ground, a dry pavement is needed. The velocity of water should be limited by providing additional catchment drains, considering the maximum flows to be expected during rainy season. Around the drains, a sand and gravel filter should be built up with gravel. The purpose of this filter package is to support the water bearing layer and prevent the fine particles that often comprise this layer from being washed out into the protection structure, resulting in the subsequent collapse of the water-bearing layer. A watertight cover, in the form of a 5 to 10 cm concrete cap, should be placed on top of the drains and the gravel filter. This cover needs to extend 20 cm into the slopes on all sides of the structure. Surface water reaching this cover should be drained off to minimise the potential for groundwater contamination.

**Extent of Use**

This technology is extensively used for projects in Africa. In Malawi, huge, gravity-fed, piped water schemes have been built, tapping spring water. Likewise, in Lesotho, a number of villages are supplied this way.

**Operation and Maintenance**

The operation and maintenance of spring protection structures is simple. They require few skills to construct and manage, making them suitable for management by user communities. Where steep drops are encountered (such as in the Lesotho Highlands), good structural designs are required to cater to the increased pressures built up in the supply pipes.

Maintenance activities may include protection of the catchment area from potential contamination, periodic maintenance of the filter package, and cleaning the spring area of leaves and other terrestrial debris. Maintenance is carried out by controlling human and
animal activities around the spring, repairing the perimeter fence, and repairing the surface water drainage system. It is also necessary to control of the growth of trees around the spring to prevent roots from causing piping to occur in the sand and gravel filter beds and/or breaching the impervious seals around the reservoir and dam. Periodic testing of the water for bacterial contamination is also recommended.

**Level of Involvement**

Local input of skills and materials from the beneficiary community is often needed to implement this technology. Technical support may be needed from government, NGOs, and other implementing agencies in the conduct of hydrogeological investigations, structure design, and construction. These activities require the inputs of technically-qualified staff, which depends on the size and nature of the scheme.

**Costs**

Spring protection is an inexpensive in comparison to the development of a conventional point source. The cost of the protection structure, itself, is largely a material cost (cement, pipes). However added costs may be incurred in the form of costs associated with the delivery mechanisms, which are dependant upon the length of piping, the number of storage reservoirs, and/or the number of pressure break tanks needed.

**Effectiveness of the Technology**

Springs have been used by local communities as a source of water supply for many years. Their relatively good quality water, and generally very low operation and maintenance costs, coupled with the ease of community management, make them quite effective for supplying rural communities with water for domestic purposes. Protecting these water sources from contamination is an natural way of ensuring the continuity of this supply.

**Suitability**

This technology is suitable in locations where springs occur and no unresolved pollution problems prevail. They may be managed as point sources for communities or distributed to individual households by connection to a distribution system.

**Environmental Benefits**

No environmental impacts have been reported.

**Advantages**
The advantages of this technology are several-fold: groundwater is a relatively safe water source for use without treatment, springs are the most inexpensive source of groundwater, and spring protection structures can be constructed using local skills and materials. Further, this technology incurs few or no operating costs, and requires very little maintenance, if the water is obtained at its source.

**Disadvantages**

Service level is dependent on groundwater yields, which seldom can be improved (unlike in conventional systems). Further, there is difficulty in ensuring the hygiene of the springs, especially during the rainy season when it is not always possible to protect the spring from surface water intrusion. The location of springs is not always near the point of consumption and, in many cases, access is difficult. Springs may also run dry during times of drought.

**Cultural Acceptability**

Spring water is associated with witchcraft amongst some East African communities. It is also the belief in some communities that women who have given birth to twins and/or whose husbands have died must not use springs before certain cleansing rituals are performed for fear that their "unclean" condition would cause the springs to dry up. In Southern Africa, communities often associate the placement of cement on springs with the spring drying. Such communities would be reluctant to install concrete catchments around their springs.

**Further Development of the Technology**

The technology does not require any further technical development, but it may be necessary to carry out social research on the cultural beliefs of communities to determine their basis and the effect this has on spring protection.

**Information Sources**

**Contacts**

*Ministry of Land Reclamation Regional and Water Development*, Post Office Box 30521, Nairobi, Kenya, tel (254 2) 716103.

*Blair Research Laboratory*, Post Office Box CY 573, Causeway, Harare, Zimbabwe, Tel. 792747

**Bibliography**
2.1.2 Rock and Roof Catchments

Technical Description
Rock catchments are simple systems for the collection of rainwater. Siting of these structures should take into account ease of access of the users and the geological structure of the site. The best sites are found on the lower reaches of bare rock inselbergs, where runoff losses to the soil, vegetation and structures is minimised. Storage may be provided in dams or open tanks.

Roof catchments are suitable for individual household use, and use in schools and other institutions where sufficient impermeable roof cover exists. To collect rainwater from roof catchments, gutters and ground storage tanks are required (Figure 28). "First flush" water from each shower should be prevented from entering the storage facility to reduce the degree of pollution of the stored water by dust, leaves and bird droppings washed from the roof top into the reservoir. Underground tanks may also be used (Figures 29 and 30).

Figure 28. Lateral view of a rainwater catchment system.

When calculating the size of the storage for rock or roof catchments, the demand for water, and the length of the dry periods, must be considered. The required catchment area also depends on the amount and variability of rainfall. In most cases, however, the available area is often the limiting factor due to local conditions. Figure 29. Rock catchment with underground storage tank.

Extent of Use
This technology is extensively used in arid and semi-arid areas of Africa, such as Mauritania, Benin, Burkina Faso, Uganda and Kenya.

Operation and Maintenance
Limited regular maintenance of gutters, and removal of leaves and other debris from the catchment surface, is required. Cleaning of the tanks is necessary before and after the first
rains. All of these activities can be handled by the community. Water is drawn by bucket or taps fitted to the storage tank.

**Level of Involvement**
This technology is installed and operated primarily by local communities, sometimes using hired labour. Technical advice from government, NGOs, or private sector agencies may be required. Once the technical training of locals has been completed, the roof catchment system installation and management can be left in the hands of the householders.

**Costs**
In 1994, a typical roof catchment system in Benin, constructed of ferrocement, cost $346/7 m³ storage, $496/12 m³ storage, or $800/24 m³ storage. In Burkina Faso, Uganda and Kenya, costs ranged from $852/20 m³ storage, constructed of ferrocement, to $1016/30 m³ storage constructed of masonry.

**Effectiveness of the Technology**
Rain water catchment systems have been successfully utilized by people all over the world for many centuries. Presently, rain water is collected from many types of surfaces to provide water for domestic, livestock, agricultural and fish-farming use. Rain water is also used as a supplement to piped water supplies. The effectiveness of rain water collection systems depends on the type of roofing material used. For example, thatched grass gives lower yields than corrugated iron sheets.

Figure 30. Artificial roof catchment with ground water storage tank.

**Environmental Benefits**
No environmental benefits have been reported.

**Suitability**
This technology has good potential in areas of rugged and steep terrain. It is more feasible in high rainfall areas, because rain can fill the storage reservoirs more frequently. On the other hand, it is quite suitable for arid and semi-arid areas where rain water is the most accessible water source. It also has good potential for community management.

**Advantages**
The advantages of using this technology are that water is provided at the point of
consumption, and there is good potential for community-based management of the collection systems (with low operating and maintenance costs). Relatively good quality water can be obtained using this technology.

**Disadvantages**
Disadvantages of this technology include difficulties in controlling the water quality, an high per capita cost of development, and a lack of reliability as a source of water. It cannot serve large users, although, it is usually adequate to provide a low level of service, suitable for family use.

**Cultural Acceptability**
No negative cultural factors have been observed.

**Further Development of the Technology**
There is very little that needs to be done to further develop this technology.

**Information Sources**

**Contacts**

*Ministry of Land Reclamation Regional and Water Development*, Post Office Box 30521, Nairobi, Kenya.

*CREPA*, Ouagadougou BP. 7112, Ouagadougou, Burkina Faso, tel 310359, fax: 310361.


*AGRITEX*, Post Office Box CY 639, Causeway, Harare, Zimbabwe.

*Ministry of Agriculture*, Private Bag 003, Gaborone, Botswana.

*Ministry of Agriculture*, Post Office Box 92, Maseru 100, Lesotho.

*Coordenacao Geral dos Projectos Integrados, Prorural*, Ruo da Resistencia 1746, Maputo Mozambique.

*Direction de l'hydrologie et d'hydraulique*, Programme d'Hydraulique Pastorale, Mauritane, Tel. 251611, Fax 251602.

**Bibliography**

2.1.3 Fog Harvesting

Technical Description
Fog droplets are much smaller than both raindrops and drizzle drops, with diameters varying from 1 to 40 microns, and fall at velocities ranging from less than 1 cm/s to about 5 cm/s. These low velocities result in fog droplets being influenced even by light winds that can cause the droplets to travel almost horizontally. An appropriate fog droplets collector, therefore, is a vertical or near vertical surface. Such surfaces can be constructed as vertical mesh panels on which fog droplets are intercepted and condensed.

Extent of Use
Fog harvesting is a rarely used technique in Africa. In Namibia, for example, the technology is still in the experimental stage. However, the actual application of this technology on a limited basis did begin in late 1995, as a project of the Ministry of Agriculture, Water and Rural Development.

Operation and Maintenance
Operational requirements include the measurement of the volume collected and the recording of meteorological data, either manually or by automatic weather station, since changes in weather conditions may change the operational design of the harvesters. Problems encountered include dust, rodents, game, and irregular fog formation. However, virtually all of the input materials to construct, operate and maintain the system are available locally.

Costs
The input costs are not yet known. However, an automatic weather station costs about $50 000 to purchase and install.

Effectiveness of the Technology
A surface area of about 50 m² can harvest a significant amount of fog and convert it into water. However, experimental data from the system in Namibia are still forthcoming.

Suitability
Fog harvesting is suitable in regions which have hills or mountains close to potential users, on a coastline with a cold current offshore. The quantity of derived water is a function of the scale of the project and the fog available. In Namibia, the resulting water is slightly salty as a result of the inclusion of some marine aerosols, and contains some dust.

**Environmental Benefits**

No direct environmental benefits have been reported or are foreseen.

**Advantages**

No extensive, permanent structures are necessary to implement this technology, and the derived water is normally potable. The technology can easily cater to the water needs of coastal, or desert, settlements or camps currently relying on a saline water source or some other expensive option such as tanker delivery. The water is available within the demand area and therefore requires little, if any, pumping. The water source is also sustainable over many years. Clouds normally bring a large amount of water and extend over a wide front. Therefore, the amount of water collected can be varied by varying the number of collectors installed. The collectors are simple and require no energy other than the wind.

**Disadvantages**

Deforestation can lead to reduced fog water inputs. Further, it may result in dust and other pollutants entering the harvested water.

**Information Sources**

**Contacts**

**P. Heyns**, Department of Water Affairs, Ministry of Agriculture, Water and Rural Development, Private Bag 13193, Windhoek, Namibia, Tel. 061-263141, Fax 061-263222.


**Bibliography**


2.1.4 Groundwater Abstraction in Urban Residential Areas
Technical Description
This is the abstraction of groundwater through boreholes, by private householders or water supply agencies.

Extent of Use
The technique is extensively used in a number of countries in Africa. In rural areas, it may be the only reliable source of water supply. In urban centres, it augments conventional municipal supplies.

Operation and Maintenance
The operation and maintenance requirements for groundwater abstraction systems usually relate to type of pumping system used. For poorly constructed boreholes, collapse may be experienced.

Level of Involvement
Both household and water supply agencies make use of this technology.

Costs
Borehole drilling and components costs have been estimated to be about $3 000 for a typical installation. Energy costs depend on source of energy used, usually the cost of electricity.

Effectiveness of the Technology
Household use of groundwater reduces demand for treated urban water. It is also efficient for industrial use since each industry can treat the water to meet its own requirements.

Suitability
This technology is suitable in all areas with groundwater reserves, in particular, during droughts.

Environmental Benefits
There could be environmental damage from over pumping as the water table recedes. In years of water shortage, this over-pumping may negatively affect the groundwater discharge into rivers, lakes and reservoirs.

Advantages
The advantages of this technology include its site-specificity; no significant delivery (reticulation) systems are necessary. The technology may be used where urban services are poor or unreliable.
Disadvantages
Over pumping may lead to ground subsidence. Subsidence is of great concern in crowded urban areas. Further, groundwater is susceptible to contamination from wastes.

Cultural Acceptability
Generally, there are no cultural problems with the use of groundwater supplies.

Further Development of the Technology
Techniques for the rapid assessment of safe yield to avoid over pumping are required.

Information Sources

2.1.5 Groundwater Abstraction Using Handpump-equipped Wells
Technical Description
Handpumps tap groundwater from shallow or medium depth aquifers and from deep aquifers if the at rest water level is high enough. Handpumps are water conveyance systems used to bring groundwater to the surface. There are a number of such pumps in operation in Africa and numerous textbooks provide specific descriptions of these devices (Figure 31).
Model "B" bushpump
Volantia pump
Afridev pump
Figure 31. Some commonly used handpumps.
In normal circumstances, handpumps are installed in wide diameter wells, which can be constructed by hand to depths of up to about 15 m, or drilled by rigs to much greater depths. The type of well most widely used is the hand-dug well, which is one of the cheapest means for providing a small supply of water in rural areas. A depth of about 10 to 20 m is usually considered the limit of practical manual sinking. The diameter of the well should not be less than 1.2 m, allowing two persons to work together in the well. A lining, that serves several purposes, should be used as the well is sunk. The lining is a protection during construction against caving and collapse, and retains the well wall after completion. There are many materials suitable for linings; e.g., masonry, brickwork, and
plain or reinforced concrete. On the bottom of the well, it is usual to place a filter of graded layers of gravel to prevent the ground material from being drawn upwards into the well with the water. At the surface, the lining of the well should be raised at least 0.6 m above ground level and provided with a protection platform to channel drainage away from the well.

Small diameter wells may also be constructed by means of an auger. The auger, which is usually about 100 mm across, may be rotated by hand. Mechanised augers, or power augers, are also available. Once the water-bearing layer has been penetrated, the necessary length of piping, tipped with a screened wellpoint, or strainer, is lowered into the hole; a pump attached to its upper end, and the well "cleared" by pumping. Tube wells consist of a perforated or screened pipe which is jetted or driven into the groundwater-bearing aquifer. Tube wells can yield large quantities of water, but the depth to which they can be driven is limited and the ground formation must be appropriate for their use. Their most common application is in the extraction of groundwater from waterbearing sands, especially those forming the beds of ephemeral streams.

Tube wells can also be installed in perennial rivers, making use of the natural filtering properties of sandy beds of the rivers by drawing water through the river beds instead of from the rivers themselves. The pipes are usually 25 to 100 mm in diameter. The wells constitute a good means of obtaining water from areas with relatively coarse sand.

**Extent of Use**

Wells using handpumps are extensively used throughout Africa.

**Operation and Maintenance**

The operation and maintenance of handpumps varies depending on the type and complexity of the pump. Attempts at designing a reliable pump which can be maintained at the village level continue. Experimentation with these village level operation and maintenance (VLOM) schemes are shifting gradually to focus on institutional-level operation and maintenance. Preventative maintenance operations carried out by villages and institutions include greasing moving parts (taking care not to contaminate the water supply with oils and greases), tightening bolts, replacing seals (for some pumps), and cleaning the surroundings.
Level of Involvement
Local inputs to implementation of this technology are generally in terms of skilled labour and materials. Technical advice may be necessary in the conduct of hydrogeological investigations and well drilling.

Costs
While hand dug wells are quite inexpensive, boreholes drilled by rigs are fairly expensive in terms of initial capital costs. Dug shallow wells and augured tube wells have a per capita construction cost of $6 to $20, with an operation and maintenance cost of $0.02 to $0.14 per capita per year. Machine-drilled boreholes, equipped with a hand pump and serving a population of about 200 to 300 people, will have an estimated per capita construction cost of $19 to $23, and an operation and maintenance cost of $0.26 to $0.52 per capita per year.

Effectiveness of the Technology
The delivery rate of most handpumps is around 20 l/min, and their ease of operation makes them ideal for rural operations.

Suitability
Dug wells are an appropriate option in areas where groundwater is less than 20 m below ground level. Augured tube wells, dug using motorised and/or manual rigs and augers of limited penetration, are appropriate in areas in which groundwater occurs at depths between 20 and 35 m. Motorised, conventional drilling rigs are an ideal means of developing water supply sources in areas where groundwater occurs at depths greater than 35 m below ground level, or in hard rock between 20 and 25 m depth, where the weathered material is thin.

Environmental Benefits
The existence of a well may lead to increased erosion in its immediate vicinity. However, wells are focal points for other development such as the planting etc.

Advantages
Well water is relatively safe without treatment. Hand dug wells are inexpensive and can be constructed using local skills and materials; community participation is easy to organize. Further, the operation of handpumps requires no external power and few skills, and the pumps may be maintained by local technicians. The use of spare parts is small.
Disadvantages
The capacity of a well is limited, and service supply levels are lower than in piped schemes supplied from conventional sources. Hand dug wells are reliable only in areas where good quality groundwater is available at shallow depth. The hygienic quality of the wells, especially shallow wells, is not always satisfactory as a result of surface water intrusions leaking through the slab and superstructure, and around the pump casing.

Cultural Acceptability
There are no cultural problems in utilizing groundwater for domestic purposes. However, communities do not like wells to be developed too close to sacred places such as shrines.

Further Development of the Technology
There is need to improve on the methods of digging the shallow wells. Also, the handpump needs further developmental work to make it more suitable for village level operation and maintenance. Maintenance systems require further development to ensure sustainability.

Information Sources
Further information can readily be obtained from the Departments of Water in the various countries, and also from organisations such as UNICEF, World Vision, CARE, and Save the Children, among others.

2.1.6 Rope-washer Pump
Technical Description
The rope-washer pump consists of a rope with knots or rubber washers, whose diameters are slightly less than the diameter of the pipe, placed at intervals along it (Figure 32). This assembly is drawn up inside a rising pipe, and is capable of drawing relatively large volumes of water to the height of the pump. During operation, the pipe is inserted into water and the rope drawn upwards through the pipe by means of a winding drum with a crank. Water is also drawn up and discharged at the top. The rope and washers pass round the winding wheel and return to the bottom of the pipe thus completing the circuit. This design can be modified to avoid slippage of the rope on the pulley by using old tyre casings to make the pulley wheel. To prevent the washers getting caught, and to support the bottom of the pipe above the bottom of the well or river bed, a suitable pipe stand and rope guide is necessary. Friction should be kept low by allowing leakage between the
washers and the pipe stem.

Figure 32. The rope and washer pump (Lambert, 1990).

**Extent of Use**
The rope-washer pump is receiving moderate use in Kenya, Zimbabwe and Burkina Faso.

**Operation and Maintenance**
Rope-washer pumps rely are manufactured locally, and, therefore, are amenable to local repair and maintenance using simple, locally-available materials.

**Level of Involvement**
The components of this technology are community-manufactured and operated. Government and NGOs are often involved in the promotion of this technology and development of refinements.

**Costs**
Rope-washer pumps cost between $30 to $50 to construct. The construction cost increases in proportion with the lift required.

**Effectiveness of the Technology**
This technology is appropriate for all domestic uses and micro-irrigation or garden irrigation uses. This pump can pump high volumes with a low lift.

**Suitability**
The technology is suitable for abstraction from shallow wells of up to 10 m depth or from rivers and streams. It is easily adaptable to changing volumes by adapting the diameter of the pipe and washers.

**Environmental Benefits**
The introduction of a simple device such as the rope washer pump, lends itself to microscale gardening and the accompanying positive environmental management practices.

**Advantages**
The pump has no valves and does not require complicated bearings. It is easy to manufacture, with local resources, and is ideal for flood irrigation of small gardens.

**Disadvantages**
The pump has limited lift and poor pumping efficiency, as water is allowed to leak through the valves.
Cultural Acceptability
There are no known cultural inhibitions.

Further Development of the Technology
The rope-washer pump technology needs to be further disseminated to gain additional field experience of its operation. The efficiency of the pump needs to be improved.

Information Sources

2.1.7 Artificial Groundwater Recharge

Technical Description
Artificial recharge is the use of infiltration basins (Figure 33) or injection wells (Figure 34) to recharge groundwater resources. Infiltration basins can take many forms. For example, a storage dam can function as an infiltration basin under certain conditions. With infiltration basins, it is essential to construct the pond on an infiltration zone lying above an impermeable layer.

Extent of Use
Infiltration basins and injection wells have been implemented in Botswana, Egypt, Tunisia, and Algeria. In Zimbabwe, small infiltration dams are being developed.

Figure 33. Recharge by infiltration basin.

Operation and Maintenance
There is need for a source of the water to be recharged. Groundwater recharge using infiltration basins in areas with high evaporation rates is not likely to be effective. Likewise, the presence of clay lenses covering parts of an aquifer can be a problem as they can prevent the infiltrated water from reaching the aquifer. Both problems can be overcome through the use of injection wells, which allow the recharge water to be inserted into an aquifer under pressure.

Figure 34. Recharge by injection well.

Level of Involvement
Construction of recharge basins can be undertaken by local personnel with experience in
well digging. Government assistance may be required to identify appropriate recharge sites.

**Costs**
The costs are moderate, depending on the scale of operations.

**Effectiveness of the Technology**
Recharged water may take on the qualities of normal groundwater, as impurities are removed within the soil profile. However, there is also the possibility of introducing contaminants into the groundwater system through the use of this technology, depending on the source of the recharged water. Groundwater recharge as a stormwater management technology creates the least cause for concern, and ensures the reliability of water supplied from nearby wells.

**Suitability**
This technology is appropriate for arid regions lacking alternative water sources. Water reclaimed in this fashion may be used as an alternate source of drinking water. Recharge may be appropriate in areas where behaviour of naturally-occurring groundwater is uncertain.

**Environmental Benefits**
The construction of infiltration basins may help to control soil erosion. The basins are usually appropriate habitat for a number of birds and wild animals.

**Advantages**
Groundwater recharge, especially using injection wells, conserves water through reduced evaporation. Clean drinking water may be recovered from wells in the vicinity of the recharge field without using complicated treatment systems.

**Disadvantages**
The water from a recharged aquifer cannot be used without a system of abstraction. There is also a possibility of polluting the aquifer with the recharged water.

**Cultural Acceptability**
The technique is culturally acceptable.

**Further Development of the Technology**
There is limited scope for further development of technology, especially in terms of ensuring the quality of the recharged water and the prevention of groundwater pollution.
2.1.8 Well-tank Borehole Well

Technical Description

This is a type of borehole in combination with a well. The latter serves as storage. This technology is used in cases where hydrogeological conditions are such that neither structure alone can meet the operational needs of the beneficiaries.

The borehole is drilled to groundwater level, and the well-tank, which is 0.5 m to 1 m away from the borehole, is drilled to a depth such that the static level of the borehole is at least 6 m higher. This difference in elevation provides a sufficient water level in the well to permit easy abstraction of the stored water. This water depth in the well-tank is maintained by the construction of a junction between the well-tank and the borehole at the bottom of the well-tank at the static water level (Figure 35).

Extent of Use

This technology has been used in projects in Mauritania. Similar systems, with slightly different arrangements of the components, exist in Egypt, Libya and Sudan.

Operation and Maintenance

Since the well-tank is below the static water level in the borehole, water enters the welltank by gravity through the perforated junction between the well and the borehole. The depth of water in the well-tank becomes that of the borehole. Abstracting of water is carried out in the traditional way from the well-tank. Maintenance is carried out periodically by cleaning the well-tank as and when necessary. The well-tank should be protected against contamination as described elsewhere in this volume.

Figure 35. Well tank - borehole well.

Level of Involvement

The capital investment in the borehole may be prohibitive for individuals, but the technique can be established jointly by individuals within communities. The technology
can be implemented with limited technical support from extension agencies.

**Costs**
The costs include the drilling costs of the borehole and well-tank, on the one hand, and the cost of providing the superstructure of the well, on the other. The cost per linear metre of establishing the borehole, which can be up to between 100 m and 400 m deep, is over $300. The cost of establishing and protecting the well is between $260 and $408/linear metre.

**Effectiveness of the Technology**
The borehole well is as efficient as the simple well, and, generally, is more reliable. The well-tank system experiences fewer seasonal fluctuations in water level compared to other wells in the regions in which the technology has been applied, and, as a result, rarely dries up. **Suitability** Well-tanks are adaptable for use in all terrains. However, in areas with discontinuous aquifers, where groundwater is captured in very hard, fractured geologic structures, and/or where wells cannot readily penetrate the substrate, storage can be provided by surface cisterns. Similarly, in sedimentary basins, shallow wells may be more appropriate storage structures.

**Environmental Benefits**
Use of this technology makes groundwater readily available at the surface. If used within conservation areas, this technology can provide water for environmental rehabilitation programmes, especially in areas where this would otherwise be impossible. However, care should be taken to avoid over-abstraction of groundwater, and prevent contamination of groundwater from surface sources.

**Advantages**
Use of this technology allows the use of simple abstraction methods, and can provide a reliable source of water.

**Disadvantages**
The technology has an high capital investment cost, and is dependent upon a reliable groundwater source.

**Cultural Acceptability**
There are no known cultural inhibitions relating to the use of this technology.

**Information Sources**
2.1.9 Use of Cisterns

Technical Description
Cisterns are an ancient method of water harvesting, dating back to the early Roman empire. There are artificial reservoirs constructed by excavating bedrock, such as limestone, to depths of between 3 and 7 metres to provide water storage throughout the Roman world. While serving a similar purpose, modern cisterns are usually built with cement blocks or fired bricks. Cisterns collect water in the form of runoff from a rock-lined catchment or other suitable, nonporous surface. There is commonly a settling basin at the cistern entrance which serves to settle sediments borne by the runoff. A screen is also provided to remove larger particulates.

Extent of Use
This technology is used in a number of north African countries, where it is known by a variety of different names. These names are indicated in brackets. The technology is used in Libya (where it is known as Fusqia or Majen), Algeria (Sahrij), Egypt (Roman reservoir), Tunisia (Fuskia pool), Morocco (Al Majel), and Sudan (ground reservoir). Operations and Maintenance Routine maintenance is necessary to reduce losses to leakage by repairing cracked walls. There is also a need for the periodic removal of sediments which might choke the entrance.

Level of Involvement
This technology can be constructed, operated and maintained by villagers.

Costs
The cost of implementing this technology is reasonably low, as most of the construction of the cisterns can be done by communities. However, mechanization is increasingly used for the digging of the cistern, which increases the cost.

Effectiveness of the Technology
The volume of water harvested depends on the amount of rainfall and the size of cistern. Major losses of water generally occur in the catchment area, through infiltration and evaporation, rather than from the cistern itself, provided the cistern is maintained.

Suitability
The technology is suitable for use in all regions of Africa and is similar to rock catchment systems. In areas of high evaporation, the cistern should be covered to minimize evaporative losses.

**Environmental Benefits**
The use of cisterns to capture runoff has no known negative environmental effects, and can provide water for a variety of environmental purposes in dry areas.

**Advantages**
This technology has the advantage of being a simple, low cost technology which can increase the yield of water from rock catchment systems.

**Disadvantages**
Use of this technology may require provision of an abstraction system to draw the water from the cistern. Because of the likelihood of contamination from surface sources, this technology is not ideal for use as a potable water source.

**Cultural Acceptability**
This technology is culturally acceptable by the communities in which it has been used.

**Information Sources**

**2.1.10 Use of Palm Petioles for Rainwater Harvesting**

**Technical Description**
A suitable tree is planted in the homestead grounds. Suitable trees usually have broad leaves which collect rainwater which is channelled to a collecting pot (Figure 36). Figure 36. Various methods of collecting rainwater using trees, leaves and plant materials.

**Extent of Use**
This technology is used in Nigeria.

**Operation and Maintenance**
The technology has very limited maintenance requirements. Level of Involvement The technology is usually used by individual households.
Costs
Costs are negligible, and, depending on the type of tree used, may result in a net profit to the householder.

Effectiveness of the Technology
The effectiveness of this technology depends on the effectiveness of the collecting channel. There are often significant losses resulting from spillage and other leaks within the system.

Suitability
The technology is suitable for collecting small volumes of water at the household level.

Environmental Benefits
Use of this technology promotes the growing and maintenance of trees. It may encourage the propagation of indigenous vegetation.

Advantages
It is a low cost technology that does not require extensive knowledge to construct or complex equipment to operate.

Disadvantages
Large volumes of water cannot be collected using this technology. Also, the water may be contaminated with dust, insects and bird droppings as well as plant material.

Cultural Acceptability
The technology is culturally accepted in those areas where it is practised.

Information Sources
United Nations University, Institute for Natural Resources in Africa, ISSER Building Complex, Nasia Road, University of Ghana, Accra, Ghana.

2.2 WATER QUALITY IMPROVEMENT TECHNOLOGIES

2.2.1 Denitrification of Groundwater

Technical Description
Denitrification is the process whereby nitrogen is removed from water. When employed in water quality improvement technologies, denitrification treats water to reduce its nitrate-nitrogen content to potable levels. There are three principal approaches to nitrate removal: ion exchange, chemical reduction and biological denitrification. The first two are well-documented in various publications (Gauntlett, 1975; Metcalf, 1975) and are not,
therefore, further described here.

With biological denitrification, aerobic heterotrophic bacteria, under anaerobic conditions, utilise the oxygen molecules that, together with nitrogen, form nitrate. This oxygen is used in place of dissolved elemental oxygen. Removal of the oxygen molecules converts nitrate to nitrite, ammonia or nitrogen gas. This process is common in waterlogged soil and other aquatic environments. Within the organisms, the nitrate-derived oxygen acts in the same manner as elemental oxygen, as an acceptor for electrons and hydrogen. Chemical energy to drive the process is added in the form of organic carbon, methyl alcohol, ethanol and acetic acid.

When this process is used to treat water, there is need to create an environment for the bacteria that mimics the soil conditions in which this process occurs naturally. This environment is generally created in biological reactors, like attached growth reactors (packed columns, rotating disc units and fluidized bed columns), suspended growth reactors and underground reactors for the treatment of nitrates, in order to bring the denitrifying bacteria into contact with the water to be treated (Figure 37). Generally, also, the chemical energy needs to be added artificially to the system to stimulate the denitrification process. Thus, a denitrification plant, in its most basic form, comprises an injection well for adding nutrients, a biological reactor, and a pumping well for the abstraction of treated water.

**Extent of Use**

This technology has been used in projects in South Africa.

**Operations and Maintenance**

Denitrification technologies have high energy requirements associated with the suspended growth reactors. Electrical energy is required in order to keep the bacterial floc in suspension by stirring. Chemical energy sources are also required in many systems. The use of methyl alcohol as a carbon source has economic and operational advantages because of the resulting low solids production (Dahab, 1988).

With underground biological denitrification, problems may arise as aquifer pore spaces clog with biological matter. In such cases, the recommended approach is to undertake denitrification in an above-ground biological reactor with underground recirculation of
the treated water as a secondary treatment.

**A B**

(A) Sectional view of underground denitrification.

(B) Sectional view of aboveground denitrification with groundwater recharge.

(C) Plan view of sections.

C

Figure 37. Groundwater denitrification unit (Latimela, 1993).

**Level of Involvement**

This technology requires specialised skills and knowledge to operate effectively. Thus, while communities can participate by funding the units and their installation costs, government participation is required to design, install, operate and maintain the systems.

**Costs**

Biological denitrification has been found to be cheaper than ion exchange (Latimela, 1993). The treatment costs for a design capacity of 20 m3/day were found to be $0.26/m3. The capital and operating costs for biological denitrification for a 10 m3/day capacity were found to be:

- Capital cost/m3 $0.33
- Running cost/m3 $0.07
- Treatment cost/m3 $0.40

**Suitability**

This technology is suitable for the reclamation of nitrate-contaminated groundwater.

**Advantages**

Denitrification technologies remove nitrate from the waters to reduce the risk of methaemoglobinaemia in infants and others. Use of biological treatment methods do not require regeneration of media and, hence, there is no problem of brine disposal. With underground denitrification, both denitrification and secondary treatment are performed in situ, reducing the need for infrastructure.

**Disadvantages**

Because this is a biological system, there will be fluctuations in quality. In some cases,
there may be a sensitivity within the service population to bacterial toxins. A large bacterial population, free of pathogens, has to be developed. If the system breaks down, this bacterial mass may be lost. Should this happen, no further treatment of water is possible until the bacterial population is reestablished.

**Further Development of the Technology**

Further studies are essential to determine the potential of aquifer pore spaces to clog with biological matter under operational conditions, and to identify suitable remedial measures to overcome this problem short of reconstructing the system as an above-ground reactor. Development is also needed to ensure a more constant output water quality from these systems.

**Information Sources**


**2.2.2 Iron Removal**

**Technical Description**

Many countries have experienced groundwater quality problems due to high levels of iron in groundwaters. In most cases, these high levels of iron are due to the composition of the bedrock and soils (such as lateritic soils), although, in some cases, high iron concentrations can be caused by the corrosion of the metallic iron pipes within the abstraction or distribution systems.

This technology is designed to make iron-rich groundwaters potable, using a simple and low cost technique. The "Iron Removal Unit" (Figure 38) is composed of an aeration channel (at its head), from which aerated water drops into a rectangular settling basin.
The particles of ferric oxide flocculate and settle at the bottom of the settling basin, creating a deposit of iron mud. At five to ten centimetres from its bottom, clarified water from the settling basin is removed to an adsorption basin containing two layers of gravel: the first layer of gravel is usually a 45 cm deep layer of 1.5 to 2.0 cm sized gravel; the second layer of gravel is usually a 25 cm deep layer of 2.5 to 5.0 cm sized gravel. Water flows over a weir at the outlet of the adsorption basin to the sand filtration basin. The sand filter is constructed using a 40 cm thick layer of 0.2 to 5.0 cm sized gravel at its bottom, topped by a 20 cm thick layer of 0.2 to 4.0 mm sized sand. The filtered water is collected by a pipe and distributed to the users.

The various basins that comprise this system have a different direction of the flow in the various basins: in the settling basin, flow is from top to bottom; in the adsorption basin, flow is from bottom to top; and in the filtration basin, flow is again from top to bottom.

**Extent of Use**
A number of water points in Burkina Faso and Mali are equipped with this type of iron removal unit.

**Operation and Maintenance**
Users must be trained in the maintenance of the unit. However, once this training has been completed, the unit is very easy to operate and maintain. When people begin pumping, the unit operates continuously without further intervention, except for routine cleaning of the basins to remove accumulated particulates and the back-washing of the sand filter. This technology provides good quality water from otherwise saline water sources.

**Level of involvement**
Technical assistance is necessary during the construction. Once the system is built and the local people trained for the maintenance and operation, there is no external involvement.

Figure 38. Schematic of a typical iron removal unit.

**Costs**
This is a low cost technology. Typical costs in Mali and Burkina Faso range from $250 to $300 per unit.
Effectiveness of the Technology
Studies have shown that there is a considerable decrease in the iron level in the treated water provided by this technology. Based on these studies, the efficiency of iron removal averages between 90% and 96%.

Suitability
The technique is most suitable in regions with lateritic soils where the high level of iron often results in the abandonment of handpumps by users.

Advantages
The technology uses local materials and labour to install and operate the unit. It is simple to operate, and requires no chemicals except for those necessary to disinfect the unit after each cleaning. Use of the unit can rehabilitate what would otherwise be abandoned water sources.

Disadvantages
If not cleaned periodically, the system may become blocked with the iron floc.

Cultural Acceptability
This technology is culturally acceptable in areas where it is used.

Information Sources
Contacts
Centre Regional Pour l'Eau Potable et l'Assainissement a Faible Cout (CREPA), 03 BP 7112 Ouagadougou 03, Burkina Faso. Tel (226) 310359/60, Fax: (226) 310361.

Bibliography

2.2.3 Use Of Natural Plants
Technical Description
The Moringa oleifera is a small tree which grows to about 10 m high in the Sahalien and Sudano-Sahalien zones of Africa. The seeds of this tree can be used as a flocculent aid for water purification. Enough Moringa seeds must be ground in proportion to the quantity of water to be treated. The necessary quantify of powder is mixed with a little bit of water and allowed to stand for a few minutes before use to allow the ground seeds to
settle. This water is decanted through a sieve and is mixed with the water to be purified. Once mixed, the vessel holding the water to be treated must not be moved for at least an hour to allow the process to work in an efficient way (Figure 39).

Figure 39. *Moringa* seed water purification using traditional gourds as treatment vessels.

**Extent of Use**
Water treatment based on this technology is used in all West African countries. In West and Central Africa, the *Moringa oleifera* is used most commonly by housewives in the preparation of sauces. The tree grows along water courses and in the plains, and is called by different common names according to the language used in each portion of its range throughout this vast area. However, the use of seeds for water purification is not so well known.

**Operation and Maintenance**
The *Moringa oleifera* seed powder must be prepared just before its use. The means of preparing and using the seeds is as follows:

(i) remove the skin of the fruit and trim seeds;
(ii) dry the seeds;
(iii) crush or grind the dried seeds to a powder;
(iv) mix the necessary quantity of the powder with a little water;
(v) decant the water and mix the liquid with the water to be purified;
(vi) mix the water and the liquid rapidly with a stick for at least 5 minutes;
(vii) place the water being treated where it will not be disturbed;
(vii) cover the water container, wait 1 to 2 hours, and collect the purified water.

**Rapid Gravity Sand Filtration**

**Technical Description**
Raw water is pumped into a flocculation chamber into which aluminium sulphate is added to aid in coagulation of contaminants. In some cases, electrolytes or other chemicals are also added. The floc is then settled before the water is filtered through a rapid gravity filter. The filter bed must be periodically cleaned by back washing to avoid clogging.

**Extent of Use**
This technology is used throughout Africa.
Operation and Maintenance
Use of this technology requires pumping units and other chemical dosing units which need periodic inspection and calibration. The sand filter requires periodic back-washing.

Level of Involvement
This technology requires a technically qualified operator.

Costs
Costs are fairly high in comparison with other systems, especially if additional electrolytes are required.

Suitability
The technology is suitable for large urban centres.

Environmental Benefits
The are no known negative impacts associated with properly maintained systems. However, sludge from the flocculation chambers may cause pollution if not properly disposed of.

Advantages
This technology provides high quality water, and is a proven method for large-scale water supply.

Disadvantages
The technology is expensive to operate.

Effectiveness of the Technology
The technology is effective in polishing raw water to produce pathogen-free potable water.

Cultural Acceptability
This is a global technology; no cultural problems have been noted.

Slow Sand Filtration
Technical Description
Raw water is filtered through a sand bed made of uniformly graded sand overlying a gravel bed. Treatment occurs through physical, biological and chemical processes. Some treatment occurs in the "schmutzdekke".

Extent of Use
This technique is widely used in rural areas of Africa.

**Operation and Maintenance**
Minimal maintenance is required.

**Level of Involvement**
Use of this technology requires few technical skills.

**Costs**
Costs of construction and operation are reasonably low.

**Suitability**
Slow sand filtration is suitable for small settlements.

**Environmental Benefits**
There are no known negative impacts of using this technology.

**Advantages**
The technique provides high quality potable water at low cost, without the need for chemicals.

**Disadvantages**
The filters need regular resanding and periodic removal of the top sand layer for optimal operation.

**Effectiveness of the Technology**
The technology produces a product water with near zero coliform counts

**Cultural Acceptability**
This is a global technology and is culturally acceptable.

**Level of Involvement**
In west and central Africa, making water drinkable by using the *Moringa* is still in the experimental stages. Both government authorities and the communities are still not heavily involved in using this technology.

**Costs**
The cost of using this technology is in terms of the time spent in gathering the seeds, preparing them, grinding into powder, and using the powder to purify limited volumes of water. Each family must have several containers, depending on size. For ease of preparation and use of the treated water, a vessel with a tap should be used. A typical installation for using this technology ranges in capital cost from $7 to $10.
**Effectiveness of the Technology**
This technology eliminates up to 99% of bacteria found in water. A good, full seed will typically purify 5 l of water that is not turbid; two seeds will purify between 2.5 l and 5 l of water that is slightly to moderately turbid; and three seeds will purify 2.5 l of very turbid water.

**Suitability**
The *Moringa* can be cultivated, in well drained soils, such as those soils which are suitable for purifying unsafe wastewaters.

**Advantages**
*Moringa*-based technologies are simple and are a practical method of water purification. It is an inexpensive technology.

**Disadvantages**
*Moringa* seeds are not available throughout the year, which curtails the ability of this technology to perform year round.

**Cultural Acceptability**
The purification of water using the *Moringa* is little known in West and Central Africa, but leaves are already eaten by members of most societies.

**Information Sources**

**Contacts**
*CIEH*, B.P. 369, Ouagadougou, Burkina Faso. Tel. 307112. GTZ, Dog Hannarsk Joedureg 1-2, D6236 Eschborn 1 RFA.

**Bibliography**

2.2.4 In-stream Water Quality Upgrading

**Technical Description**
A typical water quality enhancement unit consists of a low diversion dam, infiltration gallery and clear water reservoir. A low diversion dam is constructed using a pile of rocks bound together with cement or mortar. The filter box is constructed of concrete according to designed specifications. There could be one or two filter boxes depending on the quality of the stream water. The filter box is then filled with a filter media which is
comprised of 20 cm of gravel and 1.2 m of sand packed on top of the gravel. The inlet end of the intake pipe is covered with nylon mesh to prevent large suspended particulate matter from entering the intake pipe. The portions of the pipe within the filter boxes are perforated. Using such an arrangement, water could flow from a raw water source onto a filtration medium through which it is filtered and advanced to the collection well, all under gravity. The clear well reservoir, in which the filtered water is collected, is constructed of concrete. The size of the reservoir depends on the size of the population.

Having been provided with a design, the construction of this system can be accomplished by a community with the help of local artisans living in the community. A typical unit, constructed on the Nima Creek in Accra, Ghana, was designed to deliver a minimum of 30 litres/person/day into the filtered water well (Figure 40). This well was 5 m deep and 2 m wide, extending 2 m below the water table in depth. The filtered water in this system was accessed by using a handpump fitted onto the collection reservoir. However, for small communities with populations of 1,000 or less, outlet pipes with valves fitted to the clear water well are cheaper alternatives.

**Extent of Use**

This technology has been used widely in some rural communities in Ghana. In the last twenty years, however, the technology has not been actively used, having been replaced by other technologies for rural water supply, augmented by the electrification scheme started by the government. Nevertheless, the technology has recently been revisited and improved for application in rural water supply.

**Operation and Maintenance**

The local residents operate and maintain the system using simple tools. Preventive maintenance involves cleaning the nylon mesh cover of the intake pipe two to three times per week.

**Level of Involvement**

This technology was adopted as a community built and managed system. The planning and design of the system are the only aspects of the project which require the involvement of expert personnel. Figure 40. Infiltration gallery on the Nima Creek, Accra, Ghana.

**Costs**
A community can develop this technology with very little guidance. The approximate costs of construction are as follows: Intake civil works $15/m Filtration gallery and clear water well civil works $600.

**Suitability**
This technology is suitable for low income, rural communities that cannot finance and sustain conventional water supply systems. It is also suitable for refugee camps where electric power supplies are not available, or in other areas where chemicals and equipment for water purification are difficult to obtain.

**Advantages**
The technology is low cost and needs no power supply, no chemicals, and few spare parts to function. It can be constructed, operated and maintained by semi-skilled people in local communities.

**Disadvantages**
It is difficult to backwash the filter without a power source; thus, the quality of the filtered product water and a satisfactory filtration rate may not be sustained. In such situations, the filtration media may have to be replaced on a frequent basis for best efficiency and quality of product water.

**Further Development of the Technology**
Development of methods for backwashing the filter material is necessary to maintain the sustainability of the system.

**Information Sources**

### 2.3 WASTEWATER TREATMENT TECHNOLOGY AND REUSE

**Waste Stabilization Ponds**

**Technical Description**
Waste stabilization ponds consist of
(i) preliminary treatment stages which include a screening chamber for the removal of large solids, a grit chamber for the removal of grit and other inert materials, and a flow recording system;
(ii) facultative ponds, which are responsible for the removal of BOD5
largely through sedimentation and biological degradation; and,
(iii) maturation ponds, which are responsible for the removal of pathogens through exposure of the pathogens to conditions inhospitable to the microorganisms.
Where the ponds are expected to treat "strong" wastes, anaerobic pretreatment ponds may be installed upstream of the facultative ponds.

**Extent of Use**
Ponds are extensively used in Africa for the treatment of urban waste.

**Operation and Maintenance**
At the pond edge, maintenance involves the removal of grasses to limit mosquito breeding habitat, plugging holes caused by birds and rodents, and maintaining pumps were necessary.

**Level of Involvement**
Municipal artisans or technicians of similar qualification and/or experience are required to operate and manage these facilities.

**Costs**
This technology is low in cost in comparison with other treatment systems. Suitability Ponds are suitable in most countries of Africa.

**Effectiveness of the Technology**
Ponds are effective in removing BOD and suspended solids.

**Environmental Benefits**
This technology is not capable of removing nutrients, which may lead to the enrichment of the receiving waters (eutrophication).

**Advantages**
The technology is effective in removing BOD at low cost.

**Disadvantage**
Ponds demand a large land area and cannot remove nutrients.

**Cultural Acceptability**
Residents complain of smell if homes are built too close to a poorly operated and maintained plant.

**Further Development of the Technology**
Ponds work well but need more research to improve design efficiency and enhance nutrient removal capabilities.

**Information Sources** Standard textbooks and more specifically work by Marais (South Africa) and Mara (Zambia).

Wastewater recycling and reuse technologies fall into three major classes:

- Direct reuse
- Indirect reuse
- Internal reuse (described under "Mining and Industry", below)

These three classes have different technical descriptions, extents of use, and operation and maintenance requirements, but are otherwise similar. The technical descriptions for the different wastewater treatment systems are given in the text boxes below. Because these are well-known technologies, numerous engineering texts exist which detail aspects of their design, construction and operation. Standard text books should be referenced for such detailed descriptions.

### 2.3.1 Direct Reuse of Treated Municipal Wastewater

**Technical Description**

Direct reuse involves the abstraction of effluent from sewage treatment works and, after further treatment (e.g., tertiary treatment or retention in maturation ponds), mixing it with raw water at the inlet of a water treatment works.

**Extent of Use**

This technology is extensively utilized in Southern Africa, especially in South Africa, Namibia, Zambia and Zimbabwe, as well as in Mauritania and Burkina Faso in West Africa.

**Conventional System**

The simple conventional system is described here, although this could be operated as activated sludge system.

**Technical Description**

The technology consists of

1. the preliminary treatment stage which has a screen chamber, a grit chamber and flow recorders similar to the waste stabilization system;
2. primary sedimentation basins for the settlement of organic solids;
(iii) biological reactors which in Africa are commonly trickling filters for the biodegradation of soluble organics;
(iv) secondary sedimentation basins for settlement of biomass;
(v) sludge treatment systems such as digesters or drying beds.

**Extent of Use**
The technology is widely used in Africa.

**Operation and Maintenance**
Maintenance consists primarily of inspecting and repairing pumping systems and screens, and sludge removal.

**Level of Involvement**
These systems may be constructed by local artisans, but designed by engineers.

**Costs**
Costs are relatively high compared to ponds.

**Suitability**
This technology is suitable in all countries, but for reasonably large settlements.

**Effectiveness**
The technology is effective in removal of BOD.

**Environmental Benefits**
The use of this technology usually improves the water quality of the discharged wastes but can potentially result in nutrient enrichment of surface and groundwater.

**Advantages**
The technology is effective in removal of BOD5. Disadvantages This technology needs skilled manpower to operate, is costly to run, and does not remove nutrients leading to potential pollution problems.

**Cultural Acceptability**
Poor operation results in odour problems which are objectionable to community. Also, Africans are not usually at ease with seeing their own excreta.
Information Sources
Standard text books and research organizations in Africa.

Operation and Maintenance
Catchment quality control is essential. This involves the segregation of industrial effluents from the catchment of the reclamation plant to avoid contamination with persistent organic contaminants, heavy metals, and other substances deleterious to human health. The wastewater should undergo the both biological and physico-chemical treatments: chemical coagulation and flocculation; solids separation; disinfection; activated carbon filtration; reverse osmosis filtration; and stabilisation. These steps may be considered to be routine water reclamation stages. Further, because of the flocculation and solids separation stages, sludge management practices are required when using this technology. There is a need for a steady supply of wastewater entering the reclamation process. This is usually in contrast to the irregular urban flows. Balancing inflows is normally accomplished through the use of maturation ponds.
Also, quality analysis is essential since each reuse application has its own quality requirements. Specific approaches to reclamation technologies vary depending on the quality of the wastewater. This, in turn, dictates the specific operation and maintenance requirements for each approach. It is essential to the proper operation and maintenance of these systems that the correct procedures be adopted. Regular and frequent monitoring is required for the safe use of this technology, including flow measurement, continuous monitoring of selected parameters, sampling for quality control, maintenance of instrumentation and operating systems, and visual observation and bio-monitoring of the product water.

Modified Activated Sludge (MAS) System
The MAS system is a wastewater treatment system aimed at polishing the effluent to remove nitrates and phosphates which can contribute to eutrophication of surface waters.

Technical Description
The MAS system has a preliminary stage similar to conventional wastewater treatment systems, including the primary sedimentation process. MAS treatment involves the passage of settled wastewater
through a series of anoxic and oxic zones. In the oxic zone, nitrification of ammonia nitrogen compounds take place, and, in the oxic zone, the reduction of nitrates take place. Microorganisms in both zones utilize soluble phosphorus for biomass production (growth). The excess biomass thereby generated is settled in the sedimentation basin. Oxygen in oxic zone is provided by electrically drive aerators. The effluent produced in this way can be discharged to a receiving water body with low dilution potential, and in situations where effluent from conventional systems would result in nutrient enrichment of the water body.

**Extent of Use**
MAS systems are used in South Africa, Zimbabwe, and Namibia, and are being used experimentally in other countries.

**Operation and Maintenance**
Electric motors and rotors need regular inspection. All other operation and maintenance requirements for conventional wastewater treatment plants apply.

**Level of Involvement**
Use of this technology requires skilled operators and support staff. Costs MAS systems are expensive to operate, especially given the electric power input required. Suitability The technology is suitable for urban centres that need to, or may need in future to, recycle water.

**Effectiveness of the Technology**
The technology is very effective in removal of BOD, suspended solids and nutrients Environmental Benefits MAS treatment reduces the dangers of pollution of surface water bodies. Advantages MAS treatment removes nutrients, and produces a product water that may be recycled immediately. Disadvantages The technology requires high energy inputs, making it expensive to operate.

**Cultural Acceptability**
There are no known cultural problems recorded for the specific
technique of nutrient removal, but communities object to having a wastewater treatment plant close to residential areas. There are religious restrictions on direct reuse of wastes.

**Information Sources**
City Engineer, City of Harare, Zimbabwe. City Engineer, City of Pretoria, South Africa. Design details may be found in standard wastewater engineering textbooks.

**Level of Involvement**
The major player is the wastewater collection and treatment agency, normally the local authority. The user receiving secondary effluent becomes responsible for its tertiary treatment, even though he would have to depend on the local authorities for the implementation of the necessary catchment quality control.

**Costs**
Costs vary from moderate to very high depending on method. Major factors are the capital costs of treatment facilities; labour, spares and energy; reticulation systems; and land. In Bulawayo, Zimbabwe, the costs of sewage treatment using coagulation, clarification, rapid sand filtration and chlorination stages is about $0.05/m³

**Effectiveness of the Technology**
The group of technologies is extremely effective as for each unit of wastewater recycled an equivalent amount of freshwater is saved.

**Suitability**
This technology is appropriate in regions experiencing severe water shortages, and where wastewater is collected in a sewerage system. Direct recycling is most appropriate for use in towns with modified activated sludge (MAS) plants since these plants have the capacity to remove nutrients. However, effluent used for irrigation need not undergo MAS treatment since the nutrients are beneficial for plant growth.

**Environmental Benefits**
Poor or absent control of effluent quality can have serious health problems for the users. However, most countries using this technology have both water quality and public health standards in place. Use of wastewater for irrigation can enhance crop or plant production and improve surface water quality.
**Advantages**

It is a proven technology that is effective in water resources management. Costs and production efficiencies are predictable. Moderate skill levels are required. Use of this technology typically reduces pollution problems by turning wastewater into an economically attractive substitute water source for irrigation and non-potable industrial use at reasonable cost. It therefore increases water availability.

**Disadvantages**

Wastewater reuse may be culturally and aesthetically unacceptable. Increased nutrient loads may lead to enhanced algal growth in surface waters and the need for higher rates of chemical usage in water treatment. There is also a possibility of ground water pollution. As noted above, health problems can occur if the effluent has been poorly treated. Poor or incomplete treatment can also lead to a risk of contamination of potable water with heavy metals and organic compounds. Because salts are not significantly affected by these treatment techniques, there is the risk of gradual build up of proportions of dissolved salts to unacceptable levels with direct reuse.

**Cultural Acceptability**

The acceptability of this technology depends on the region. Some cultures do not accept the handling and direct reuse of wastewater. It is essential to determine an appropriate balance between cost and efficiency.

**Further Development of the Technology**

There is a need for legislation and regulations for the control of both treatment and use, where these do not exist, and, where they do, for their consistent application. Studies need to be undertaken to determine the variations in effluent quality and its effect on the raw water being reused.

**Information Sources**


Department of Water Affairs 1986. *Management of the Water Resources of the Republic*
2.3.2 Indirect Reuse

Technical Description

Indirect reuse is the process whereby effluents from treatment plants are discharged through a secondary polishing process before the water is abstracted elsewhere. Such polishing regimes may be in an underground mine, across a dispersion field, via a river, or through some similar, intermediate step between the point of effluent discharge and raw water abstraction. The polished water may be mined using boreholes, after being discharged to surface water courses or to aquifers for subsequent abstraction, as in the case of heated effluent from some power station cooling plants.

Extent of Use

Indirect reuse is widespread in Botswana, Zimbabwe, South Africa and Malawi.

Operation and Maintenance

Quality control of effluent is necessary to ensure that it meets the desired standard. The standards should be set so that the effluent receives the appropriate degree of treatment prior to the treated effluent being abstracted for further use. In this regard, poor monitoring of receiving water body quality is a major concern in a number of countries in Africa.

Where pumping of effluent is required, pump spares may be a problem since these are usually imported in most cases.

Level of Involvement
Use of this technology involves the employment of skilled technical personnel, especially in the conduct of the quality assurance practices.

**Costs**
Transfer techniques used to move the effluent from the treatment plant to the receiving polishing regime largely determines the cost. If transfer can be accomplished using gravity flows, costs are significantly less than if pumping is required. These costs are added to the cost of the conventional treatment stage.

**Effectiveness of the Technology**
This technology can be effective in polishing treated wastewater for reuse. The transfer of the treated wastewater from the treatment plant to the polishing regime is usually highly efficient, but recovery of the discharged water is problematical, depending on the nature of the polishing regime. Recovery of water from surface polishing regimes may be greater than recovery from underground regimes.

**Suitability**
The technology is suitable for use in all countries in Africa where appropriate conditions for transfer and polishing exist.

**Environmental Benefits**
While this technology can augment conventional water sources, the possibility of polluting both surface and ground waters is high.

**Advantages**
It is a proven technology that is effective in water resources management. Costs and production efficiencies are generally predictable, and use of the technology can reduce water pollution problems. Moderate skill levels required, particularly in quality control. Because the wastewater generated is economically attractive for irrigation, this technology can increase water availability.

**Disadvantages**
The discharges associated with this technology may be culturally and aesthetically unacceptable. Increased nutrient loads demand the increased use of chemicals in raw water treatment. There is also a risk of contamination of potable water with heavy metals and organic compounds, and a possibility of surface and ground water pollution.

**Cultural Acceptability**
The acceptability of this technology depends on the region. Some cultures do not accept the handling and reuse of wastewater. However, the indirect nature of this technology may overcome such prohibitions on use of wastes.

**Further Development of the Technology**

Studies need to be undertaken to determine the variability of effluent quality and its effect on the raw water abstracted for reuse.

**Information Sources**


**2.3.3 Regeneration Water**

**Technical Description**

Use of regeneration water involves the indirect reuse of water that has already been used, primarily in the agricultural sector. In some instances, this water is utilised for urban purposes. The objective of this technology is to augment the available water through reuse.

In irrigation, excess irrigation water applied to the land surface drains via subsurface drains to open channels where it is conveyed away from the fields to prevent waterlogging of the crop roots. Traditionally, such water is discharged to the nearest
surface water course, where it is effectively removed from the irrigation system. In contrast, this technology conveys the drainage water to collection areas where it is pumped into reservoirs, mixed with fresh water and reused for irrigation.

**Extent of Use**
In Zimbabwe, use of regeneration water is currently practised on the sugar estates of Hippo Valley, Chiredzi and Triangle, and in other agricultural areas. For example, the Town of Glendale, Zimbabwe, depends for its water supply on regeneration water emanating from the irrigation of large citrus plantations in the Mazowe Valley.

**Operation and Maintenance**
Regular inspection, repair and maintenance of pumps and accessories is required.

**Level of Involvement**
Depending on the scale of the irrigation operations, government, large and small farmers, and other institutions may make use of this technology.

**Costs**
For irrigation purposes the major cost is pumping. The amounts of money involved depend on the size of the pumps, which, in turn, is dependent on how much water is available. Therefore, cost of this technology is very much a function of the size of irrigation operation. Irrigation pump installation costs in Zimbabwe are about $2 000/ha.

**Effectiveness of the Technology**
Water from the drains is put to use instead of being "wasted". Additional water for irrigation is made available. With flood irrigation, water collected in the drains accumulates at as much as 3 l/s from a 400 ha section. This water is enough to irrigate an additional 3 ha of cropland. In the case of Glendale, the water requirements of the small town, 32 l/s, are more than covered by the volume of regeneration water recovered through this technology.

**Suitability**
This technology is appropriate wherever water shortages are experienced. The use of regeneration water may not be appropriate where the regeneration water has a high concentration of dissolved salts.

**Advantages**
Additional water is made available for many other purposes through the use of this
technology. Extra hectares may also be cropped as a result.

**Disadvantages**

Regeneration water has been found to be extremely saline, having electrical conductivity values greater than 4 million mS/cm at 250°C, in some situations. This leads to salinity problems where applications of regeneration water are of high volume and/or prolonged. In cases where the regeneration water is utilised in the area where it is generated, there are usually some increased costs due to the extra pumping required to lift the regenerated water to the head of the irrigation scheme.

**Cultural Acceptability**

No cultural problems relating to the use of this technology have been recorded.

**Information Sources**

*Hippo Valley Estates*, Post Office Box 1, Chiredzi, Zimbabwe, tel. 263-96-2381, fax: 263-96-2554.


**2.4 WATER CONSERVATION**

**2.4.1 Urban Water Conservation**

**Technical Description**

The techniques included in this option take various forms and include the following water conservation measures which may be implemented by local authorities:

1. The development of an appropriate tariff policy: Under this approach, tariffs are levied as steep progressive rates, which subsidize the very poor and may also offer special rates for the promotion of industry. However, cost recovery is essential in order to ensure a sustainable operation, and pricing levels should be such so as to guard against water wastage.

2. The metering of individual stands and flats: The metering of individual properties puts the burden for water conservation on the consumer, which is the most effective means of ensuring urban water conservation.

3. The institution of efficient meter reading and billing mechanisms: Well-maintained and working meters, read accurately and regularly, and followed-up by efficient billing procedures ensure that consumers do not abuse municipal
Monitoring of such systems for changes in rates of consumption and rates of return or payment of bills provides accurate data for planning purposes. Relating consumption paid for to the amount of water produced provides a check on unaccounted for water and can alert the water utility of leakages or breaks in the supply system.

4. The use of water-saving fittings: By using water-efficient fittings such as low flush toilets, low-volume shower heads and taps, and flow limiters, consumers can achieve the same degree of benefit from a lesser volume of water.

**Extent of Use**

Water conservation approaches have met with varied responses in the African region:

1. Development of appropriate tariff structures is generally a weak area in most countries in Africa. While some form of tariff structure exists in all of the countries of Africa, those that have attempted to set economic tariffs still fail to separate the water account from the rest of the municipal (general) expenditure account, which typically negates the benefit to the water utility of setting economic tariffs. (Such benefits, include the availability of finances to update or expand their production and distribution networks; by considering water revenues as general revenues, the water utilities are forced to compete for funds with all other municipal services.) For this reason, privatization of water services is being encouraged in a number of African countries.

2. Although metering is encouraged in most countries of Africa, not all consumers are metered appropriately. Bulk supplies and stand posts are common in the rural areas, while, in large cities, only the affluent urban areas are typically metered.

3. Billing mechanisms are in place in most countries of Africa, but these are not properly monitored. Lack of monitoring of payments significantly reduces the recovery rate for monies invested in water treatment and distribution. Unaccounted for water, including illegal connections, accounts for up to 30% of potable water generated in most countries. Likewise, lack of monitoring and efficient bill collection generally means that development of water distribution systems lags well behind the rate of urbanisation.

4. Water saving fittings are being promoted in the dry countries of Africa, especially
in Southern Africa.

**Operation and Maintenance**

The techniques described above are largely social strategies aimed at conserving water. Additional actions may be needed to operationalise these strategies. The following operation and maintenance techniques may be applied by water utilities when implementing water conservation measures:

1. Pressure and flow control: Municipal water distribution systems normally have different ages. The tendency to leak is highest within the older portions of the network. To minimize leakages, it is essential that these different regions are zoned, and supply pressures be varied accordingly. Scheduled maintenance and leak detection systems are essential.

2. Consumer information programming and conservation promotion: Conservation is promoted through the formulation of rules and regulations for promoting efficient use of water and minimizing wastage, and by effectively informing consumers of measures to reduce wastage of water.

3. Distribution system maintenance: Corroding pipes cause leakage. Replacement of corroded pipes with non-perishable pipes, such as PVC piping, reduces water losses through leaks and ensures insofar as possible an uninterrupted supply to consumers. Regular maintenance reduces the risk of service interruptions due to breaks in the supply lines.

4. Monitoring and policing in cases of misappropriation, theft and fraud: Replacement of faulty meters, training of meter readers, and efficient administrative oversight can detect and reduce illegal connections to distribution systems, thereby protecting the revenues of the water utility and reducing losses within the distribution system. For efficient operation and administration, it is essential that the network be divided into district meter zones and that an accurate and up-to-date map of the distribution system is made and maintained.

**Level of Involvement**

The urban authority is usually the major player in promoting water conservation. However, Government agencies as in some municipal areas may be the single largest consumer of water and should be enlisted to support the water conservation promotion
program. Civic organisations and NGOs can also play a role in consumer information programming.

Costs
The costs vary depending on the measures taken, but more efficient use of water reduces or delays need for expenditure on new water supplies while ensuring that revenues are available for this purpose. Informational programming costs are minimal, especially if combined with other informational programming, such as school curricula in environmental sciences, health awareness campaigns or similar on-going activities, while provision of water-saving hardware to replace conventional plumbing supplies may be more costly. Manpower costs to improve distribution system maintenance and management are also relatively high but are typically offset by the increased revenue generated from these actions.

Effectiveness of the Technology
With effective leak detection and pipeline repair programmes in place, it has been categorically shown that the real savings far exceed the costs. For example, low volume flush toilet cisterns can reduce the volume per flush from 15 to 8 litres.

Suitability
Use of water conservation techniques is appropriate in all countries.

Advantages
Use of these techniques can result in saved water that can be put to other uses. There is a significant reduction in costs, and an increase in water utilization efficiency (and revenues). Capital projects for the construction of new water reservoirs may be deferred to a latter date, or capital made available for expanding the distribution system to meet new demands.

Disadvantages
Some expenditure is necessary to put a water conservation programme into action. Once the system is in place, use of water saving fittings may reduce wastewater flows to below the design flows for older trunk sewers and can sometimes result in blockages, necessitating a system redesign and retrofit. While the cost of such actions may be offset to a degree by increased revenues generated by charging consumers an economic rate for water, services charged at economic rates may be too expensive for the poorest segment
of the community to afford, requiring additional arrangements to minimise illegal
connections to the system.

**Cultural Acceptability**

No cultural problems have been noted, although the societal implications of charging
economic rates for water should be recognised and accommodated in an equitable
manner.

**Further Development of the Technology**

There is need to undertake studies to correlate soil resistivity with leak occurrence in,
especially, steel water mains, taking into account pipe age and technical specifications.
Research is also necessary to determine the most appropriate management systems
required for water conservation in Africa. In cases where low volume fittings are
adopted, it is necessary to consider their impact on trunk sewer slopes and reduced flows.

**Information Sources**

**Contacts**

*Castle Brass Holdings (Pty) Ltd.*, Post Office Box 4082, Luipaaardsvlei 1743, South
Africa.

*City Engineer's Department*, Post Office Box 4323, Johannesburg 2000, South Africa.

**Bibliography**


**3. MINING AND INDUSTRY**

Water is one of the key elements in mining and industrial operations. Mines tend to be
self sufficient in the development, management and use of their water requirements, while industries normally rely on municipal water supply. For environmental and economic reasons, industries and mines increasingly are adopting water recycling techniques as a means of reducing their consumption of water. This both reduces costs of production and enhances the environmental benefit that accrues to the community. However, in so doing, technologies are required to improve and restore the quality of recycled waters. However, the technologies in these sectors can vary considerably both in complexity and extent, depending on the type and sophistication of the industry or mine. While all of the technologies described in this chapter may be considered for use by the mining and industrial sectors, some may be similar to ones described above for the agricultural and domestic water supply purposes.

3.1 FRESHWATER AUGMENTATION TECHNOLOGIES

Industries traditionally rely on municipal water supply systems for water used in their operations. In a number of African countries, municipal supplies are unreliable in terms of both quantity and quality of water delivered, and are often costly. The current trend in industry, therefore, is for companies to develop their own water supply system. These systems are frequently based upon water harvesting from either surface or ground water sources. The amount of water harvested is entirely dependent on the need, the amount available, and ability to harvest the water, which is dependent on the type of technology used. Water is harvested in all its forms for industrial use notably as rainwater, groundwater, and surface water.

3.1.1 Groundwater Harvesting

Technical Description

Borehole depths vary, depending on geological formations. In sedimentary rock formations, depths of between 25 and 200 m are common. Technically, borehole or well development starts with a geophysical investigation to identify a suitable site. Subsequently, the borehole is drilled through the overburden, weathered surface rock, and fractured bedrock. Usually during the drilling process, slotted screens and solid casings are installed to improve the integrity of well. When groundwater is harvested for industrial use, high yield boreholes and wells are drilled on industrial premises and fitted with pumps, powered by either electricity, oil, or solar energy, to deliver water for use
within the production lines of the industry.

**Extent of Use**
Groundwater harvesting is widely used by breweries and in the canning industry, among others, in water short areas of Africa.

**Operation and Maintenance**
The principle operation and maintenance requirements of a groundwater harvesting system relate to the pumping system and associated distribution network. Solar panels, although requiring less regular maintenance, have high capital costs. All pumping systems can be maintained at the maintenance section of the industry with back up support from the manufacturers.

**Level of Involvement**
This technology is typically implemented at the local level by individual industries.

**Costs**
Costs vary considerably according to size of the industry, its demand, pumping rate, type of pumping system, pump efficiency, energy costs, and other related factors that are industry and site specific.

**Effectiveness of the Technology**
Groundwater generally supplies a significant percentage of the water needs in industries using this technology.

**Suitability**
This technology is suitable for use in areas of water shortage, or where municipal supplies are expensive. The abstraction of groundwater, however, may be regulated by the government in times of drought or emergency.

**Environmental Benefits**
Few negative environmental impacts have been recorded, but regulation of pumping rates may be necessary to avoid overpumping. In karstic areas, such regulation may be needed to minimise the potential for the creation of sink holes.

**Advantages**
Water is made available on site in an appropriate quantity, and groundwater is generally of high quality. Use of groundwater resources over municipal supplies can result in significant saving in costs of production.
Disadvantages
Uncontrolled pumping may have a negative impact on the environment.

Cultural Acceptability
Use of groundwater is culturally acceptable.

3.1.2 Surface Water Harvesting

Technical Description
Water demands in industrialized areas tend to outgrow the available water supply. Thus, in order to meet demand, it is necessary to transfer water to the site from another basin. Such inter-basin transfers (IBTs), although expensive, are becoming the only solution to meeting industrial and mining water demands. The technique involves building large reservoirs to capture runoff in watersheds that may be several hundreds of kilometres away from the centre of activity, and transferring this water by pipeline or canal to the area of use.

Extent of Use
Due to large financial investment required, this technique is limited to economically viable projects such as the Lesotho Highlands project in South Africa and the water projects of Libya.

Operation and Maintenance
These systems have high operation and maintenance costs. There is usually a need for large and powerful pumping systems as well as extensive networks of pipelines and canals.

Level of Involvement
Highly qualified engineers and technicians are required to plan, design, implement and operate inter-basin transfer schemes. Costs This technology has high capital and operational costs.

Effectiveness of the Technology
This technology is generally effective in ensuring a reliable supply of water to areas that would otherwise be classified as water short areas. It is dependent, however, on the rainfall and availability of water in the remote catchment area, which may be subject to the same vagaries as the surface water resources in the centre of activity.
Suitability
This technology is suitable for use in areas where the rate of financial return is high, such as in the mining complexes of South Africa or the oil fields of Libya.

Environmental Benefits
There are numerous drawbacks with the use of this technology. Many affect the biodiversity of the waterbodies connected by the transfer scheme, and often include public health impacts, especially where there are open water transfer canals that can serve as water-borne disease vectors.

Advantages
This technology provides water where it is most needed for economic production, and can assist in bringing development to remote places.

Disadvantages
Water provided using this technology is expensive and, hence, the water may not be affordable by the poor. There are also potential biodiversity and public health impacts that must be monitored and contained.

Cultural Acceptability
This technology is culturally acceptable and is widely used in water-poor regions of Africa.

Further Development of the Technology
Options need to be thoroughly analysed before embarking on project. Development of an economic and environmental assessment protocol would be beneficial.

Information Sources
Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001, South Africa.

3.2 WATER QUALITY IMPROVEMENT TECHNOLOGIES
3.2.1 Electrodialysis

Technical Description
In this process, a direct current electrical source is connected to two electrodes immersed in saline water. The charged ions in the solution migrate towards an electrode of opposite charge. Two sets of membranes, having alternate charges, are installed. The cation membrane will allow only positively charged ions to pass through, while the anion
membrane will allow only negatively charged ions to pass through (Figure 41). Desalination is thus achieved by the removal of the charged ions from the water. A strong brine solution develops in the compartments which retain a high concentration of ions. Alternate compartments contain water depleted of ions which is the processed water. For brackish mine water, pretreatment may be needed to remove suspended solids, and minerals like manganese and iron. Sodium hexameta-phosphate is added into the brine stream to prevent the precipitation of barium sulphate and resultant scale formation within the membrane stack.

(a) MOVEMENT OF IONS IN A DIRECT CURRENT ELECTRIC FIELD
(b) A SIMPLIFIED ELECTRODIALYSIS PROCESS

Figure 41. Electrodialysis process.

Extent of Use
This technology is used in mining operations in South Africa (Juby and Pulles, 1990).

Operation and Maintenance
Monitoring of plant operations and output water is required. Operational monitoring is required to estimate chemical usage and power consumption costs. Also, regular analysis of the membrane-treated water samples is necessary to ensure effective operation of the technology. Anion and cation membrane life is estimated at 4 and 7 years respectively (Juby and Pulles, 1990). One major problem with the electrodialysis process is the fouling and scaling of the membranes, which results from the trapping of certain ions in the membrane's polymer network. This problem has been resolved by use of a "flushing" step, effected by reversing the polarity of the direct current source, thereby reversing the movement of ions, which then alters the configuration of the compartment. This innovation improves the process and is referred to as Electrodialysis Reversal (or EDR). Frequent reversals of the current (3 to 4 times per hour) are essential for effective operation. However, the product water quality deteriorates as a result of contamination when the brine and product compartments are switched after such polarity reversals. In order to avoid loss of partially desalinated water during this 30 to 60 second period, the product water is recycled back to the feed tank.

The feed and processed water flow rates and stack pressures are controlled by valves.
Monitoring of plant pressure stage voltages and currents is essential. Cross leakage can pollute the product stream. This is avoided by maintaining the brine loop pressure slightly below that of the dilute stream (about 450 and 480 kPa, respectively).

Operation of the system also requires the continuous removal of brine and gases formed as by-products of the electrodialysis process, including hydrogen, chlorine and oxygen.

**Level of Involvement**

Implementation of this technology is generally undertaken by mining or industrial concerns as part of their production operations. Highly skilled staff are required.

**Costs**

The operational costs for a 46 l/s (4 Ml/day) plant, including labour and membrane replacement, are estimated at $0.21/m³, based upon an electricity consumption of 2.4 kWh/m³ at a cost of $0.03/kWh. The capital cost for a 46 l/s (4 Ml/d) EDR installation is estimated at $3.4 million (Juby and Pulles, 1990).

**Suitability**

Electrodialysis plants remove up to 80% of the salts in the feedwater. The product water from the EDR unit is generally better than that required for discharge in terms of most general wastewater effluent discharge standards.

**Environmental Benefits**

The processed water meets effluent disposal standards, although care must be taken in the disposal of the liquid and gaseous byproducts and, especially, the brine solution.

**Advantages**

Electrodialysis is an effective method for upgrading the quality of brackish water. The product water can be reused in the mine or, with a slight amount of further treatment, as drinking water. Removal of salts helps to protect the mine service reticulation systems from corrosion.

**Disadvantages**

This is an advance technology which does not lend itself readily to small-scale applications due to its high capital and operational costs, and requirement for highly trained human resources. Further treatment of the product water is required if it is to be used for potable purposes.

**Cultural Acceptability**
There are no known cultural problems, although the concerns over water reuse for potable purposes may apply to reused mine water.

**Further Development of the Technology**

No further technological development is anticipated. This is a fully developed technology.

**Information Sources**


### 3.3 WASTEWATER TREATMENT TECHNOLOGIES AND REUSE

#### 3.3.1 Industrial Water Reuse

**Technology Description**

A major thrust in the treatment of industrial effluent is to minimise the impact of pollutant loads leaving a factory premises and to promote an higher degree of water reuse within the factory. This involves the removal of excess carbohydrates (oxygen-consuming substances), cooling, removal of nitrates, and removal of heavy metals.

Technologies which are applicable in various industrial situations have been developed within each major industrial sector. These technologies, then, act as a guideline for other industries to follow and as guidelines for local authorities in prescribing pollution control requirements for other, similar sector industries.

**Extent of Use**

Various guides in the "Water and Wastewater Management" series have been produced by the Water Research Commission in South Africa. These guides currently govern water and wastewater management in the following industries: malt and brewing; metal finishing; soft drinks; dairy; sorghum malt and beer; edible oils; red meat; laundry; poultry; tanning and leather finishing; sugar; paper and pulp; wine; and, textiles.

**Operation and Maintenance**

The operation and maintenance of the various technologies used in industry are industry specific, and implemented on a site-specific basis by individual manufacturing companies.

**Level of Involvement**
Each proprietor is responsible for the implementation of those guidelines most relevant to their industry. However, government involvement is often a prerequisite in the formulation of relevant pollution control regulations, and an enforcement agency might also oversee policing. Sometimes, industry councils or cooperatives may impose a degree of self-regulation upon their membership to reduce the need for governmental regulation of their industry.

Costs
The costs are technology- and industry-dependent.

Suitability
The suite of technologies used to minimise water pollution have proven to be an effective water conservation technique which should be appropriate throughout Africa.

Environmental Benefits
Reuse limits water wastage and wastewater treatment processes ensure that contaminants that would otherwise be pollutants are reduced or eliminated from the waste stream, resulting in better quality water downstream and overall benefit to the environment and other users.

Advantages
Water reuse and reclamation within industries provides surplus water than can be used to meet other demands.

Disadvantages
Some investment in equipment is almost always required. Operator training to ensure the optimal functioning of this equipment is essential.

Further Development of the Technology
Other industrial processes need to be evaluated with respect to their water saving potential. In South Africa, the Water Research Commission is continuing to gather and interpret data from various industries, and is publishing further guides in their "Water and Wastewater Management" series.

Information Sources
Contacts
Council for Scientific and Industrial Research - Division of Water Technology, Post Office Box 395, Scientia, Pretoria, South Africa.
3.4 WATER CONSERVATION

3.4.1 Dry Cooling at Power Stations

Technical Description

Conventional coal-fired power stations operate on the principal of converting thermal energy to electricity. Large quantities of waste heat are generated and are dissipated to the environment by partially evaporating water in a wet cooling draft tower. Even though this technique is efficient, large volumes of water are lost to evaporation. To overcome this loss of water, a recent innovation, known as dry cooling, is an approach which dissipates the waste heat to the atmosphere through an air-cooled heat exchanger. This technique operates on the principle of a closed water circuit in which the water on one end is in contact with the heat source and, on the other end, is in contact with an air cooling system. The heat picked up from the heat source is dissipated in the air contact section.

Extent of Use

The Matimba Power Station in South Africa, run by the Electricity Supply Commission (ESKOM), operates on this technology. This technique also being introduced at ESKOM's three new power stations.

Level of Involvement

This technology may be utilised by power utilities who have trained, skilled human resources.

Costs

The costs are the full investment costs for a new power station.

Effectiveness of the Technology

The technique is five times more water efficient than conventional wet-cooled techniques, and, therefore, significantly impacts water conservation potentials within the
power generation industry. The quantity of water consumed per unit of electricity delivered is as little as 0.68 litres compared to 6 litres in older conventional stations, and 4 litres in newer, wet-cooled stations.

**Suitability**
This is an appropriate technology for use in regions prone to water shortages, and which utilise thermal power stations as a source of energy.

**Environmental Benefits**
No negative environmental impacts have been recorded.

**Advantages**
Use of this technology limits the impact of droughts on power production, and reduced the need to situate power station in close proximity to rivers or other water sources.

**Disadvantages**
This technology has an higher capital cost and is less efficient than wet-cooled systems. Use of this technology also requires raw water of an appropriate quality. This requirement may mean that an higher quality feedwater be produced, which may required some degree of pretreatment.

**Cultural Acceptability**
This technique poses no cultural problems.

**Further Development of the Technology**
There is need for further study of the effect of heat exchanger height on recirculation, which has been observed to be something of a problem in these plants.

**Information Sources**

**Contacts**
*Water Research Commission*, Post Office Box 824, Pretoria 0001, South Africa.

**Bibliography**


3.4.2 Utilisation Of Seawater For Power Station Cooling

Technology Description
Seawater is used for power station cooling in place of freshwater.

Extent of Use
The nuclear power station at Koeberg (Western Cape Province, South Africa) is cooled by seawater.

Operation and Maintenance
Qualified and skilled personnel are required to operate and maintain this technology, which requires an high level of maintenance due to the corrosivity of seawater.

Level of Involvement
This technology is operated at the industry level by a power utility.

Costs
Cost data are not available for this technology. However, the initial construction of this system, which requires corrosion resistant piping and pumps, has high capital costs. Once installed, however, the running costs of this system are low.

Effectiveness of the Technology
The technology eliminates the use of freshwater for cooling, thereby freeing these resources for other uses.

Suitability
This technology is appropriate for use in countries which have a coastline. It is especially appropriate for use in the nuclear power industry or other industries with an high demand for cooling water.

Environmental Benefits
There are few environmental hazards resulting from the technique, although, in the nuclear power industry, there may be concern over the discharge of radionuclides to the environment in the event of an accident. There may also be concerns regarding thermal pollution if the cooling systems are operated as through flow systems.

Advantages
Freshwater resources are freed for other uses.

**Disadvantages**

Use of this technology is limited by the requirement that the industry be in close proximity to the sea.

**Cultural Acceptability**

No cultural problems have been noted.

**Information Sources**


**PART C - CASE STUDIES**

4.1 Tied Ridging -- Domboshawa, Zimbabwe

**Introduction**

Zimbabwe has experienced low and erratic rainfall for the decade prior to 1995. To offset agricultural losses related to low rainfalls and variations in rainfall related to these vagaries of nature, researchers investigated tillage methods that conserve soil moisture. The major objective in moisture conservation tillage methods is to conserve moisture in the soil in order to increase germination and yields. Runoff is greatly reduced and infiltration rates are increased. Moisture conservation tillage technologies include tied ridging, mulching, contour ploughing and minimum tillage, described in Part B, Chapter 1, "Agriculture".

This case study looks at ridging and tied-ridging in Domboshawa, an area about 30 km north of Harare, the capital city of Zimbabwe. It is located in the Highveld of Zimbabwe at an altitude of about 1200 m above sea level. The average annual rainfall ranges from 800 mm to 1 000 mm per annum. The rainfall is seasonal with approximately 90% falling in the months of October to March.

**Technical Description**

Ridging and tied-ridging as carried out in Zimbabwe is widely documented (FAO, 1966). Most of the equipment used for ridging and tied-ridging was locally manufactured, and designed to be animal-drawn. A typical, ox-drawn disc ridger, developed by the Department of Agricultural and Technical Extension Services (AGRITEX) in
conjunction with GTZ, is illustrated in Figure 42. The high wing ridger body is used for making the ridges, and is an accessory to the mouldboard plough. When making ridges, the ridger body is attached to the plough instead of the mould board. The ridger produces ridges which are 250 mm high.

The high wing ridger is of French design but is manufactured locally. The ridger has two adjustable discs angled to form a wide `V' shape. Although the unit looks heavy, the draft requirement is actually less than that required for the conventional mouldboard ploughs. Depending on the ridge requirements, the disc sizes and shapes can be varied.

Ridges made using this technology can be tied using hand hoes. In Zimbabwe, simple oxdrawn tie-makers have been produced locally. As illustrated, these can be made from old mouldboard plough shares or discs fitted on to metal or wooden uprights. In order to avoid having too many operations, ties can be coupled to the ox-drawn disc ridger (Figure 43). They can also be fitted onto cultivators (Figure 44). Ties are made by scraping the tie-maker along the furrows between the ridges until enough soil has been collected. The collected soil should be about 1/2 to 2/3 the height of the ridges.

Figure 42. Ox-drawn disc ridger with tie-maker attached.

Source: Makoholi Research Station

**Extent of Use**

The Ministry of Agriculture, through AGRITEX and the Department of Research and Specialist Services (DR&SS), was responsible for the research and extension of the technology. The programme started with field trials. During trials a few farmers were selected to participate. Results from the trials proved that the tied-ridging method of tillage produced better yields than the conventional methods of tillage traditionally used by farmers in this area. The fact that farmers saw the benefits of the system made it easy for the extension personnel to convince the rest of the communities to adopt the method. Nevertheless, there has been some measure of resistance to changes in the traditional methods of cultivation. This resistance was compounded by shortages of labour and draft power. Shortages of labour resulted from male migration to urban areas in search of employment, while the shortage of draft power resulted from reduced animal stocks due to the drought. All of these obstacles have not yet been overcome, and, although the
method is acceptable to the farmers, it is not widely practised. Only 1% of the farmers in the area use the method (Elwell, 1993)

**Operation and Maintenance**

Ridgers and tie-makers do not require any special skills to operate or maintain. There are few components that need replacement, and, hence, the technology is very suitable for communal operations. Disc-ridgers and ridger bodies wear out with time, but replacement is not a problem since the equipment is locally manufactured.

**Level of Involvement**

The government, local communities and non-governmental organizations were all involved in the project. The government provided the personnel for the research and extension while GTZ provided some of the funding.

Figure 43. Ox-drawn disc-plough tie-maker.
Source: Institute of Agricultural Engineering, Harare, Zimbabwe

Figure 44. Light Cultivator with tie-maker mounted.
Source: Institute of Agricultural Engineering, Harare, Zimbabwe

**Costs**

The major cost is the purchase of the ridgers and the tie-makers. Where the farmers already have mouldboard ploughs or cultivators, the cost will be low because the ridger body and the tie-maker can be fitted easily. A new ox-drawn ridger costs $300 and a new mouldboard plough costs $30. If the farmers do not have their own implements, the cost of hiring the equipment to have one hectare ploughed and tie-ridged will be $250.

**Effectiveness of the Technology**

As shown in the following table, the results of the field trials showed that there was a reduction in runoff from fields with tied-ridges compared to those with conventional tillage.

**Advantages**

The advantages of tied-ridges include reduced erosion and conservation of soil moisture. The equipment used is simple and easy to use, and capable of being locally manufactured and maintained. The field trials clearly showed improved crop yields.

**Disadvantages**

Tied-ridgers require new or additional equipment, and substantial time and effort required to prepare the lands each year. This increases farmers' costs. In areas with highly variable
rainfall, ridges can fail due to overtopping. When this occurs, greater soil losses may result.

**Further Development of the Technology**

The technology has great potential for use in arid and semi arid regions. However, in order for the technology to be accepted and adopted, much effort has to be put in the research and extension services. The government has to be strongly involved in the exercise. The technology is easy to adopt if the farmers are mechanized and they have enough draft power. Availability of draft power is essential because substantial time and effort is required for the land preparations. For countries wishing to adopt this technology, it is very important to make sure that an effective extension service, adequately financed, is in place.

**Sources of Information**

**Contacts**

**D. Dube**, ARDA, Post Office Box CY 1420, Causeway, Harare, Zimbabwe.

**Institute of Agricultural Engineering**, Post Office Box BW 330, Borrowdale, Harare, Zimbabwe, tel. 263-4-860119 or 263-4-860055.

**I. Nagambie**, Conservation Specialist, Institute of Agricultural Engineering, Post Office Box BW 330, Borrowdale, Harare, Zimbabwe, tel. 263-4-860119 or 263-4-860055.

**G. Nehanda**, Chief Planning Officer, Head of Station, Institute of Agricultural Engineering, Post Office Box BW 330, Borrowdale, Harare, Zimbabwe, tel. 263-4-860119 or 263-4-860055.

**A. Senzanje**, Department of Soil Science and Agricultural Engineering, University of Zimbabwe, Post Office Box MP 167, Mount Pleasant, Harare, Zimbabwe.

**Bibliography**


4.2 Freshwater Augmentation -- Cloud Seeding, Zimbabwe

Introduction

Zimbabwe covers 390,000 km² in area, and has a population of 10.4 million people (CSO, 1992), of whom 74.3% (or 7.73 million) are rural (CSO, 1989). The country is situated in southern central Africa between latitudes 15° 30' and 22° 30' South and between longitudes 25° 00' and 33° 10' East. The country falls into various land use (agro-ecological) zones determined by rainfall, temperature and soil types as shown below. The country has a seasonal rainfall pattern, which varies across the country, with the highest rainfalls of over 2,000 mm falling in the Eastern Highlands and the lowest rainfalls of around 400 mm falling in the low areas, particularly along the area bordering South Africa. In the middleveld, the rainfall varies from 700 to 1,200 mm. Runoff is generally 8% of the mean annual rainfall (DWD, 1980). The majority of rivers are nonperennial.

An attempt to fully utilize this runoff has led to an extensive dam construction programme. While these reservoirs are used as sources of water for mainly urban centres, some supply water for irrigation and mining purposes.

<table>
<thead>
<tr>
<th>Region</th>
<th>% of Land</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1.5</td>
<td>Very high rainfall, above 1,000 mm; low temperatures, below 15 C. Forestry, wattle, tea, coffee, deciduous fruit, barley and potatoes. Intensive beef and dairy farming.</td>
<td></td>
</tr>
<tr>
<td>2 18.7</td>
<td>High rainfall, 700 to 1,000 mm; warm summers, cool winters. Maize, tobacco, cotton, winter wheat and market gardening - intensive farming. Intensive beef and dairy farming.</td>
<td></td>
</tr>
<tr>
<td>3a 17.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Moderate rainfall, 550 to 700 mm; high temperatures and dry spells. Drought resistant cotton, soya and sorghum. Beef farming and breeding.

3b 33.0 Low rainfall, 450 to 600 mm; seasonal droughts. Irrigation of drought resistant crops. Semi-extensive controlled grazing.

4 26.0 Very low rainfall, below 500 mm; very hot. Sugar, citrus, cotton and wheat irrigation schemes of lowveld.

5 3.0 Not suitable for agricultural activity without irrigation. Some beef production and wild life. Source: (School Atlas for Zimbabwe)

The majority of Zimbabweans live in the communal and resettlement areas where they rely on agriculture for a living. Commercial agriculture is a major contributor to the country's economy. The country, therefore, is heavily dependent on agriculture, and, as a result of recent droughts, precipitation augmentation has become a vital component of this economic sector. Rainfall augmentation operations are carried out during all seasons which do not have sufficient natural rainfall.

**Technical Description**

This technique involves the beneficial modification of summer convective rainfall to increase rainfall production efficiency. Only about 30% of the atmospheric water vapour entering the region's storms naturally reaches the ground as precipitation (McNaughton, 1980). The approach encourages efficient rainfall formation through a collision-coalescence process which is enhanced or accelerated by the addition of hygroscopic nuclei into a storm updraft at cloud base. Augmentation provides additional water to crops when weather conditions are favourable and is required during periods when little or no rainfall would otherwise occur.

In Zimbabwe two methods of cloud seeding are used:

1. The high level seeding method which has been used since cloud seeding was first practised, and which involves flying into the top of a suitable cloud and injecting it with silver iodide.

2. The low level seeding method which is experimental and involves burning flares which emit hygroscopic smoke material into the base of a cloud.
This technology is described in Part B, Chapter 1, "Agriculture."

**Operation and Maintenance**

Major equipment requirements are aircraft, radar, materials and skilled personnel. In this instance, the aircraft were supplied mainly by the farming community, with the government paying for their use, with some additional aircraft supplied by the government. One problem was the shortage of aircraft. The numbers of aircraft were hardly enough for a comprehensive aerial coverage.

Aircraft and personnel are on standby during the rainy season, waiting for the right clouds/conditions. The main rainy season in Zimbabwe is from November to March. Rain sometimes falls in other months, mainly September, October, April and May, and, during the rainy season, there are spells of completely dry weather. Therefore, an operational cloud seeding organisation would normally be inactive on about half of the days in the rainy season, including occasions which are too wet for additional rainfall to be required.

**Level of Involvement**

The private sector, in particular the farming community, assisted governmental implementation of this technology, mainly with aircraft. Thus, in this application, there was a high degree of community involvement, but this could vary in other applications.

**Costs**

Average annual cost of Zimbabwe's national cloud-seeding operation between 1973 and 1979 was about $10,000. The highest annual cost was $13,700 in 1978/79, which was the busiest season ever, during which chartered aircraft were used. For the 1995/96 season, $12,500 has been set aside for cloud seeding operations.

**Effectiveness of the Technology**

It was observed in Zimbabwe that the cost of cloud seeding was significantly less than the resulting benefit from the maize yield alone. This analysis did not take into account other crops or non-agricultural benefits. Hence, cloud seeding is considered to more than pay for itself (McNaughton, 1980).

**Advantages**

In Zimbabwe, the extra maize yield from the national cloud seeding programmes in the late 1970s was estimated at between 0.5% and 1% of the national total (McNaughton, 1980). Pastures and grasslands also benefited. Further, seeded rainwater was determined
to be cheaper than piped water with respect to irrigation ($0.12/km³ versus $1.76/km³; McNaughton, 1980). Extra benefits accruing from the cloud seeding programmes included: (i) fog and stratus disposal around airports; (ii) hail suppression; and, (iii) cyclone (hurricane) modification.

**Disadvantages**

Experimental operations are costly, often requiring the simultaneous use of three aircraft -- one for seeding, a second to monitor weather conditions (such as cloud top temperatures during the five to ten minutes after seeding), and a third to measure precipitation at the cloud base in a rain collector. Cloud-seeding operations/aircraft have to select suitable clouds as they arise. This selection cannot be controlled or easily predicted in the long term. Therefore, it is difficult to supply water when and where it is required. Also, chartered aircraft are expensive to operate from the point of view of standing charges.

**Further Development of the Technology**

Currently the Zimbabwe cloud seeding fleet has aircraft based in Harare and the Lowveld. Depending on the occurrence of potentially suitable clouds during the height of the wet season, additional aircraft should be made available during January or February. If maize is planted in December, it is recommended that at least one aircraft should be on standby until late April. While jet aircraft can cope with larger numbers of clouds, and, therefore, reduce the number of cloud seeding aircraft required, these aircraft are more expensive to operate. There is also a need for a daily radiosonde data in areas with a high suitability for cloud seeding during this period, and a need to carry out further experiments with reference to the atmospheric conditions which permit cumulus development.

**Information Sources**

**Contacts**

*W. Marume*, Department of Meteorological Services, Post Office Box BE150, Belvedere, Zimbabwe.

*Kamanzira*, Department of Meteorological Services, Post Office Box BE150, Belvedere, Zimbabwe.

**Bibliography**
4.3 Tidal Irrigation, The Gambia

Introduction

The Gambia is one of the smallest countries in the Sahel region of West Africa, surrounded on all sides by Senegal, except on the western side of the country which borders the Atlantic Ocean. The Gambia is bisected by Gambia River and lies in the east-west direction between the longitudes 160 50' and 130 45' W and latitudes 130 00' and 13o 50' N. The country is approximately 480 km long and nowhere is it more than 50 km wide. Its total surface area is about 11 000 km2, with about one third of its surface area covered by the Gambia River and the marsh lands along its banks. The main topographic feature is the low lying basin of the Gambia River. The river runs through the whole length of the country with only a few points above 50 m in elevation. Its capital is Banjul. The Gambia has savanna vegetation and lies in the Sahel of West Africa. The climate is uniform across the country due to its small size and relatively flat features. The country has a single rainfall season annually, which starts in June and ends in October. The rainfall in the country varies evenly from 1 100 mm in the south-west to 700 mm in the north and east. The rainfall is highly seasonal with all but 1% or 2% falling in the raining season.

The Gambia River rises in Guinea and passes through Senegal before finally entering The Gambia for an approximately 500 km journey to the sea. The flow in the river is highly seasonal. The maximum flow occurs at the end of the rainy season in late September or October with a flow of about 1500 m3/s. The minimum dry season flow is less than 4.5 m3/s, both measurements taken at Gouloumbo in Senegal. Due to the large variation in river flow and the flat nature of the country's terrain, the Gambia River is tidal, and thus saline, for much of its length.

The position of the interface between the freshwater and saltwater varies with river flow.
During the low flow period, the freshwater-saltwater interface, defined as the point at which the salinity is 10 ppt, is 250 km from the sea. Under high flow conditions, this interface is located 150 km from the sea. Due to the perpetually saline conditions which exist in the Gambia River and its tributaries for 150 km from its mouth, where the population centres and tourism facilities are located, surface water is rarely used as a source of potable water in The Gambia. The potable water demand for urban areas, tourism, industry, and irrigation and livestock watering comes from groundwater sources. Groundwater is available in all parts of The Gambia. The country is located on one of the major sedimentary basins in Africa often referred to as the Mauritania/Senegal Basin. It is characterised by two main aquifer systems with water table depths varying from 10 m to 450 m.

**Technical Description**

This technology is intended to supplement rain fed agriculture. The availability of tidal water at high tide was used as source of irrigation water supply. Due to the use of this technology, a double cropping of rice is achieved annually in a country with seven months of dry season.

The land along the Gambia River is relatively flat, and, since the river is tidal all through its length in The Gambia, tidal irrigation schemes become feasible. Tide heights vary from 3.5 m at the mouth of the river to 0.9 m at Basang, 310 km upstream. Special intake structures were constructed with gates which, when opened at high tide, allowed tidal waters to enter irrigation channels leading to the farms. During high tide, the gates were opened from 3 to 24 hours, depending on the size of the area to be irrigated. In two rice growing areas, at Jahally and Pacharr, tidal and pump irrigation are coordinated. Tidal heights of 1.3 and 1.0 exist in the Gambia River at Jahally and Pucharr, respectively (Figure 45). Tidal water is utilized to irrigate low lands nearer the banks of the river while water is pumped from the river to irrigate large areas of land at higher elevations.

The project began operations in 1983 and 1984 at Jahally and Pacharr, respectively. This technology is described in Part B, Chapter 1, "Agriculture."

Figure 45. Jahally irrigation pumping units.

**Effectiveness of the Technology**

The technology has been successful in paddy rice cultivation as a rural development
project. Using tidal irrigation, double cropping of 167 ha and 850 ha was achieved annually at Jahally and Pacharr. Similarly irrigation of 440 ha and 125 ha is achieved annually at Jahally and Pacharr, respectively using pump irrigation (Figure 46).

Figure 46. Jahally irrigation field.

**Costs**

The projects were financed by the Gambian Government, the International Fund for Agricultural Development (IFAD), the African Development Bank (ADB), and the German Government. During the design and construction stages, the project management was in the hands of the financier and exact capital cost figures were not available from the current local project management. Nevertheless, the estimated cost of the project, in 1983/84 dollars, was approximately $7.5 million. Assuming a 7% inflation rate, a 25-year life, and 7% discount rate, the annual cost of project may be estimated at $643 583, or $40/ha. Current operation and maintenance costs are $220/ha/yr. The resultant yield per hectare is 9 tons/yr, incurring an annual cost per unit of output of $70/ton.

**Suitability**

The technology is appropriate in areas where there is a river with a relatively flat basin and high tide intrusion. Arable land must be available near the banks of the river. The rainfall in the area must be sufficient to encourage constant and high river flows. The technology is also good for use in areas with fairly large rivers and sufficient rainfall to keep the water level high. The rivers must also be tidal.

**Operation and Maintenance**

Trained local staff must be available to perform the farming operations and management. Additional manpower needed to implement this technology include: (a) one power tiller operator for each 15 ha cultivated per month; (b) two tractor operators; and, (c) two experienced mechanics. There should be about 20% local community control or management.

**Advantages**

This technology is good because, once the intake structures and irrigation channels have been constructed, the operation is relatively cost free. Maintenance work on the irrigation channels and clearing of weeds and brush from the channels and irrigated area can be done by the local farmers.
Disadvantages
There is a difficulty being experienced in the availability of spare parts locally.

Environmental Benefits
The breeding of mosquitoes and snails is enhanced by water ponding on the farms, which could lead to public health concerns if control measures are not imposed.

Cultural Acceptability
No cultural inhibitions have been experienced. This technology provides for viable commercial farming in a poor rural area.

Further Development of the Technology
No further development appears to be required at this time.

Information Sources
Director, Department of Water Resources, 7 Marina Parade, Banjul, The Gambia.

4.4 Spring Protection -- Mukono District, Uganda

Introduction
This study outlines the experiences gained during the implementation of spring protection programmes in the Mukono District of Uganda during the RUWASA project. Mukono is one of eight RUWASA project districts. The project aimed at improving the quality of life of the rural people through provision of water supply and promotion of sanitation and good hygiene. The project was identified in 1989, after the area was found to have harsh socio-economic and health conditions related to poorly developed water supplies and poor sanitation.

The Mukono District lies between 32° 30' 30" and 33° 25' E, and latitudes 1° S and 1° 30' 30" N. The district is bounded by rivers on the east and west, Lake Victoria on the south, and Lake Kyoga on the north. The northern and central parts of the Mukono District are underlain by undifferentiated gneiss of the basement complex. Recent sediments cover the contour boundary along the Nile. The southern parts are underlain by the Buganda Toro system (granitic and partly metamorphosed rocks) with basement complex (granite gneiss) exposures running in a northeasterly and southwesterly direction. From a monotonous flat topography in the north, the land changes to an undulating topography in the central parts, becoming hilly in the southern parts. The central parts have intermediate to thick overburden while the southern parts have very
thick overburden in the Buganda Toro system areas. Rainfall varies from an average of 1010 mm/year of rain in the northern half to 1 625 mm/year in the south.

In 1991, the population was 750 000 people. The population was largely rural, with over 90% residing in the countryside. The majority of the people are self-employed in agriculture, growing food crops for domestic consumption with the surplus, if any, being sold to urban centres.

The water and sanitation coverage in 1991 was about 10% and 30% of the population, respectively. It was estimated that water sources in the District were distributed as follows: 21% spring sourced, 43% shallow well sourced, and 36% borehole sourced. An inventory carried out in 1990, however, indicated a great number of protectable springs were located primarily in the south. Bacteriological tests showed that most of the springs were contaminated with faecal coliform bacteria.

Technical Description

The RUWASA spring protection project started in 1990. To date, about 800 springs have been protected in the Mukono District, benefiting an estimated 120 000 people.

Protection activities start with source identification carried out by technical officers and the community. The criteria used to recommend a spring for protection include the following:

(i) There should be at least 50 users, or about 10 households for the protection project to be economically viable.

(ii) The spring should be perennial (confirmed by the users).

(iii) The spring should have a flow greater than or equal to 10 l/min.

(iv) There should be an adequate ground slope to provide ample drainage after construction of the retaining wall.

The structure or retaining wall placed around the spring to be protected was originally constructed using stones and/or hard core. However, this was changed to concrete blocks, except in the case of the wing walls. This was because stone-masonry work was slower since the stones provided by most communities were small, and greater skills are needed by the mason to fit the stones into the wall. The skill of the masons may be a problem in the application of this technology elsewhere, especially with new masons. A 2½ inch galvanised iron pipe, used to protect the PVC outlet pipe, is cast into the retaining wall.
flush with the back and extended 50 mm at the front. At the back it is sealed off with cement mortar in order to avoid contact with the spring water. The 50 mm extension offers a good outlet, making the water easy to draw with the water buckets, but too small to make it an attraction for children to stand or sit on. It is important not to block off any spring eye.

The work of clearing and digging the drain, with an appropriate notch shape and slope, that protects the spring from surface runoff and from back flows into the spring from the surrounding land surface, tends to be rather hard, and the communities tend to leave it uncompleted. Thus, they have been encouraged to complete work on the drains in one operation before any of the other work takes place.

**Extent of Use**

Natural springs have traditionally been used as a source of water, especially for domestic purposes. This project has improved the protection of such springs from pollution and improved the method of collecting and distributing the spring water. The technology, therefore, is acceptable, especially since the water acquired from the springs is softer than most deep borehole water.

In a few cases, people have tried to resist the implementation of spring protection measures for fear that the eyes of the springs would disappear. These fears have been minimised by informing people about the causes of such disappearances, and by demonstrating examples of protected springs in neighbouring villages.

The speed with which protection is implemented is affected during the rainy season because, during the planting season, people are busy in the fields. The rains also make some roads impassable, and the delivery of materials difficult.

**Operation and Maintenance**

The operation and maintenance of spring protection systems is well within the capacity of the local communities. Apart from keeping the area surrounding the spring tidy, maintenance consists of fencing sensitive areas, especially the area behind the retaining wall, and maintaining the storm water and runoff drains.

**Level of Involvement**

The responsibilities of the communities in each of the spring protection projects undertaken during the RUWASA project included: (a) selection of at least six members
of the community to create the Water User Committee (WUC); (b) selection of two caretakers, one of whom must be a woman; (c) provision of manual labour and locally available materials for use in the protection project; and, (d) assisting in construction work on a self-help basis.

Prior to the construction of the protection works, the community is responsible for clearing the drain and providing hard core, plaster-sand, and clay, where available.

The responsibilities of the WUC include: (a) ensuring that individual members actively participate in the construction activities; (b) ensuring that the water sources are well looked after; (c) assisting and supervising the caretakers in carrying out their assigned duties; (d) proposing and enforcing by-laws, approved by the water users, regarding the use and up-keep of the village water supply; and, mobilising the community through the promotion of sanitation and hygiene education activities.

The government or project manager produces guidelines for community based operations and maintenance activities; facilitates the training of caretakers and the WUC; and, pays for the skilled labour (masons and supervision), the transportation of materials to the site, and the acquisition of locally unavailable materials. Such materials may include cement, pipes, and lake sand.

A further pilot project, using the private sector operators, started in 1995. The private contractors carry out the physical construction under government/district supervision, and with coordinating input from the village.

**Costs**

Protection of a spring is estimated to cost about $1 000. The value of the in kind community contribution (unskilled labour and locally available materials) is also estimated to average $1 000. Materials provided by the community are mainly sand, hard core and clay.

**Effectiveness of the Technology**

In general, the spring protection project was considered successful, although a high proportion of the springs continued to fall above the bacterial water standard. Unfortunately, during the 1993/94 drought, a large proportion of the protected springs were reported to have dried up. Notwithstanding, a study in May 1994 showed that, of 743 springs checked, 52% passed the minimum design yield criterion of 5 l/min, 42%
were over 7.5 l/min criterion (the theoretical minimum to supply 20 litres per capita per day to 150 people over 8 hours, with 20% spillage), 34% were over the criterion of 10 l/min required for a spring to be protected, and 26% were completely dry. Over-night storage tanks are being constructed for low yielding springs.

Given the community concerns regarding the drying of springs, additional investigations were made of the 26% of springs that have become dry. Some reasons for drying were found to include:

1. Poor construction due to the contractors not following the specifications (e.g., the wall not being carried down deep enough, or the spout placed too close to the top of the water table so that even a small drop in the water table results in the spring drying up).

2. Blockages of the spout, usually with a banana, in order to "save" the water which can result in a build up of a water pressure and the groundwater finding an alternative route to the surface at another location.

The studies showed that there was no difference in the protection provided to the springs in which polyethylene materials were used instead of clay as a seal.

Because of the early concerns regarding the contamination of the springs, investigations into the water quality of the protected springs were also conducted. Water quality in the protected springs was generally satisfactory from a toxicological point of view as shown below. However, a survey carried out in the wet season showed that 3% exceeded the 50 Escherichia coli counts per 100 ml (EC/100 ml) criterion, 12% exceeded the 25 EC/100 ml criterion, and 52% exceeded the 3 EC/100 ml criterion. (Faecal coliform measurements were not made.) In 65% of cases investigated, there were higher levels of contamination at the household level than at source level, indicating that contamination occurred within the distribution system.

**Parameter Percentage Exceeding: Criterion**

- **Hardness** 0.5%: 300 mg CaCO3/l
- **Total Iron** 0.5%: 1 mg/l
- **Manganese** 4.8%: 0.1 mg/l
- **Chloride, Sulphate and Nitrate** 0%
- **Total Dissolved Solids** 0.2%: 1 500 mg/l
Fluoride 1.3%: 1 mg/l  

pH 95.7%: 5 units  

Other studies have suggested that springs located within less steep countryside had a higher percentage of better quality, in terms of both coliform counts and turbidities, than springs located in steeply sloped areas. It was also found that better the maintenance of the spring, such as maintaining the storm drainage, resulted in better the bacteriological water quality. 

Some communities have started growing vegetables to take advantage of the continually flowing spring water.  

Advantages  
The advantages offered through the use of spring protection technologies include:  
1. Ease of construction and maintenance, as a high level of technical knowledge is not required.  
2. Improvement of a community water supply already used and accepted by the community.  
3. Low cost of construction and maintenance.  
4. A potential to up-grade the system by collecting the water in a tank and pumping it up a storage tank and distributing it through a pipe system as economic conditions permit.  

Disadvantages  
The disadvantages of spring protection technologies include:  
1. No improvement in the service level associated with the community water supply, since protecting the water source has not effect on walking distance to the source.  
2. Interference with the flora and fauna down stream if a storage facility is provided in case of low yielding springs, since spring water is retained at the source.  
3. Poor accessibility if the spring is located at the bottom of a hill and most households are located on the hilltop.  
4. Limited improvement in the bacteriological quality of water and continued difficulty in improving the quality to a higher standard. 

Further Development of the Technology  
Although the village inventory indicated a great number of protectable springs (3 200),
only 40% met the project criteria for protection. Many reported springs were traditionally
dug water holes in valley bottoms that could not be protected through this programme.
Spring identification should be carried out during the dry season to minimise risk of
protecting seasonally drying springs. Declines in the water table due to drops in rainfall
were a major cause of drying springs. More detailed water resources studies are required
to document the relationship between rainfall (seasonal and annual variations) and spring
yields. In the meantime, the minimum yield criterion for a spring to be considered for
protection was revised from 10 l/min to 15 l/min, and , in the case of low yielding
springs, construction of a storage tank to collect water overnight is being explored and
should be considered. The work plan for construction of spring should take into account
the seasons (e.g., the demand for labour during the planting season).
Human activity in the catchment area of a spring has a big affect, especially on the
bacteriological quality of the water. Preferably, 30 m around and upgradient of a spring
should be kept free of human activity to minimise the potential for contamination from
this source. By-laws to this effect should be encouraged where possible. There is a need
for improved and recorded observations on spring site features which might correlate
with the vulnerability of the spring to pollution. Similarly, monitoring and record-keeping
relative to the sensitivity of a spring to seasonal discharge changes would be desirable.
Some general monitoring of subsequent performance of the spring would also provide
valuable information with which to measure project success.
Rural water quality guidelines should take into account the resources available and the
coverage of public water supplies. In this case, if the project guidelines were strictly
followed, 52% of the water sources which provide water to over 60 000 people would be
condemned on the basis of excessive E. coli counts. Notwithstanding, hygiene education,
especially the safe water chain, is important as the contamination level at the point of
drinking in household is much higher than at the source.

Information Sources
DANIDA (Danish International Aid Agency) 1995. Project Document: RUWASA Phase
II. DANIDA, Copenhagen.
The Potential for Different Abstraction Technologies for Rural Water Supply in Uganda.
4.5 Water Augmentation -- Laikipia District, Kenya

Introduction

This case study describes the experiences gained during the planning and implementation of a rainwater harvesting project at three locations in Laikipia District of Kenya (Sipilili, Olmoran and Machunguru Locations). The project demonstrated that a well-planned rainwater harvesting initiative can bring about sustainable development in communities in an isolated and marginal area, far from riverine water sources.

The Laikipia District lies on the leeward side of Mount Kenya and has an annual average rainfall of approximately 700 mm. Rain falls in two distinct seasons, known as the long rains and short rains. The area is categorized as semi-arid. The communities in the three locations comprise subsistence farmers growing crops (mainly maize and beans) and keeping livestock (cattle, sheep and goats). There are frequent droughts, resulting in frequent crop failures and decimation of the livestock herd.

Prior to the initiation of the rainwater harvesting project, most of the people living in the three locations did not have access to clean water. The only source of domestic water was from earth dams situated far away. The dams were also used for livestock watering. There was considerable soil erosion arising from inappropriate farming practices, resulting in heavy sedimentation in the dams. These factors rendered the water unsafe for human consumption. The heavy sedimentation also reduced the volume of water in the dams to such an extent that there were times when water was not available, even for domestic use. The dams had to be desilted, manually, every third year, which placed a tiresome burden on the communities.
Further, many households had no pit latrines and the level of basic hygiene was low. The lack of availability of safe water, low levels of nutrition and poor health status resulted in an overall situation at the homesteads of dependency, desperation and insecurity. Many of the subsistence farmers abandoned their plots and went to urban centres in search of employment.

In the light of these circumstances, the Laikipia West communities in 1985 requested the Church of the Province of Kenya to initiate a community-based resource mobilization project. The project is still operating, and, apart from its own activities, has worked in partnership with the Ministry of Health's environmental hygiene programme, the Ministry of Agriculture's soil conservation activities, and the United Nations Development Programme (UNDP)-supported Pastoral Water Programme, as well as with other, similar initiatives.

Participatory rural appraisal (PRA) was used as the means of initially identifying the major problems. The exercise involved the villagers, and pointed to the need for a human-centred approach in which peace, security, improved quality of life, preservation of the environment, justice and democracy were important elements of development.

From the PRA, it became evident that the type of land use and farming practices in the area were unsuitable as they resulted in serious soil erosion, gully formation, general land degradation and inadequate agricultural production to sustain the families. Water was identified as the top priority among the communities, the traditional sources being too distant from the homesteads.

Women were spending considerable time in fetching small quantities of water, which had been rendered inadequate through drought and unsafe through pollution. Assessments showed that other sources of water such as groundwater were inaccessible at great depth and often saline. It therefore was necessary to design an alternative intervention that was based on both social and technical considerations.

In this regard, rainwater harvesting was considered a feasible option which addressed not only water supply issues but also other areas of social and economic development, such as the improvement of health and agriculture. The concept of rainwater harvesting was not new to the communities as many homesteads were already using household utensils to collect drinking water from rooftop catchments, and a few had developed techniques
for collecting runoff water for use in irrigating their home gardens. However, only 25% of homesteads had corrugated iron roofs essential for roof catchment water harvesting. It therefore became necessary to gradually develop additional techniques to provide water for households.

**Technical Description**

The water augmentation programme began by introducing 200 l drums and 2 500 l water tanks for collection of roof catchment water. Based upon the demonstration of the potential of these small containers for rainwater harvesting, the communities decided to venture into large systems, and, by the end of the project, they had constructed several 10 000 l ferrocement tanks to capture and store rainwater.

The extension strategy adopted involved provision of technical advice which included, for example, advice on the calculation of the correct volume of tank in relation to the roof area and the amount of expected rainfall. Training was also provided in construction techniques such as determining the proper material mix, the slope of the gutter and the provision of splash-guards. Thereafter, the villagers did the actual construction. Both men and women participated in the programme. Women built the tanks on site while men were more interested in being trained in the techniques of tank building. One outcome of the project was that it promoted gender-balanced participation in the planning, as well as in the construction and maintenance, of the water facilities.

This technology is described in Part B, Chapter 2, "Domestic Water Supply."

As previously noted, other measures were also implemented during this programme. Laikipia is a semi-arid district, and soil moisture is the most limiting factor in crop production. Supplemental moisture, therefore, is necessary to ensure a harvest. Farmers were encouraged to practice runoff farming. The technique involved directing runoff from roads and upper slopes into groundwater tanks or directly onto the gardens for macro-irrigation using bunds made of soil and stones. Farmers were also encouraged to practice soil conservation, to establish tree seedling nurseries, and to plant trees around the boundaries of their farms, along the contours, and around their homesteads. They were also encouraged to plant communal and individual woodlots. Planting vegetative cover along soil conservation bunds was also promoted. These practices are reported to have increased food production on a sustainable basis.
These technologies are described in Part B, Chapter 1, "Agriculture."

**Extent of Use**

Maize production was increased as a result of improved land use and runoff farming techniques. In the Machunguru area, for example, yields were 8 bags of 90 kg each (720 kg) per acre prior to the initiation of the project, while, today, good farmers can attain yields of 20 bags (1 800 kg) per acre. The additional maize stover produced is fed to livestock during dry periods.

Prior to the water augmentation programme, vegetables were not grown in the area, but were obtained from Nyahururu and Nyandarua some 100 km away. Improved land use and runoff farming techniques have enabled vegetable production to meet household requirements and provide surpluses for sale to augment household incomes. In addition, farmers have diversified their crops from the traditional maize and beans to include potatoes, carrots, onions, soya beans, millet, bananas and fruit. This diversity has contributed greatly to food security and balanced diets.

Likewise, prior to the water augmentation project, the semi-arid area had very few trees, the original trees having been cut down for building, charcoal burning and for fuel wood. As part of the development package, the project encouraged production of tree seedlings and planting of trees within homesteads, along farm boundaries and contours, and in farmed woodlot, as well as afforestation on communal hilltops. Enterprising farmers derived considerable income from the sale of seedlings.

**Operation and Maintenance**

A number of in-ground storage tanks were built by the community to take advantage of, and maximise, the efforts made toward, and the benefits from, soil and water conservation in the District. Runoff water from roads, the upper reaches of slopes, and rooftop catchments was directed towards these tanks. The water so harvested had various end uses, including vegetable production and livestock watering.

Although the programme was centred on the provision of water, the project had some spin-offs and positive effects on other sectors of community development. This is attributed to the fact that members of the community were interacting continuously in a participatory manner, exchanging ideas and learning from each other. In addition, the existence of an organized community made it easier for extension services from other
agencies to deliver advice.

Effectiveness of the Technology
The use of contaminated water resulted in an high incidence of water-borne diseases. Stomach and other gastro-intestinal ailments were prevalent. Costs for medical treatment for a family were as high as Ksh 700 per annum ($15, or one month's wages for an average Kenyan). Availability of clean drinking water from the rooftop catchments reduced the incidences of these diseases, resulting in fewer sick days, increased economic activity of members of household, and savings in medical expenses which could be redirected to other household expenses.

It was also observed that increased levels of food production, accompanied by crop diversification, reduced the once prevalent high levels of malnutrition. Households had improved calorie intakes and more varied diets than was the case before the project was initiated.

Further, the number of households with corrugated iron roofs increased from 25% of homes to 70% of homes during the 10 year period. At the same time, the number of houses with sufficient rooms to accommodate family members, and those showing other improvements, increased from 40% to 70% of housing units.

As in the case of water supplies, the availability of toilet facilities is essential to maintaining the public health. The numbers and types of latrines built were continuously monitored during the project period. Within the project area, the percentage of simple pit latrines doubled, improved latrines tripled, and VIP latrines rose from zero to 24% of household units.

Suitability
The performance of this project can be measured by its outputs and the benefits it brought to the communities. In all cases, the approaches taken and technologies used during this project were not only suitable for the area in which they were applied but they were also successful in achieving the broadly-based goals of the programme under which they were carried out. The key achievements can be summarised as follows:

- Approximately 1,000 tanks of various types and sizes were built by the communities, with technical advice and essential material assistance provided by the project, providing approximately 9,600 people with access to water.
• A significant number of households became involved in various rural development activities that did not exist in the area prior to the project.
• The percentage of households involved in vegetable growing, tree planting and seedling production, and home improvement activities increased from zero to 100% (vegetable growing); 90% (tree planting); 50% (tree seedling production); and 70% (home improvements).

**Location No. of tanks built No. of people served**

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of tanks</th>
<th>No. of people served</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sipilili</td>
<td>500</td>
<td>5,600</td>
</tr>
<tr>
<td>Machunguru</td>
<td>200</td>
<td>1,500</td>
</tr>
<tr>
<td>Olmoran</td>
<td>300</td>
<td>2,500</td>
</tr>
<tr>
<td>Total</td>
<td>1,000</td>
<td>9,600</td>
</tr>
</tbody>
</table>

**Further Development of the Technology**

Several independent evaluation teams state that, after 10 years of implementation, the program has considerably improved the living standards of the communities, with regard to water availability, public health improvement, farm management, and overall socioeconomic status of the people. The project was planned and implemented in such a manner that the activities initiated should be self-sustaining, replicable and sustainable.

**Information Sources**

*Rolf Winberg*, Swedish International Development Authority, Post Office Box 30600, Nairobi, Kenya.

**4.6 Recycled Water -- Achimota Brewery, Ghana**

**Technical Description**

The process involves the use of recycled water to blend with incoming cold water as feed water for boilers. Hot water obtained in the process is used in the brewing process or as a boiler feed water and filling pasteurizer. This technology is described in Part B, Chapter 3, "Mining and Industry."

**Extent of Use**

This technology is used in the brewing and bottling industry in Ghana, and specifically at the Achimota Brewery.

**Operation and Maintenance**
The regular maintenance of the mechanical systems is done by trained artisans employed by the Brewery.

Level of Involvement
The level of involvement is primarily within each factory and is, therefore, industry specific. Generally, the availability of trained artisans is the principal requirement for implementing this technology.

Costs
Initial capital costs may be high if plant operations need to be restructured and new equipment installed. However, these costs are usually offset by the long-term savings in water costs. No information on operating and maintenance costs is available, but the costs may be assumed to be reasonably low and similar to the cost of using conventional technologies.

Suitability
This technology is suitable in any industry that demands a large volume of boiler water. The application used within the Brewery is similar to that applied to thermal power generation cooling systems (described in Part B, Chapter 3, "Mining and Industry").

Advantages
Use of this technology, which can be easily integrated into the industrial process, results in a significant savings in both water demand and water costs in the industry. The technology also can be easily modified to include other sources of blending water such as groundwater.

Disadvantages
Use of this technology is limited in application to situations where there are heat exchangers. Also, impurities within the blended water stream may result in boiler scale.

Further Development of the Technology
This is a fairly old technology. Current research is focusing more on improving the efficiency of the boilers rather than on the degree of recycling.

Information Sources
Achimota Brewery Limited, Achimota, Accra, Ghana.

4.7 Water Recycling -- Tarkwa Gold Fields, Ghana

Technical Description
In this process, groundwater and wastewater from drilling operations are pumped into an underground sump. The sump water is raised in stages into a surface reservoir where it is mixed with raw water pumped from streams. The water in the reservoir is allowed to settle.

Through this process of dilution and sedimentation, water quality is improved, and the water is then recycled for use in underground mining operations.

This technology is described in Part B, Chapter 3, "Mining and Industry."

**Extent of Use**

This technology is used by mining operations in the Tarkwa gold fields in Ghana.

**Operation and Maintenance**

This is a very flexible system, quick to install and designed to provide only a limited supply of process water to any location where water is needed. The pumps normally operate 10 hours per day.

**Level of Involvement**

This technology is industry-specific and is generally operated as part of the production process within the specific industry. Trained personnel are needed to maintain the pumping systems.

**Costs**

Costs are difficult to determine, but capital costs can be assumed to be high given the need for pumps, pipelines and related equipment. Operating costs, however, are probably similar or somewhat less than the costs of using raw water for the same operations.

**Effectiveness of the Technology**

And water supply. It has proven to be very effective in conserving water resources, while meeting the production demands of the industry.

**Suitability**

Water re-use systems can be installed in any sub-surface mining operation. The possibility of including a water treatment system within the pumping network, to upgrade water quality if necessary, is high.

**Environmental Benefits**

By containing the contaminated water generated in sub-surface mining activities, direct pollution of surface water resources is minimized. Contaminants are typically sediments
and other dissolved chemicals which are amenable to removal using conventional treatment methods. However, the disposal of waste products should be monitored to limit negative inputs on the environment.

**Advantages**

Use of this technology limits the pollutant load to surface and ground waters.

**Disadvantages**

The technology, which is based on pumping, has a high energy demand.

**Further Development of the Technology**

The advantages to be gained from using this system depends on the quality of ore purification to be achieved, and the chemical processes used. Therefore, any future development of the technology has to be in the area of in-line water quality improvement.

**Information Sources**

*Goldfields Corporation*, Tarkwa and Ashanti Goldfields Corporation, Ghana.

PART D -- ANNEXES

Annex 1

1. **List of Abbreviations**

ARDA - Agricultural and Rural Development Authority, Zimbabwe

CREPA - Centre Regional pour l'Eau Potable et l'Assainissement a Faible Cout, Ouagadougou, Burkina Faso

ED - Electrodialysis

EDR - Electrodialysis Reversal

FAO - Food and Agriculture Organisation

GTZ - German Technical Co-operation

IWSD - Institute of Water & Sanitation Development, Zimbabwe

l/s - Litres per second

ML/d - Mega litres per day

MLGRUD - Ministry of Local Government, Rural & Urban
Annex 2

2. Table of Conversion Factors for Metric and U.S. Customary Units

This water-quantity equivalents and conversion factor lists is for those interested in converting units. The right-hand column includes units expressed in two systems - US Customary and International System (metric). Units, which are written in abbreviated form below, are spelled out in parentheses the first time they appear. To convert from the unit in the left-hand column to that in the right, multiply by the number in the right-hand column. Most of the quantities listed were rounded to five significant figures. However, for many purposes, the first two or three significant figures are adequate for determining many water-quantity relations, such as general comparisons of water availability with water use or calculations in which the accuracy of the original data itself does not justify more than three significant figures. Quantities shown in italics are exact equivalents - no rounding was necessary. Regarding length of time, each calendar year is assumed (for this list) to consist of 365 days.
PART E - INSTITUTIONAL PROFILES

1. The UNEP Water Branch

The UNEP Water Branch was established on 1 January 1996, with the consolidation of the former Freshwater Unit and the Oceans and Coastal Areas Programme Activity Center (OCA/PAC).

A main function of the Water Branch is to promote and facilitate integrated water management, focusing on rivers, lakes and other freshwater systems, groundwater, and the coastal and marine waters into which they ultimately drain, including their living resources. The Water Branch integrates UNEP's water activities across (i) physical boundaries, (ii) disciplines, and (iii) types of water (fresh and marine waters). Particular attention is directed to internationally-shared water systems, including promotion of mechanisms for enhancing international cooperation for their sustainable management and use, as well as assisting riparian countries to undertake trans-boundary diagnostic analyses and to develop comprehensive management action plans. The focus is on both the scientific and technical issues (water supply and demand, pollution sources, flora, fauna, etc.) And the social, economic, institutional, legal and political issues that fundamentally shape the way in which humans use their water resources.

The Water Branch is UNEP's focal point for its role as secretariat of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities, including its Technical Coordination Office in The Hague, The Netherlands. The Water Branch also administers and supports UNEP's 13 Regional Seas Programme involving more than 140 coastal States throughout the world, as well as UNEP's activities in support of such initiatives as the Barbados Programme of Action for Sustainable Development of Small Island Developing States, the International Coral Reef Initiative and the Global Plan of Action for the conservation, Management and Utilization of Marine Mammals.

The activities of the Water Branch reflect the objectives and goals of Chapters 17 and 18 of Agenda 21, as well as other chapters of Agenda 21 relevant to the sustainable management and use of water resources, and to the direction provided by UNEP's
Governing Council. The Water Branch supports activities of the International Environmental Technology Centre (IETC) and the Office of Industry and the Environment (IE) of UNEP on matters related to the development and transfer of environmentally sound technologies (EST's) aimed at water resource management. It also participates in inter-agency initiatives involving common UN agency water issues. To address its tasks and responsibilities, The Water Branch brings together expertise in river and lake limnology, groundwater hydrology, hydrologic engineering, coastal zone management, marine biodiversity, resource economics, monitoring and assessment, environmental technology, environmental law, capacity-building and public awareness. It also works with partner UN agencies, inter-governmental bodies, and international and non-governmental organizations on integrated freshwater and coastal water resource issues.

2. Institute of Water and Sanitation Development (IWSD)

The Institute of Water and Sanitation Development is a non profit organization building capacity in the water and sanitation sector of the Southern Africa region. Formed as a UNDP-World Bank Project in 1989, the Institute has established a sound basis for its sustainable operation on a self financing basis.

Support from the UNDP-World Bank Water and Sanitation Programme (RWSG-EA) ended in 1996 having been instrumental in the formation and growth of the Institute since 1989. It is expected that the Programme will continue to be closely associated with the Institute and use its services from time to time.

IWSD considers training as one of the important elements of human resource development, awareness creation and institutional strengthening. Training activities of the Institute are continuously growing. While the Institute's Community Management of Water Supplies and Sanitation course continued to be popular, the introduction of a course dealing with leak detection is welcomed in particular by the Local Authorities. The Institute took over responsibility for the training of water and waste water plant operators in 1996 at the request of the City of Harare. Since 1997 this programme is fully managed by the Institute.

Several research projects are being developed by IWSD with a focus on water management and water and the environment. A NORAD funded project on waste water
treatment being carried out with the City of Harare has progressed well and provides valuable lessons.

A wide range of clients are using the Institute's technical support services. The client base will be expanded and opportunities are sought where IWSD would contribute meaningfully to policy change in the management and delivery of water and sanitation services. The information and advisory support services of IWSD are also becoming an effective resource for the water and sanitation sector in the African region.