Drinking Water Source Protection

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A review of environmental factors affecting
community water supplies

M.D. Lee and T.F. Bastemeijer

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Preface

This Occasional Paper was prepared by IRC with financial support from the Drinking Water Department of the Netherlands Ministry of Housing, Physical Planning and Environment (VROM). Our special thanks go to Anneke Goedkoop of the VROM ministry, who encouraged IRC to explore the subject and also participated in various meetings and discussions.

Sources of information were IRC's bibliographic database (IRCDOC), periodicals, resource persons in relevant institutions, and documentation provided by a range of organizations and projects. The cases referred to in the report show the nature of water source problems and protection measures, but do not intend to provide a full picture of the local situations as this research did not include field studies and laboratory analysis.

It is anticipated that field studies will be initiated in a next phase of this research, preferably in co-operation with national institutions in the countries which face problems in protection of sources and which have shown an interest to solve them. Field studies would provide the information needed to prepare coordinated action at national level with support from external support agencies and specialized institutions.

From the information available, it is clear that protection of drinking water sources has become a key factor affecting sustainability in drinking water supply and sanitation provision. Achieving the goals set by governments and external support agencies when they met in Delhi in September 1990, therefore, depends largely on the priority given to water resource management in general and the protection of drinking water sources in particular. It is hoped that this paper will contribute to greater awareness concerning environmental factors affecting water sources, and will stimulate governments and external support agencies to develop effective strategies to address the issue.

Summary

Background

Drinking water supply systems are affected by and affect water resources, but agriculture and industry are often the main users of water and also the main polluters. Protection of drinking water sources in particular sources of small and medium size community water supplies deserves urgent attention, in view of an increasing number of these systems and the need to ensure their sustainability.

Although a worldwide water shortage is not expected within the next 150 years, problems already occur at a regional and national scale. In a recent study concerning water resource problems 15 out of 35 countries were facing more or less severe shortages (Cessti, 1989). In most countries water use grows faster than the population. Consequently, the number of countries facing shortages is likely to increase and acute problems are expected to arise more frequently over the coming years. Irrigation accounts roughly for 80% of water use (WHO, 1990), and contributes 10% of the pollution. The total area under irrigation has tripled between 1951 and 1980. This rate of increase continues for the time being. Industrial use, estimated at 10% of total water consumption and accounting for 80% of the pollution, is expected to continue to increase (Committee on Development Planning, 1990). Domestic consumption accounts for less than 10% of the total withdrawal of water, but is increasingly affected by the above water resource problems.

There are many examples showing the urgent need for protection of drinking water sources and water resource management. In Maharastra state, India, exploitation of groundwater for sugar production causes village wells to dry up and aquifers to become saline. Processing factories started using water from deep boreholes and the consequent rapid groundwater depletion from 1985 to 1987 resulted in a staggering increase of villages with no permanent source of drinking water from 1,800 to 23,000 as public and private wells ran dry. In Gujarat State, along the coastal region of Saurashtra, the switch to mechanized pumping of groundwater for sugar-cane irrigation and processing lead to a lowering of the water table from 10 to 35 meters and saline water intrusion due to a reversal of the hydraulic gradient. Over 12,000 wells were estimated to have been put out of use affecting 280,000 people.

In Baluchistan, Pakistan, groundwater levels have been falling in certain valleys at a rate of 26 cm/year since the 1960s as a result of land degradation due to overgrazing and groundwater extraction for irrigation. In Cape verde, groundwater recharge was seen to double after reforestation with pinus trees, but this experience could not be replicated due to legal and institutional constraints, even though there is shortage of water for irrigation and domestic uses. In Latin America, the Reconquista and Matanza rivers in Argentina, the Choqueyapu-Reni rivers in Bolivia, the Tiete river in Brazil, the Magdalena river in Colombia and many others receive serious levels of toxic industrial pollution due to untreated factory discharge. In Yemen, monitoring of groundwater levels on the Sana'a plain has shown groundwater levels have fallen by
20 meters in ten years.

This occasional paper presents an overview of available information concerning such problems, analyses their causes and their nature, identifies experiences to solve or control these problems with specific emphasis on drinking water sources for small and medium size water supply systems and on the role of user communities in protecting sources of drinking water. It also identifies priorities in initiating country level activities and suggests ways to deal more systematically with the issue of water source protection.

Environmental sustainability and community management

It can be estimated that if the goal of clean water for all in the year 2000 is reached, the available supply of clean and reliable drinking water must be increased 4 or 5 times. Considering the rapid growth in demand and subsequent increase of environmental problems, the relative importance of source problems as concerns the sustainability of water supply systems and the health of the people, will dramatically increase in all countries. This is true even in countries where such problems are not yet considered to be serious. Management of water resources and protection of sources is therefore essential to increase efficient use of existing water supplies.

The population is often insufficiently aware of the environmental factors affecting their drinking water sources. Considering that user communities are increasingly involved in the management of small and medium size water supply and sanitation systems, there is a need to explore ways to involve them more effectively in protecting or improving their drinking water sources. Integrating environmental issues in systematic processes of community involvement appears important to raise the interest of authorities and achieve higher priority for the protection of drinking water sources.

Identifying causes of source problems

A source problem occurs when a water source is no longer adequate or reliable. An adequate source is one that ensures supply of drinking water in sufficient quantity and quality, both from the viewpoint of the user community and the responsible water agency or government department. Once a water source has become inadequate or unreliable, it may still remain the best available source. For instance, polluted water may continue to be used if there is insufficient awareness concerning health risks among the users. This is especially the case when the nature of pollution does not affect the taste or colour, or there is no alternative water source. Therefore, it may be assumed that the effects of deteriorated water sources on health are widespread, but often not recognized.

Water sources can be broadly divided into groundwater and surface water sources. Considering the various types of water sources, making a distinction between small and large sources is useful in considering the nature of source-catchment linkages. Small sources are generally fed from identifiable local catchments. They usually supply drinking water to small and medium size communities. Small sources include springs, ponds, shallow aquifers, and small streams. Large surface and groundwater sources are fed from larger catchments which are comprised of many smaller individual catchments. Large sources include regional aquifers, rivers, large lakes and large artesian springs. These sources are used for small and large drinking water supply systems.

Users of both small and large water supply systems are affected by poor water quality and insufficient source yield. For small community water supply systems the nature of the problems may be such that solutions could be found locally. For instance, environmental factors like the use of on-site sanitation systems, the disposal of organic waste, deforestation and overgrazing are often specifically affecting small sources with a local catchment area. Possible solutions to such specific source problems could include physical protection of wells, improved sanitation, improving agricultural practices, and regulating water use.

Solving specific source problems is more difficult when they are caused by environmental problems occurring at a wider scale such as chemical pollution, salt water intrusion and changes in the hydrological regime of larger catchment areas or river basins. Control of environmental factors like industrial waste and waste water disposal in open water systems, the use of pesticides and fertilizers, over-extraction of groundwater for large-scale irrigation, soil erosion and urbanization requires the involvement of national and local authorities, and effective implementation of legal measures with the support of specialized institutions. Strategies to control these environmental factors could, for example, include creating economic incentives, land-use planning, capacity building for water resource management and enforcement of waste control.

In identifying the factors causing source problems, it is necessary to take into account geo-hydrological processes as well as the size of catchment areas. Catchment areas vary from a few hectares to thousands of square kilometres. Their size largely determines the relative importance of environmental factors and specific causes of source problems.

User communities often contribute to source problems and can play an important role in avoiding or diminishing them. There are numerous field documents and publications citing the contamination of water sources in small community water supply systems. Accumulation of organic material causing nitrate pollution of sources seems to be a pressing problem for many village water supply systems. Waste disposal into or near a water source causes both organic and chemical pollution.

Poor functioning of drinking water supply systems is often interlinked with increased water losses, vandalism, and increased competition between different user groups. These different factors may lead to insufficiency of the water source. The use of this water for other purposes increasingly affects drinking water supply for small communities.

Many problems are also caused by changes in land-use as population pressure and economic activity increase. Environmental degradation and desertification have become issues of great importance in many countries. Increasing population pressure linked with traditional land-use systems all too often result in erosion, declining soil fertility and deforestation. These elements contribute directly to water source problems.

The main environmental factors affecting the water quality of larger sources are pollution by industrial waste products, pesticide and fertilizer contamination and domestic sewage pollution. The yield of larger water sources appears to be affected predominantly by extraction of groundwater beyond sustainable yields, and by unsustainable land-use changes taking place on a wider scale.

Assessing environmental factors affecting water sources

Field experience shows that good source selection and adequate siting of intakes contribute to the reliability of water supply systems, but more active protection of catchment areas is often needed. This involves a systematic appraisal of catchment areas for surface or groundwater sources and the identification of environmental problems related to human

activities.

Once a natural water source is developed, human activities tend to intensify in the catchment areas. It is sometimes useful for planning purposes to distinguish protection zones with different degrees of vulnerability, i.e. the inner zone, defined as the area in which there is a direct risk of contamination; the outer zone, defined as the area in which the water may be at risk from indirect contamination; and the catchment area.

Assessing the risk that pollution might occur may include sanitary surveys to examine the physical conditions around point source water supply systems, and identify possible causes of contamination of the water.

Community motivation and awareness is important, since many water pollution problems are caused directly and indirectly by the water users. However, motivating people to take an active role in assessing environmental factors and protecting their water sources is often difficult. Community-based maintenance and management of water supply schemes is a good starting point for a more integrated approach to water source protection and environmental conservation, provided there are direct links between the community and the water source.

Need to address water source protection more systematically

Based on the information received and the documentation reviewed, there is a definite need to address source protection problems and their underlying causes more systematically. Water related environmental problems have received attention in recent years because they affect the sustainability and the effectiveness of drinking water supply improvements and other development efforts. However, there is no clear overview of ways to deal with the issue. Too few examples of success in controlling environmental factors degrading sources of drinking water have been reported upon. Though often poorly documented, these examples show that there is scope for better water resource management.

Examples of solutions being implemented include improvements in sanitation, physical protection of wells and intakes, soil and water conservation, treatment of waste water, recycling of waste water, artificial recharge and reforestation. Strategies to protect drinking water sources often combine such measures with institutional and legal improvements. Increased attention is being given to partnership between communities and government agencies in developing capacities to manage and protect water resources. Legal issues relating to drinking water resource management have recently been listed by WHO, which is continuing its research in this important area.

Lack of reliable information

There are insufficient data on the magnitude and the nature of drinking water source problems. Lack of information is possibly one of the main reasons why so far few countries have formulated overall policy objectives concerning environmental protection of drinking water sources. This may also explain their failure to make appropriate legal and institutional provisions.

Field experience in local water source protection mainly concerns technical approaches to solve local source problems in small catchments. Other essential elements appear to be land-use planning and control, legislation and regulations, source selection and siting procedures, and community management. However, again, there is very little documented experience in developing such an integrated concept.

More detailed analysis of environmental data is required to set standards, provide workable guidelines and promote water source protection at all levels in developing countries. This would contribute significantly to developing national water resource strategies. Possible activities by the international organizations could include:

- Developing checklists and general guidelines to identify, prevent and remedy water source problems;
- Preparing country inventories to establish the nature and magnitude of water source problems and identify possible protective actions;

Legislation not enforced

Environmental legislation and water laws mostly concern large basins. As such, they seldom provide a good basis for the protection of many of the smaller water sources on which small settlements rely. Enforcement of water resource legislation and regulations is hampered by lack of awareness of environmental problems, resource sustainability measures and the associated costs and benefits. It is critical that future legislation should be resource management oriented and take a sustainability approach.

Some developing countries have prepared new water laws to meet the present needs, but lack political priority for drinking water source protection. Source problems are felt more directly by those without access to improved water supply services, and by users of small untreated community water supplies. Consequently, drinking water sources for smaller settlements and low-income groups in urban fringe areas are increasingly affected by the pollution caused by larger settlements and economic activities. The benefits and costs of pollution control vis-a-vis non-control to the polluter and consumer are important considerations in this matter.

Lack of practical guidance for planners and decision-makers

There is a general lack of awareness of the above mentioned environmental issues among planners and decisions makers, and often among the water users themselves. In many cases, both the people and the authorities give priority to meeting short term needs and appreciate less the long term benefits of protecting land and water resources. More attention is needed for the training of local staff and users, enabling them to play a more active role in water source protection by providing the guidance they need to address the most urgent environmental issues in an effective way.

Profiles of different types of water sources in different environments and their vulnerability to environmental factors could form a basis for long term planning. Guidelines for the selection and development of surface and sub-surface sources under different catchment conditions, would be useful to engineers and planners who presently have limited means to address the issue. To monitor the environmental factors affecting the sources, simple indicators are required to determine when and where preventive or remedial action is needed.

Simple tools and methods

Small water sources could be protected by using simple tools and methods, relying upon community resources and skills. Practical examples may help to promote the idea of water source protection and trigger the development of local solutions. Detailed studies on water source protection issues in selected developing countries would have as an objective to develop these simple tools and methods which can be applied at the community level. On the basis of the information from field studies and pilot projects to promote and develop such tools and methods, community involvement in water source protection at the local level could be enhanced.

Low-cost technologies for waste water treatment and the management and control of industrial waste could be applied more often, in particular by small and medium size industries, and by public institutions like hospitals. Some are already in existence whereas others must be installed. It would be important therefore to identify and promote existing appropriate and low-cost processing technologies to: identify where the necessities currently exist, promote research on new treatment methods, and develop adequate maintenance programmes for existing methods.

Pesticides and chemicals

Little detailed information is available for developing countries on the effects on the health of water users related to pesticides and chemicals into water sources. An increasing array of chemicals are imported and used in the developing world and many countries do not have a registry of toxic imports. It is therefore important that information on pesticide and chemical use practices is collected in each country to determine high-risk water sources, and situations where contamination of sources is likely.

Information concerning the health effects of pesticides and chemicals needs to be compiled and made accessible to allow planners and engineers to assess the health risks in the planning stage and to develop suitable monitoring indicators.

1. Introduction

1.1 Background

During the last years of the International Drinking Water and Sanitation Decade, IRC has enhanced its information base and increased its efforts to gain a better overview of environmental issues relating to drinking water supply and sanitation. These issues were identified by concentrating on environmental impact on drinking water supply and sanitation programs as well as on environmental factors affecting drinking water provision.

There is little specific information concerning environmental impact of drinking water supply and sanitation. More information is available concerning the effects of economic activities and exploitation of water resources, mainly for irrigation and hydro-power. It may be assumed that the negative environmental effects from drinking water supply programmes is less significant than from land and water development for agriculture and other economic activities.

A greater volume of information is available on the impact of environmental factors on the feasibility, the quality, and the sustainability of drinking water supply programmes. Many examples from the field relate to scarcity of water resources, but water pollution is also mentioned frequently. These factors merit increased attention, because they affect the health and wellbeing of people as well as available water supply.

These considerations have directed the scope of IRC's present activities towards assessment and control of environmental factors affecting the sustainability of drinking water supply and sanitation programmes. Earlier, the IRC staff has concentrated on technical solutions to ameliorate water scarcity and enhance the role of user communities in managing their living environment. Occasional papers have been published on artificial recharge and water harvesting (1). It is anticipated that further work will be done to develop an information base concerning community-based environmental management.

The purpose of this occasional paper is to summarize the available information concerning drinking water source problems and to identify experience in solving them. It presents an overview of environmental factors negatively affecting drinking water sources in developing countries and the main impacts in terms of quality and quantity of drinking water. It addresses the causes of deterioration of small and large sources for both surface water and groundwater, and contains summary information concerning experiences in protecting or improving sources of drinking water. It also identifies priorities for initiating country level activities, evaluation studies and research. Finally, it suggests ways of dealing more systematically with the issue of water source protection.

The information presented in this paper has been obtained from a variety of sources, most of which, international organizations and specialized institutions. Country and case related information often obtained verbally or in a summary form, because most

field experience is rarely documented. Since detailed case studies and field reports are scarce, most of the examples are drawn from existing articles, publications and reports.

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(1)   Occasional Paper 9: Artificial groundwater recharge for water supply of medium-size communities in developing countries, OP 9, IRC, 1987. Occasional Paper 14: Water harvesting in five African countries, OP 14, IRC, 1990.

Some case material was presented during a working meeting on water source protection held at IRC on May 31 and June 1, 1990. The papers prepared by some of the participants have been referred to in this publication. The participants of the working meeting concluded that there is insufficient priority for water source protection and that awareness about the issue is lacking. Country institutions dealing with the issue are often inexistent or ineffective. In most developing countries there are no policies, strategies or legislation. It was clear that there is an urgent need for continued exchange of information and increased action in this important field. Further country studies are recommended as part of the research and development activities, with emphasis on economic and legal aspects of drinking water source protection. These last aspects are being taken up by the Community Water Supply and Sanitation Division in the World Health Organization (WHO/CWSS) in Geneva.

1.2   Water sources and the environment

The Report of the World Commission on Environment and Development, issued in 1987, stresses that many efforts at environmental management to date have been inappropriate: focusing more on the effects than on the problems and their original causes. The commission recommended that "in dealing with environmental issues, we must shift our attention from the effects to the causes".

During the International Decade for Drinking Water Supply and Sanitation, many people in both urban and rural areas of developing countries have been provided with an improved drinking water supply system. These systems range from protected wells with rope and bucket systems or handpumps to diesel-pumped piped supply systems with house connections. The World Health Organization (WHO) estimates that in the ten years, about one billion people will have been served, bringing the global coverage to 88% for urban areas and 61% for rural areas.

In spite of this unprecedented progress, it is estimated that the number of people still in need of a reliable, improved water supply system in 1990 is greater than in 1980 (about 1.2 billion according to WHO statistics). According to the New Delhi Statement (2) adopted by 600 participants from 115 countries, one in three people in the developing world still lacks safe water and environmental sanitation.

Most policy makers and planners are well aware that many drinking water supply systems are not functioning well. Data concerning the percentage of systems functioning below standard or abandoned by their users vary widely and monitoring data are often not available. Most estimates indicate percentages in the order of 40 to 60% in spite of the successful development of decentralized operation and maintenance systems in some countries. There is evidence that source problems are an important cause of poor functioning of water supplies, normally associated with poor operation and maintenance.

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(2)   Final statement of the Global Consultation on Safe Water and Sanitation for the 1990s, 10-14 September 1990, New Delhi, India.

When water supply systems function correctly and there is subsequent enhancement in living conditions and income levels, people are often willing to pay for improved service levels and will use drinking water for other domestic and economic purposes. Therefore, during the design life of a system, the average per capita water consumption increases if the system functions well. With multiple service levels being widely adopted, the per capita consumption (often in the order of 20 l/day at present) could rise to 40 l/day in rural and to 60 l/day in peri-urban areas.

On the basis of these indicative figures, it can be estimated that if the goal of clean water for all in the year 2000 is to be reached, the daily consumption of clean and reliable drinking water could be multiplied by about 4 or 5. Management of water resources and protection of sources is therefore essential.

Shallow groundwater and gravity sources such as springs are generally accepted as suitable for small, low-cost community water supplies in rural areas. Many of these sources are being polluted by waste products of human activities. As population growth, modernization of agriculture and industrial expansion continue at rapid pace in most developing countries, environmental problems such as pollution by solid and liquid wastes, deforestation and aquifer depletion will rapidly increase (Lee, 1990).

Considering the rapid growth in demand in combination with the associated increase of environmental problems, the relative importance of source problems affecting the sustainability of water supply systems, the health and wellbeing of the people, will dramatically increase in all countries. This is true even in countries where such problems are not yet serious. Keeping in mind the recommendation of the World Commission on Environment and Development, it is therefore necessary to direct attention to the broader context related to these source problems.

1.3   Focus on user communities

Source problems concern all water supply systems. However, for large urban water supply systems, source problems are generally considered in financial terms. Investments in developing new sources or additional treatment capacities may increase the cost of producing water by a relatively small percentage. Responsible water agencies may take this into account in the tariffs, but there will in principle be no direct negative consequences for the health and the living environment of the water users.

This is different in the case of smaller water supply systems which often have no treatment facility or a very simple one. Additional investments for better treatment or developing a new source would in proportion be much higher. In addition, operation and maintenance would become more difficult. Locally managed systems would tend to cease functioning and treatment plants would be abandoned. In general, communities using small or medium-size water supply systems are therefore more directly affected by source problems than those using larger systems.

Small and medium size systems include wells, boreholes with handpumps, spring captation systems, small piped and pumped water supplies, and gravity water supplies. Such systems serve a variety of communities, including rural villages and townships, regional centres, as well as urban low-income areas and urban fringe settlements which are not connected to urban drinking water supply networks.
These communities affect and are affected by their water sources. Water is seldom treated

and the source is prone to a number of direct and indirect causes of deterioration. The population as such, is often insufficiently aware of the health risks related to their water supply.

Finally, given that these communities are increasingly involved in the management of their water supply and sanitation systems, there is a need to explore ways to involve them in the sustainable management of their drinking water sources. Integrating environmental issues in the process of systematic community involvement seems important to raise the interest of authorities and may contribute to increased political commitment for the protection of drinking water sources.

2.   *Methodological Considerations and Definitions*

2.1   **Defining source problems**

Source problems have been defined and information reviewed concerning the natural process described in the hydrological cycle (see Figure 1).   Possible cause-effect relations were identified as a basis for information collection and analysis. A more detailed description of the processes occurring in the hydrological cycle can be found in existing literature (3).
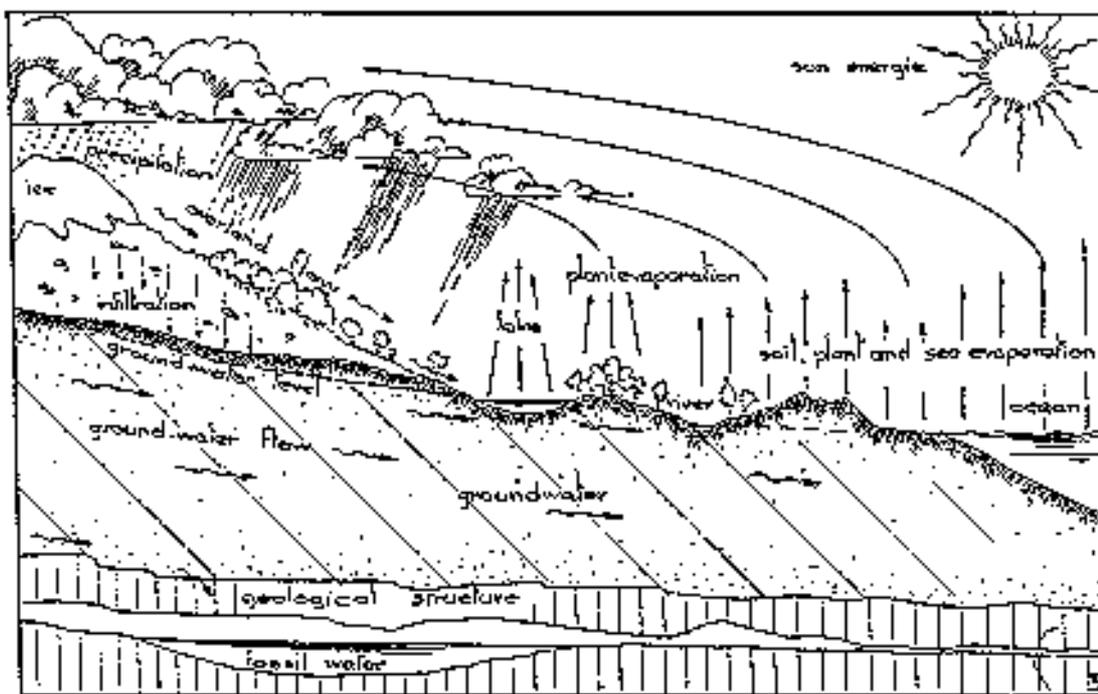
Figure 1:   The hydrological cycle

A source problem occurs when a source is inadequate or unreliable (see table 1). An adequate source ensures supply of drinking water in sufficient quantity and quality, both from the viewpoint of the user community and the responsible water agency or government department. In other words it is perceived as meeting the present demand, but does not necessarily meet future demand. A reliable source by definition, meets present and future demand according to the design criteria, in terms of both quality and quantity. In other words, it would satisfy the needs of a design population at an agreed service level during the whole year until the end of the design period. This is sometimes termed continuity (Lloyd and Helmer, 1990).

Water quality is sufficient when it meets agreed standards when reaching the consumer. Most developing countries have adopted the WHO guidelines (WHO, 1985a) as their ideal goals. Water supply sometimes includes a treatment system, designed to treat the raw water which fluctuates within certain quality limits. The quality of the raw water will therefore determine what treatment is required.

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(3)   For instance in Hofkes et al (1987), Chapter 4.

Table 1:   Defining source problems

Perceived source problem	Possible diagnosis	
	source inadequate	source unreliable
Source yield as anticipated, but not sufficient to satisfy all users due to unforeseen circumstances	x	
Source yield not sufficient to meet present demand	x	
Water demand increases more than anticipated, and exceeds source yield	x	
Yield meets present demand, but not the design demand as anticipated		x
Water quality below agreed standards	x	
Water quality deteriorates		x
Water quality not acceptable to users	x	

Water quantity of a source is sufficient when the lowest yield from the source meets the daily demand. This demand is normally determined by the daily per capita consumption for a given population. It is generally accepted that a minimum of 20-30 litres per capita per day should be provided, but many developing countries set lower objectives determined by local conditions. Some drinking water systems in arid areas are designed to supply the minimum daily biological needs of around 5 litres, the rest coming from unimproved sources. This illustrates that in determining if water quantity is sufficient, much depends on local water use habits, which are influenced by environment, socio-economic status, socio-cultural factors and governments standards.

Water sources which meet both the quality and quantity requirements for agreed uses the whole year round, with the minimum yield exceeding the demand of the design population are reliable by definition. If users are not satisfied with the service level, they perceive the source as inadequate, but the problem is not perceived as such by the engineers responsible for the scheme. On the other hand, users may find a source adequate while engineers may conclude from monitoring data that it does not always meet the demand of the target population. Provided the data are reliable, the responsible engineers will in principle define this as a source problem, even if it is not yet perceived by the user community.

A water source problem is perceived by both the users and the agency when the water quantity or quality of a specific source is found to have decreased to the extent that the consumers of the water do not get the service as agreed. Even if such problem occurs only once, the source is unreliable, but may still remain the best available source. For instance, polluted water may continue to be used if there is insufficient awareness about the health risks among the users, if the nature of pollution does not affect the taste or colour, or if there is no alternative water source.

Source problems related to quantity are sometimes recognized too late. One important reason is that the water demand may be expected to double or triple over the design period of the water supply system. For that reason, sources generally provide an overcapacity

during the first years of operation for water supply systems. Decreasing yields at the source may therefore not be noticed until a given population threshold is passed.

The choice of a water source should ideally be based on data concerning the water quality and quantity, and on a realistic assessment of possible source problems and feasible protection measures. Insufficient data or unrealistic assumptions made in the planning phase frequently have been primary causes of source problems. For instance, the conclusion that a water source meets the requirements is often based on flow measurements during short periods and on the assumption that the source is not used for other purposes, and will not be polluted once it is used for drinking water supply.

Insufficient consideration is given to possible changes in the catchment areas due to human activities. As these changes are often not monitored and land-uses not controlled, deterioration of water sources is occurring widely without being recognized.

2.2 Types of water sources

Water sources can be broadly divided into groundwater and surface water sources, springs and rainwater (Table 2).

Table 2:   Types of Water Sources

Source	Category	Captation
Groundwater in aquifers	confined unconfined shallow fossil	shallow well borehole deep well
Springs	gravity artesian	springbox open intake gallery
Surface water	river stream lake pond	direct pumping dam infiltration well riverbed filtration open intake
Rainwater	n.a.	rooftop harvesting surface catchment runoff farming

The captation system is part of the water supply systems. Source selection is part of planning and design, but the water source is not considered here as a component of the water supply system.

Water source protection aims to ensure the reliability of the sources, but may also contribute to improvement. Improvement means increasing the quality of the water, increasing the yield, or diminishing fluctuations in both. This may render the source adequate for different uses and reduce the costs of the water supply system.

As can be seen from the above table, the water source can sometimes be protected more

effectively by intervening in the catchment area rather than at the source. In this publication, many subjects relate to catchment protection as well as to water source protection, while it is in fact the combined catchment and water source which is being considered. Rainwater quality and availability is determined by global climatic factors and by air pollution. These factors are beyond the scope of this publication.

Some sources do not have a distinct catchment area to which they can be linked. This is the case for fossil groundwater and sometimes for artesian springs. In other cases, it is difficult to define boundaries of catchment areas. For example, boreholes may draw water from different aquifers with different catchment areas. Finally, drinking water sources may be influenced by a very large catchment area. This applies for instance to river basins from which large populations draw their water. This makes it sometimes more difficult to analyze causes of source problems and design remedial actions.

Small sources are generally fed from locally identifiable catchments. They usually supply drinking water to small and medium size communities. Small sources include springs, ponds, shallow aquifers, and small streams. Large surface and groundwater sources are fed by many individual smaller catchments. Large sources include regional aquifers, rivers, large lakes and large artesian springs. User communities of large water sources can range in size from the entire population of a metropolitan city to a small urban-fringe community or village. Considering the various types of water sources, making a distinction between small and large sources is sometimes useful for determining the nature of source-catchment linkages.

2.3   Catchment areas

The reliability of sources ultimately depend on the rainfall and the conditions in the catchment area. The routes water takes and the time the water requires to reach the source greatly affect the quality and quantity of the water available at the source during different seasons. The routes are determined by rainfall characteristics, topography, vegetation, soil and geological conditions.

Where rain falls in heavy showers in distinct rainy seasons, high peak discharge will occur with swollen rivers and streams and increases the sediment load in surface water. Contaminants are washed off the land and into the surface water. In these areas there will normally be a low surface flow during dry periods and pollution will become more serious as polluting substances are not sufficiently diluted. Where rainfall is more evenly distributed, more water infiltrates in the soil, surface water will flow more evenly throughout the year and will generally be less turbid after rainfall. As a result, the natural quality of the surface water will be better and it will fluctuate less.

The volume of water infiltrating per unit of time in the soil as a proportion of total precipitation is defined as the infiltration rate. It is affected by rainfall intensity and distribution, topography (slope, depressions), vegetation, and land use. Human activities in the catchment area may change several of these factors and therefore affect water sources. Surface water sources are generally affected more directly than ground water sources by changes in the catchment area. Ground water sources react more slowly, because infiltrated water takes more time to reach the point where it is

extracted and so the link between a source problem and its cause may be more difficult to establish. For instance, pollution affecting ground water sources may have been caused

years before the problem is actually identified.

In identifying the causes of source problems, it is necessary to take into account these hydrological and geo-hydrological processes as well as the size of catchment areas in order to determine the main factors contributing to the problem. Catchment areas vary from a few hectares to thousands of square kilometres. Their size and nature helps determine the relative importance of causes of problems, and the way to deal with them.

Particularly in small catchment areas, the specific causes of surface water source problems are often relatively easy to identify. The small user communities are commonly the cause of the majority of problems. Preventive and remedial solutions could be achieved at a local (district or community) level often by the communities themselves. In small catchment areas the immediate cause of a specific problem can often be identified by simple observation for which solutions may be suggested.

In large catchments a number of factors tend to contribute to a problem, where the links between causes and effects are more difficult to recognize. The small communities using the larger water sources are not the main cause of most problems although they may contribute to them. Preventive and remedial solutions may therefore require legislative measures, longer term planning and inputs.

2.4   Cause-effect links: a model

For the purpose of this review, the main linkages between the water sources, the catchment areas, natural environmental factors, user communities and non users have been studied using a simplified model (figure 2), distinguishing direct and indirect linkages. Direct linkages concern immediate impacts at the water source and the surrounding area upon the quality or quantity of the water supplied to user communities. Indirect linkages concern changing conditions in the catchment area that affect the reliability of the source.

The environmental factors relating to each of these main linkages are discussed in chapter 3 and 4.

Following an analysis of the nature of source problems, attention is focused on a range of different drinking water source protection interventions that have been adopted in developing countries in an effort to improve water sources. Relevant experiences concerning water source protection are discussed in chapter 5.
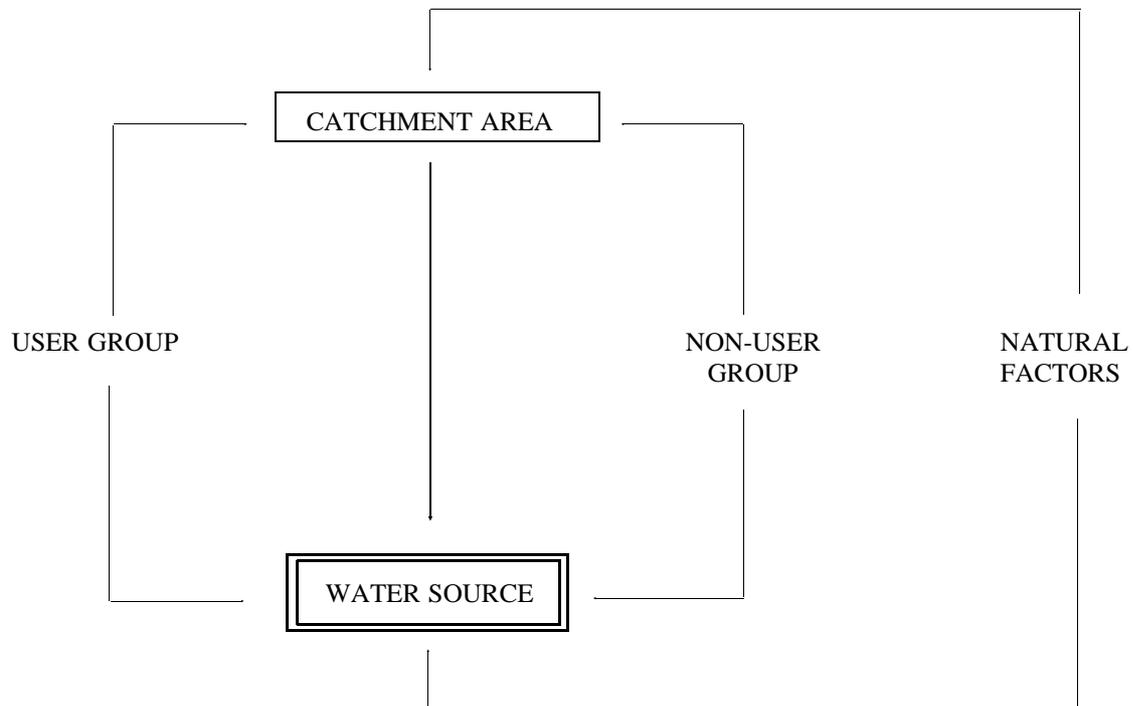
Figure 2:   Main factors affecting water sources

3. Factors Affecting Small Community Water Supplies

3.1 Overview of quality and quantity issues

The environmental factors affecting water sources for small community water supplies are presented in table 3. From this overview it is clear that user communities contribute to source problems, and can and often will play an important role in resolving or diminishing them.

Table 3: Environmental factors affecting small community water supplies

Source problem	Unacceptable quality	Insufficient yield
Nature of the problem	Contamination Taste/odour Physical appearance Chemical pollution High turbidity	Rainfall fluctuations Reduced water levels Depletion
Environmental factors	Pit latrine seepage Septic tank overflow Inadequate design Animals around source Open defaecation Human waste disposal Washing and bathing Accumulated organic waste Waste disposal in catchment Wastewater disposal near source Cutting trees Environmental degradation	Increased demand Water losses Inadequate design Wastage Vandalism Industrial demand Irrigation Deforestation Burning grass and shrubs in catchment Overgrazing Expanding agriculture
Solutions	Physical protection of wells (slabs, drainage) Improved sanitation Emptying tanks or pits Better maintenance and repair Improving hygiene Organizing waste disposal Catchment protection Drainage Wastewater treatment	Community control Repair Water use rules Improve designs Improved agricultural practices Alternative energy sources

3.2 Micro-biological contamination

Most microbiological contamination is caused by the local population. The nature of these problems is well documented. They have been extensively discussed in health and hygiene literature (van Wijk, 1984, 1985; Feachem et al, 1978) as well as in various technical papers on well design and extraction devices (Rogers, 1985; Boschi, 1981, 1982; Hanson, 1985; IRC, 1988; Hofkes et al, 1987)).
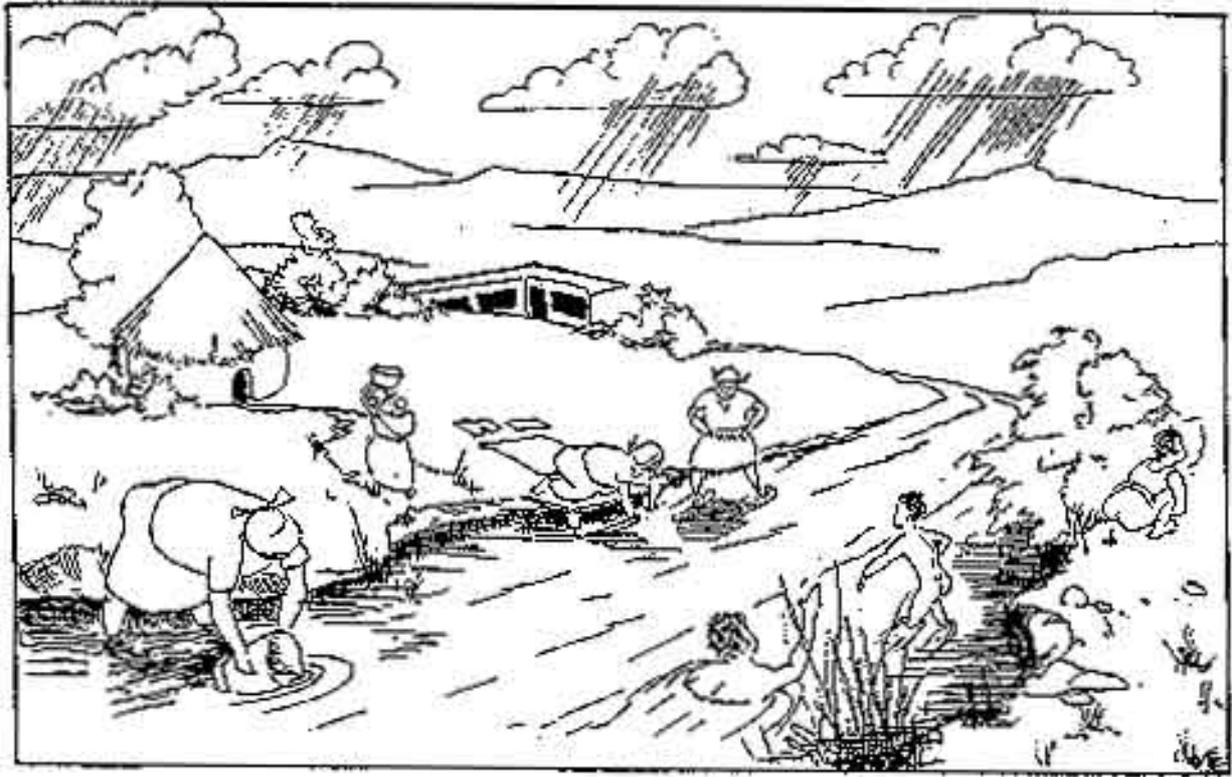
Figure 3:   Water is often contaminated by user communities

Insufficient protection of wells and boreholes facilitates contamination of water sources. This is particularly true for shallow ground water sources due to the poor design of aprons allowing waste water to wash back into wells. It is considered to be a major cause of water contamination in the pacific region (Guo, 1989 personal communication), and in Africa (Wihuri, 1989 personal communication). Another design deficiency is improper drainage, allowing waste water and polluted surface run-off to infiltrate down into the aquifer.

There are numerous field documents and publications reporting the contamination of water sources of small community water supply systems. Results of sanitary inspection and quality monitoring in a pilot water surveillance study in Yogyakarta, Java demonstrated that 65-85% of public water facilities, mostly dug wells and rainwater catchment tanks, are faecally contaminated because of poor site protection and unhygienic conditions (Lloyd, 1990). In Tanzania, analyses indicated moderate levels of contamination in wells and springs, whereas streams and rivers were more highly polluted with roughly 10 times as many E. Coli. Some water sources were infected with schistosomiasis. In Rukwa Region, faeces ended up in traditionally constructed water sources during the rainy season due to their poor protection. Rainwater runoff containing sediment, faecal materials, and animal and plant debris drained into wells and springs. Additionally, villagers took baths and washed clothes next to the water source, and animals were allowed to drink freely (Kauzeni, 1981 and Norconsult, 1981). In Kigoma Region, a study by the Norconsult Water Master Plan team in 1979/80 revealed that 98% of the surface water sources of the region were heavily polluted by faecal bacteria and outbreaks of cholera were frequent . Turbidity levels were high, reducing the effectiveness of any attempts at disinfection (Myhrstad and Haldorsen, 1984).

In Kordofan, Sudan, many villagers use a hafir as their main source of water. Hafirs are open reservoirs excavated by machinery and filled by seasonal flow from a diverted wadi stream. Although they are fitted with an outlet pipe leading to a well from which water should be drawn

for human consumption, many people frequently wade into the hafir for water. Consequently, if infected with guineaworm, they release thousands of larvae from ankle lesions which are then transmitted back to humans via the crustacean cyclops scooped up in the drinking water buckets. The prevalence of infection among hafir users was twice that of those who used other sources. Cyclops was found in all hafirs sampled (Cairncross and Tayeh (1988).

Disease transmission mechanisms are often poorly understood by users. They lack knowledge about bacteriological contamination, which makes it more difficult to generate interest for the protection of water sources This is accentuated by most health education programmes, which are not based on how people themselves perceive that water sources became contaminated, but introduce "foreign" concepts like germs and E-coli. More functional concepts of water pollution and traditional methods of water use control which people may have are seldom used in such programmes (van Wijk, 1985). A problem that is seldom mentioned, but which is nevertheless serious, is the use of pesticide containers to carry or to store drinking water. Cleaning of such containers after having served their original purpose contributes to chemical pollution of water sources.

Many traditional water sources are used for multiple functions including drinking water supply, animal watering, bathing and laundry. This is true of small water holes used by rural villages in Africa as well as large rivers such as the Ganges in India where millions of people immerse themselves each year as part of religious rituals. Where awareness of health and hygiene links are poorly developed, water users find it convenient to bath and wash clothes at the same time as collecting water (van Wijk, 1985). Shortage of water supply points, also encourages people to use the same water source for all purposes. This was evident before the International Water Supply and Sanitation Decade. For instance, in dry lowland villages in Ethiopia it was found that only 2% of the households used a separate source for drinking purposes during the dry season (Kebede, 1978).

Provision of improved drinking water supply facilities and hygiene education during the last 10 years have increased awareness about health risks and there is evidence that people are increasingly motivated to protect their water sources. For instance in Mali villagers pay for the repair of handpumps and continue to invest in improving their traditional wells (Bastemeijer et al, 1990), even though hygiene practices and sanitation are poor (Conré et al, 1989).

Human waste is often disposed of near to surface water because people defaecate near the water for convenience. In many countries it has been common practice in rural and peri-urban communities to use the fields or public places (Falkenmark, 1980). As we enter the 1990s, over two billion people (excluding China) still lack basic sanitary facilities. This contributes to the contamination of water sources (Nordberg and Winblad, 1990). The effect of open defaecation is that faecal material is washed into water sources during rainstorms, or transferred to the water source by people or animals. Animals grazing in water catchment areas are also a cause of faecal and parasitic larvae being carried into the water source.

This particularly affects catchments for small gravity water supply systems. An example is given below of a situation which is found frequently in most countries:

In an evaluation in West Bengal, the water supply from public standposts in three villages was analyzed (Dhaneshwar et al, 1985). The bacteriological quality of water during the monsoon period was below the level that is fit for human consumption, with evidence of domestic faecal

contamination. This was seen to be due to runoff from the catchment area carrying with it impurities and polluted soil into the water supply. In Chimney village, most of the 1200 villagers disposed of sullage in the open area around their houses, with only 10% having connections to an open drain. Similarly, 47% of the households disposed of garbage haphazardly around their houses. Only 28% regularly put garbage into pits within their premises. Only between 20% and 35% of Chimney villagers use pit latrines, most individuals going to open fields to defaecate. Many houses are built on the catchment hillslopes, and their waste is thought responsible for much of the contamination. Animal droppings are also responsible for contamination, being washed off the catchment surface into the two lakes that feed the gravity system supplying the villages.

In India, there is a widespread practice of disposing of "night-soil", deposited on household squatting slabs, into city drains. The faeces is collected by male and female sweepers and brought to mobile collection tankers. With night-soil systems examined in Africa and South-East Asia by Kalbermatten et al (1982), frequent problems of odour, insects and spillage were found at collecting and disposal points. Tankers are often taken to a nearby drain and emptied. The pollution caused by this is aggravated by people openly defaecating next to, and washing in water channels.

In Dhaka's urban and peri-urban slums, bucket latrines are common, with collected waste being emptied into ditches. Katcha latrines, where users squat behind a cloth screen on a support of bamboo poles with the excreta discharged directly into canals, is used by an estimated 20% of Dhaka people some time during the day. In the lowest income areas, open defaecation is prevalent.

3.3   Chemical pollution

Accumulation of organic material causing nitrate pollution of sources has so far been insufficiently considered in rural water supply programmes, and seems to be a pressing problem for many village water supply systems. Gradual build-up of nitrogenous material poses a serious threat to groundwater. Nitrates form nitrites in the stomach and can lead to methaemoglobinaemia among infants. Nitrites can also become nitrosamines in the stomach which are thought to cause cancer (Hutton and Lewis, 1980).

Nitrate seepage was found to occur in some villages in northwest Burkina Faso. Accumulation of organic waste was found to cause high nitrate levels. In 15% of drilled wells and 36% of dug wells, these concentrations were in excess of the WHO limit of 45 mg/l (Groen et al, 1988). In the areas concerned, groundwater at a depth between 10 and 60 m is recharged annually during the rainy season. Near villages with clustered housing, the long-term dumping of organic waste has concentrated nitrogen compounds in the subsoil, which percolate to the aquifers. Lateral groundwater flow displaces this zone of contamination beyond the village perimeter. Villages with more dispersed houses, mostly 100 m apart and where sorghum and millet are grown between houses, showed much lower frequency of nitrate contamination.

The conclusion is that the lower loading of nitrogenous material and the absorption by plants reduces the percolation of nitrates to the groundwater.

The above phenomenon also occurs elsewhere. In Ghana, shallow dug wells (3 to 6 m) in the town of Bolgatanga were compared with handpump-equipped shallow drilled wells (1 to 20 m) in locations outside the town. In the latter, 70% of the wells showed nitrate

concentrations below 15 mg/l with virtually none above the WHO limit of 45 mg/l. In the shallow wells within the town boundary, nitrate concentrations were considerably higher. All wells showed nitrate concentrations over 45 mg/l, with over 80% greater than 90 mg/l. Bacterial contamination was not analyzed (Langenegger, 1987).

Pit-latrines are one of the sources of nitrate pollution (Lewis et al, 1980a; Lewis et al, 1981; Gumbo, 1985). Where pit-latrines are poorly sited, for instance upstream of a well in an area where the groundwater rises seasonally, or dug too deep, the water table may intersect with the pit-latrine waste allowing bacteria, nitrites and nitrates to enter the water (Figure 4).
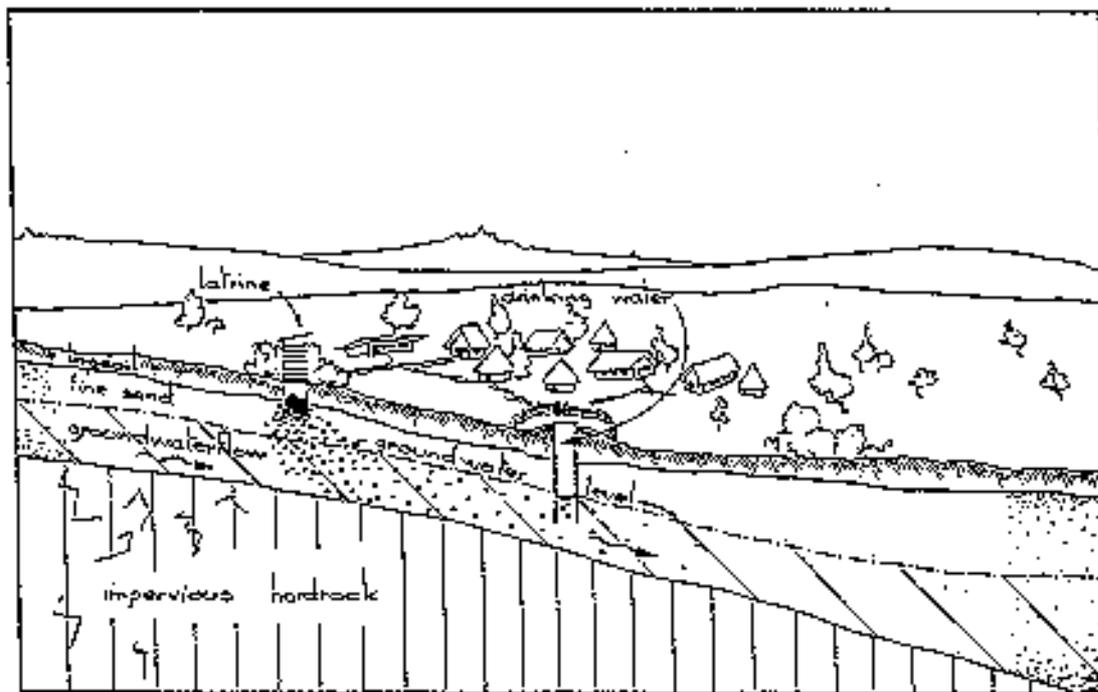
Figure 4:   Contamination of wells from pit latrines

Where soils are highly permeable or bedrock is cracked, contaminated water may travel long distances though aquifers (Rob, 1977). In Eastern Botswana (Lewis et al, 1980b), tracer studies showed rapid travel times between pit-latrines and boreholes through weathered bedrock fissures. Field studies by Wellings et al (1975) suggest enteroviruses can survive for at least 28 days in groundwater so that even slow water transmission routes may be avenues of contamination.

> In Botswana, the problems of nitrate contamination of drinking water supplies have long been known. In 1980, between 5 and 10% of all groundwater samples analyzed had nitrate levels greatly in excess of WHO recommended levels. The high-risk sources were heavily used boreholes located within village boundaries. The conclusion was that pit-latrines and open-air defeacation were the dominant source of pollution. At Mochudi village, roughly 50 km north of Gaborone, a tracer injected into a pit-latrine was detected in the supply borehole 25 m away after only 235 minutes. The highest nitrate concentration found in the village of 7000 people was 603 mg/l. Soil augerings taken near the pit-latrine showed a zone of high contamination within a radius of 15 metres and hence a massive source of leachable nitrate to contaminate the shallow groundwater located at 6 to 9 metres. Bacteriological tests at the borehole showed faecal coliforms at 10 per 100 ml (Hutton and Lewis, 1990).

The proximity of pit latrines to the water supply point is a major cause of groundwater pollution in the Pacific Region (Guo, 1989 personal communication). This problem has also been documented in Tanzania where high nitrate levels and faecal bacteria have been recorded in drinking water supplies. The wider issues and some quantitative data concerning the risk of groundwater pollution by on-site sanitation in developing countries have been well presented in an IRCWD literature review (Lewis et al, 1980a).

> In Munuki Area, Juba, a Sudan Council of Churches study (1986) found that on-site sanitation was the cause of severe groundwater pollution. Out of 73 latrines, 51% were flooded by a rising groundwater table during the 1985 rainy season. Many of these were less than 4 m deep although public health guidelines actually call for them to be 7 m deep. This leads to pollution of groundwater by nitrates and faecal bacteria. Out of two boreholes and three waterholes tested, nitrate pollution in three waterholes and one borehole exceeded the WHO guidelines for maximum consumption, one borehole and three waterholes exceeded nitrite guidelines and three waterholes exceeded ammonium guidelines. Bacteriological pollution was worse, with all water points showing faecal coliform contamination.

Data collected by Cook and Das (1980) in Central India showed clearly that plumes of nitrate contamination can develop out from a village via shallow groundwater from a village with many on-site sanitation units. Areas most at risk are those with a high density of on-site sanitation units and where nitrogen removal and groundwater recharge are moderate to low.

> Thousands of pit latrines have been introduced in Bangladesh by the Department of Public Health Engineering. Both simple, and water-seal types have been installed. However, those older than one or two years have mostly overflowed. The failure of these pits in the Dhaka area are due to the high potential for the surrounding soils to clog, preventing seepage of liquid out of the pit. With high user numbers, they are rapidly overwhelmed. Dhaka is built on a massive floodplain delta and ground elevations range from only 4 to 9 m above mean sea levels. During the monsoons, over half the city is inundated with floodwater for extended periods of time. On low-lying areas, soils are saturated and water seeps into and out of the pits. A direct route is created from the pit to the groundwater, and surface overspill from latrines is washed onto open ground and into water drains. The same is true for septic tanks, used by about 60% of households, in areas of low permeable soil (Rahman, 1987).

The nitrogen compounds in excreta stored in on-site sanitation facilities do not immediately represent a pathogenic hazard to groundwater, but can cause much more widespread and persistent problems. It must be expected that untreated sanitation schemes will frequently cause increases in groundwater nitrate concentration, even in relatively humid climates (Foster et al, 1987). In Bermuda, there is a close correlation between density of population served by cesspit sanitation and groundwater nitrate levels.

Septic tanks are also a source of nitrate contamination (see figure 5). Nitrogenous material is stored for long-periods of time within the soil. If the tank lining is cracked or porous, nitrate-rich liquid can seep from the tanks and into the groundwater. Where tanks are too small or no emptying facilities exist, pit-latrines and septic tanks can overflow and so during rainstorms, faecal material can wash directly into water sources. For example, in Tanzania, cesspit emptiers are scarce. In 1989, in the towns, there was an estimated need for 164 emptiers, but only 24 out of the available fleet of 47 were in working order. Sewage could be found overflowing from cesspits in several locations (Mosha, 1989).
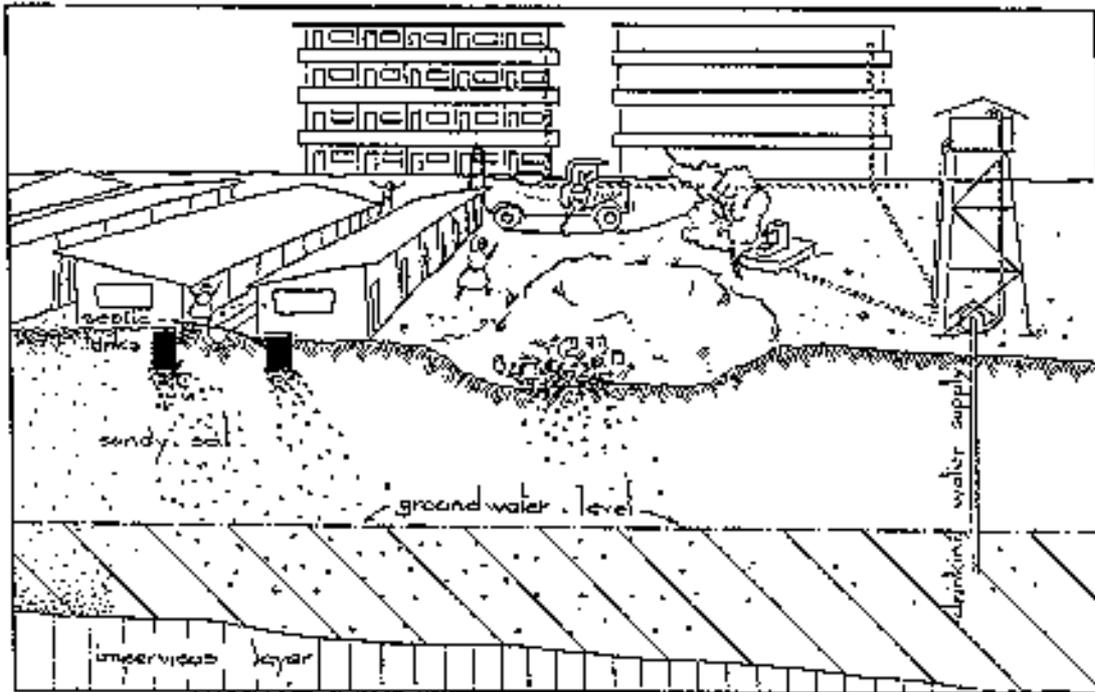
Figure 5:   Old septic tanks and waste disposal are contributing to nitrate pollution

> In Andhra Pradesh, and elsewhere in India, nitrate contamination of groundwater by infiltration
> of septic tank effluents has become an environmental problem. High concentration of nitrates in
> drinking water causes methaemoglobinaemia in infants, produces carcinogenic nitrosamines in
> the stomach and leads to gastric carcinomas (Mowli and Seshaiah, 1988). In Tirupati, a town of
> 1.8 million people, out of 139 wells supplying community groups surveyed, 59 contained more
> than the Indian Council of Medical Research permissible limits of nitrates (50 mg/litre). The
> main source responsible is septic tank effluents, although this is augmented by leakage from
> unlined open drains, sewage farms, and indiscriminately disposed of animal waste.

The result of contamination from on-site sanitation can be immediate faecal contamination
and the onset of diarrhoea and other transmissible diseases followed by longer-term
contamination of groundwater by nitrates and nitrites. The smell, taste and appearance of
ground or surface water can also deteriorate, becoming hard, brackish, brown and
bad-smelling. The long survival period of bacteria and often quick travel times of
groundwater in certain geological conditions can lead to rapid and widespread disease
transmission. Under unfavourable geological conditions, i.e cracked, permeable soils and
bedrock with high water tables and steep flow-gradients, the two major low-cost
technologies, potable unreticulated groundwater and unsewered on-site sanitation are likely
to be incompatible (Foster et al, 1987).

Waste disposal into or near a water source causes both organic and chemical pollution. In many urban areas, drainage ditches are choked with rubbish and garbage dumped down manholes where sewers are laid (Pickford, 1984). In Tanzania, rubbish heaps form part of most town and village landscapes. Heaps can be seen on pavements, in alleyways, on open-spaces, in fact everywhere (Mosha, 1989). Local government is ill-equipped to cope with this domestic rubbish due to lack of funds to buy and run collection trucks. This is often most obvious in urban slums and squatter settlements, where domestic waste is not collected. Since such areas are located in the periphery of urban centres, wells and river intakes which were originally located outside the urbanized area are now no longer protected.

The problems of waste disposal are discussed extensively in Holmes (1984). Increasingly, waste is changing from largely organic waste such as leaves, rotting fruit, etc. to solid inorganic waste such as tin-cans, plastics and paper products. Villagers may dump these next to rivers, to be washed away by the next flood. Pickford (1984) indicates that as much as 90% of Asia's waste is disposed of by this dumping process. Equally, farmers in South East Asia have been seen to wash-out pesticide and fertilizer residues in irrigation channels or streams used by other farmers for drinking downstream (Perry and Dixon, 1986).

3.4   Yield insufficient due to poor functioning of systems

Poor functioning of drinking water supply systems is often linked with increased water losses, vandalism, and increased demand and competition between different user groups. These factors may lead to insufficiency of the water source. This is particularly clear with small springs and streams and rainwater. As the yield of these sources is often insufficient to meet peak demand, storage is essential. Inefficient water systems due to deteriorated water supply installations, often result in further damage caused by users. For example, users may try to overcome poor system functioning by breaking open the system closer to the source to gain access to water. This further increases the inadequacy of the source.

Poor functioning is often caused by poor planning and construction, and by inadequate operation and maintenance. These factors are dealt with in other literature e.g. Bastemeijer and Visscher (1988) and Boot and Heynen (1988). Although not specifically dealt with here, it is clear that attention needs to be given to these aspects in order to make efficient use of available water resources.

Vandalism affects sources indirectly through the malfunctioning of water supply systems, but also directly as it concerns the source and catchment area. There are various factors causing vandalism. Users of poorly functioning systems may damage intake structures and spring source tapping boxes to get direct access to water, exposing the source to possible contamination. Persons angry at the development of a water supply system tapping into a particular source may purposely try to break it. This may for instance concern water vendors who have lost a market, downstream water users who feel that their supply is threatened by the new system or other community members who have somehow been alienated and have developed a grudge against their fellow villagers.

In San Antao, Cape Verde, social conflicts over water are intense. Water is considered a private property and there have been numerous cases in which the "owners" of water sources have destroyed community water delivery structures. The level of vandalism has been so high in some areas, that the municipality has been unable to keep up with repairs (Hemmings-Gapihan and Freitas, 1990).

Vandalism takes a number of forms. The most common is the theft of parts from the supply system such as sections of pipe, brass washers, taps, nuts and bolts, iron-sheet or fencing. In Shinyanga, Tanzania, up to 40% of handpumps had nuts and bolts missing because they were taken to use on ox-carts and ploughs (Andersson, 1982). Also common, is accidental damage due to careless use of the facility. The breaking open of a tap by children swinging from a handpump arm is an example.

Poor functioning of water supply systems causes the users to choose alternative sources which are more reliable. For instance, breakdown of handpumps on small diameter boreholes leaves the users no other alternative than to fetch their water elsewhere. If the breakdown of a handpump is longer than one day, for example, the consumer must return to the traditional source with its obvious health hazards. These are often contaminated and their use creates a health risk. From a survey taken at 26 out-of-order handpumps in Shinyanga, Tanzania, 57% of the users resorted to unsafe traditional points, while a further 27% opened up the well manhole to get water with a rope and bucket (Andersson, 1982).

3.5   Yield insufficient due to competing demands

The use of water for other than domestic purposes, frequently affects the reliability and also the quality of the drinking water supply for small communities. Increasingly, water from the smaller sources is extracted for irrigation by more wealthy farmers who own sufficient land and can afford to install a motorised pumping system. Watering livestock by pastoralists, and in some cases, agro-processing industries such as coffee, sisal or leather works is increasing demand.

Competing demand at community level also occurs with water harvesting systems. These provide a finite stored volume once the rains have finished until the dry period is over and the next rains begin. During this time, the water is available for a variety of uses although many systems are designed only to supply drinking water needs of around 5 litres per person per day. This is based on the assumption that users will go to traditional sources for bathing, laundry or livestock. However, examples have been documented of water being used for the full range of household needs (Lee and Visscher, 1990). These compete for the finite storage, resulting in depletion well before the onset of the next rains. Where systems are owned by individual families, this involves no conflict of interest. However, when systems are communally owned such as a groundtank, small earth-dam or rock catchment reservoir, the potential for social conflict between different users is high. When user rights are not established or enforced with respect to who and how one can benefit from a water source, the yield may rapidly become insufficient resulting in conflict.

Similar scenarios exist for open water sources, springs and groundwater. For example, in Mbeya, Ruvuma and Iringa regions in Tanzania, water demand increased due to use of water for brickmaking. As a result, source yields were expected to become

insufficient. Competing uses for the same water source caused problems in Mbeya and Iringa regions. The study of water rights, identification of conflicts and allocation criteria

were considered indispensable (Bastemeijer et al 1987).

For groundwater, the problems of inequality in access and pumping potential resulted in inequitable distribution, with small community drinking water supplies being most at risk. Smaller settlements in rural areas generally use shallow wells dug by hand into the water table, whereas small industries and farms generally use deeper drilled wells fitted with motorized pumps. Where water is only slowly or seasonally replenished, unregulated use results in depletion of groundwater and a fall in water levels. In India, the use of mechanised pumps has led to shortages of water for marginal rural settlements by lowering the water table below the reach of dug and step wells (Bandyopadhyay, 1987). In many developing countries, there is little in the way of official controls on private groundwater users; especially in rural areas. Groundwater extraction becomes a free-for-all in which large farmers or industries exploit a limited resource and maintain a technical and financial advantage over poorer private users. As the aquifer is depleted, the industry can switch to increasingly sophisticated and powerful pumping technology, while their poorer neighbours lose access to their resource.

3.6   Decreasing yield due to land use changes

In small catchment areas, human activities may quickly result in water source problems. Most problems are caused by changes in land-use as population pressure and economic activity increases. In most countries, population growth causes a need to bring more land under cultivation. When new land is cleared for cultivation, it often causes cattle holders using that land to shift to other, less suitable areas, causing land degradation by overgrazing and ultimately desertification. Cattle are over-stocked on smaller and smaller areas of rangeland and government programmes force previously nomadic pastoralists to sedentarize, increasing the livestock burden on a given region (Blaikie, 1985). Farmers slash and burn areas of woodland and then move on to new areas when the soil fertility is exhausted after a few seasons and the top-soil is washed away by runoff (Mishra and Ramakrishnan, 1983). Generally, little attempt is made to combine land-clearing with better land management, such as the use of organic fertilizers, erosion control, soil and water conservation and runoff farming techniques. Land scarcity also causes farmers to find other sources of income. Economic activities like producing baked bricks for construction and charcoal for fuel, contribute to changing land-use, alter vegetation cover, and subsequently affect the drinking water sources of the local population.

According to Bandyopadhyay (1987), the water resource management strategy in India has been guided by the philosophy that "water is strictly a fixed resource and we cannot really destroy it on any significant scale". However, experience has now shown that disrupting water cycles in India has often turned an abundant renewable resource into a vanishing resource. For example, the Cherrapunji river is affected by deforestation. Gradual disappearance of mixed natural woodland in the mountain catchments aggravates the monsoonal flood hazard in Bangladesh. As soon as the monsoons are over, the springs, streams and river dry up leaving the rural communities with acute water problems. Replacement of the broad-leaved mixed woodland with monoculture plantations of commercial species such as eucalyptus, as in the Terai region of Uttar Pradesh, leads to poor soil stability, decreasing infiltration capacity, enhancing flash flood potential and contributing to surface water scarcity which particularly affect small mountain communities.

Tanzania, like many other developing nations, is suffering from land degradation as hillsides are

cleared of natural vegetation, intensively cultivated and over-grazed (Christiansson, 1986). Particularly in the drier areas, large amounts of water are lost through the increased runoff during rainstorms and heavy loads of eroded sediments rapidly silt up surface water reservoirs. The most intensely degraded part of Tanzania is probably the Dodoma region which has a four to five month wet season producing 500 to 600 mm of rainfall. The local population is agro-pastoralist dependent on agriculture for subsistence and cattle for social, capital and insurance purposes (Christiansson, 1986). Population pressure has forced farmers to cultivate the steeper slopes and topsoil loss through gullying is a common occurrence. Measurements of drainage basins prior to 1986 showed that up to 600 cubic metres of soil was being lost per square kilometre on average. Erosion from individual fields varies from 2 to 10 mm per year and surface water reservoirs consequently have short lives.

In Ruvuma region of Tanzania, burning grasses and shrubs caused local small gravity sources to dry up within one year (Mandia, 1987 personal communication). Other activities like cutting of fire wood, cattle grazing and subsistence agriculture are reported to affect water source yields in Mbeya, Ruvuma, and Iringa regions (Bastemeijer et al, 1987). Production of charcoal by villagers in Nakuru, Kenya has contributed to a fall in the reliability of stream and spring flow in Catholic Diocese water projects (Woldeye, 1990 personal communication). In Kisumu, Kenya, dense populations and the subsequent pressures on available land are leading to intense deforestation. Many natural springs are drying up as a consequence (van Maanen, 1989 personal communication).

Land-use change, particularly from forest cover to scrub or subsistence cultivation causes increases in the turbidity of surface water. The suspended solids may contain various toxic elements detrimental to health if they are not removed through filtering or flocculation prior to drinking. Raised turbidity reduces the effectiveness of slow sand filtration, a simple treatment method which is often used for small rural drinking water supply systems. In fact, high turbidity is becoming the most common reason for poor operation of slow sand filters. Rapid clogging of the filters causes short filter runs, and contributes to rapid deterioration of the installations (Myhrstad and Haldorsen, 1984). In Thailand, chemical coagulation, chlorination, and slow-sand filtration systems are negatively effected by rapid changes in the content of suspended matter and turbidity (Chainarong, 1977). Along with the increased sediment load from small catchments cleared of their tree and shrub cover, the seasonal characteristics of streams and springs change. More water runs off and less seeps into the ground to replenish local aquifers. The result is destructive flooding downstream during heavy rains followed by a drying up of surface sources and a fall in groundwater levels. This seasonality may be sufficiently serious to leave water sources dry and to cause water tables to drop significantly.

The subject of deforestation and soil erosion has been widely dealt with in the literature, although not usually from a water source and supply point of view, but more in terms of deterioration of farmland, highland land slides and the siltation of rivers and reservoirs. Many references are found on the subject of environmental effects of deforestation and soil erosion in the annotated bibliography of Blackie et al (1980) and key erosion source texts such as Morgan (1981, 1985), Lal and Russell (1981) and Blaikie (1985). However, even with the wealth of existing knowledge concerning environmental problems and their possible solutions, the problem is still increasing globally as populations grow along with pressures to open up new land to meet subsistence needs.

In some areas, landslides can cause source problems. These are sometimes triggered by human activity such as mining, deforestation or road construction as well as by natural causes such as earthquakes or heavy storms. Channels are blocked, dams breached and

physical conditions in catchment areas are changed. Landslides are common problems in monsoonal, mountainous areas such as Nepal (Lane, 1989 personal communication). There, land-slides often cover springs or streams. This observation was confirmed by Strauss (1989 personal communication). In West Bengal, problems are also experienced with land slides causing breaks in piped water supplies (Dhaneshewar et al, 1985).

4. Factors Affecting both Small and Large Water Supply Systems

4.1 Overview of quality and quantity issues

The three major environmental problems affecting the quality of sources appear to be the pollution of the source by industrial waste products, contamination by pesticides and fertilizers and pollution from domestic sewage.
The two major environmental problems affecting the quantity and supply reliability of larger water sources appear to be the exploitation of groundwater above sustainable yields, and the seasonal changes in flow and recharge caused by land-use change.
The environmental factors affecting small and large water supply systems are listed in Table 4.

Table 4:   Environmental factors affecting users of small and large water supply systems

Source problem	Poor Quality	Unreliable yield
Nature of the problem	Chemical pollution Organic (faecal) pollution Salt water intrusion High turbidity	Destructive floods Falling groundwater table Seasonal fluctuations
Environmental Factors	Industrial waste and waste water disposal Use of pesticides and fertilizers Sewage discharge Over-extraction of groundwater Land use changes	Land-use changes Erosion Urbanization Dams Insufficient recharge of aquifer
Solutions	Recycling of waste Creating economic incentives Enforcement of waste control Technological improvements Improved maintenance of treatment plants Awareness raising Training Treatment plants Water resource management Better source siting	Land-use planning Reforestation Soil conservation Wastewater reuse Artificial recharge Erosion control

4.2 Industrial pollution of ground and surface water

Uncontrolled disposal of industrial waste causes surface water contamination in many developing countries. This is particularly true for the peri-urban shanty towns and the rural hinterland villages downstream of cities who are reliant on rivers passing through an industrialised area. Discharge of untreated industrial waste is a major problem for many riverine communities causing skin and abdominal health problems.

Presently most industries do not treat their waste if it contains no recyclable products which could be reprocessed or sold. As treatment would be more costly and there are generally no sanctions on discharge of untreated waste, there is seldom economic incentive to treat industrial waste.
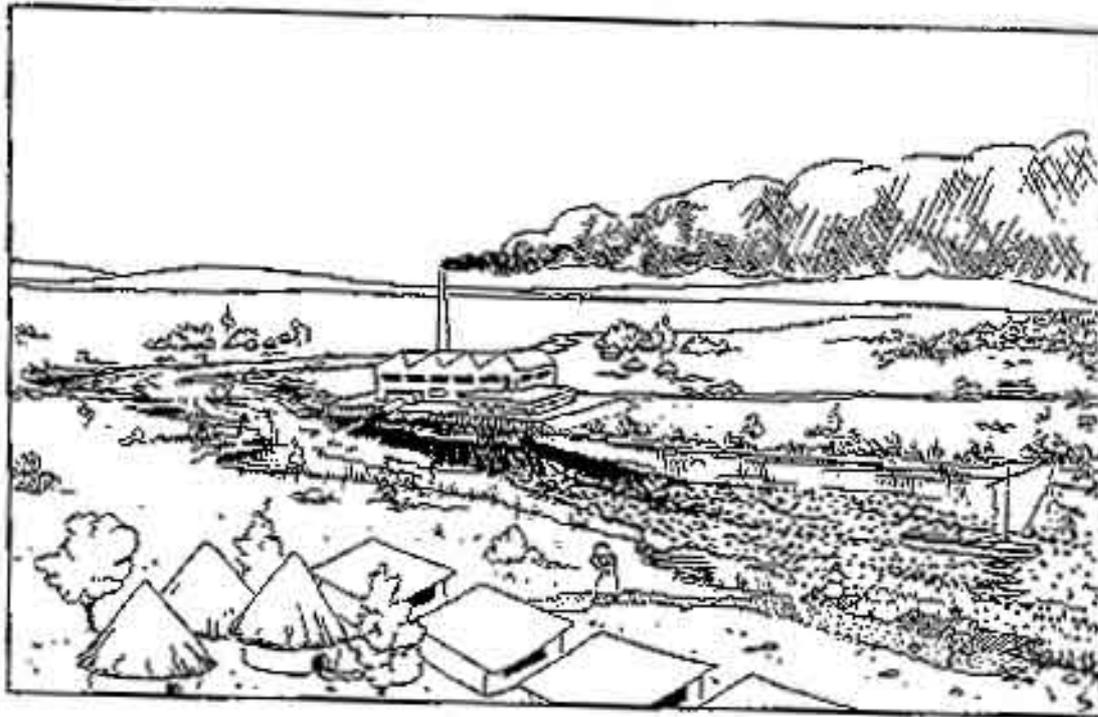
Figure 6:   Surface water pollution by industries

Even if there is an incentive or an interest, treatment is often not considered. Although this is generally caused by lack of technical expertise within the companies concerned, there also appears to be a need to develop low-cost treatment methods for small and medium size industries. Treatment is often too expensive, because most technologies have been developed for large-scale industrial operation in developed countries.

Governments are often unable to institute pollution control measures. They lack the instruments to monitor and control pollution. They are ill equipped to identify the nature and source of pollution. Institutional capacities are often insufficient to enforce regulations. Most developing countries have no toxic chemical control laws, nor the technical or institutional capability for implementing such laws (UNEP, 1989).

There are many examples. For instance, chemical effluents from coffee and sugar factories in Kenya have been poured into waterways with little control since their establishment (Wandiga, 1977). Industrial waste discharge from the leather industry in the same country has been documented by Boro (1984). In Tanzania, textile mills, tanneries, soap factories, and sisal mills cause severe water pollution since many years, and in particular in Dar es Salaam (Bastemeijer 1982). An IDRC study is underway to determine the nature and sources of pollution of the Msimbazi Stream that passes through Dar es Salaam (IDRC, 1989).

Industries in Zambia were reported to be discharging pollutants directly into waterways (Katko, 1989 personal communication). In India, rapid growth of industrial capacity has resulted in tremendous increases in the pollution of stream and river water by industrial waste. Many examples have been documented, for instance the effects of distillery waste water on the Neeva River in Andhra Pradesh. There, the colour, odour and taste, let alone the chemical characteristics makes river water unfit for domestic use (Reddy, 1987). India's major rivers are at a high risk.

At Kanpur, on the River Ganges, the existence of 45 tanneries and 10 textile mills have rendered it the most polluted city in India (Dikshit and Nigam, 1982). The industrial effluents containing carcinogenic chemicals, metals from surgical industries and highly poisonous sewage waters have made the Ganges water unfit for human consumption and bathing. A major hazard in the tannery effluent was found to be the chromium which cannot be removed by water treatment and causes inflammation of mucous membranes and eye infections for the ritual bathers (Suresh Chandra and Krishna, 1983).

It is often implicitly assumed that the major rivers of the world have a sufficiently high assimilative capacity to take all the industrial effluent and render it harmless through dispersion and dilution. No monitoring or studies are undertaken to determine the safe limits for discharge. For instance, a few years ago the water intake of the capital of Antananarivo in Madagascar situated a few kilometres downstream from the paper mill's discharge into the Ikopa river. The river carried very little water in the dry season, in particular because water was extracted upstream for irrigation of the plains around the capital. The treatment pond was apparently out of use.

Many of the problems of industrial pollution are seasonal, and subsequently related to the varying ability of the water source to dilute effluents to acceptably low concentrations. An example is the River Kali in India, which is severely polluted in the dry summer months when the river discharge is at its minimum (Bhargava, 1987). On the basis of a water quality survey of the entire stretch of the Kali, a classification and zoning based on a water quality index was elaborated. This showed that along the entire river, only at two locations was the water of acceptable quality for public water supply and only during the rainy winter months when flow levels were high and effluents could be sufficiently diluted. At no location and at no time could the water be considered fit for religious bathing and drinking without treatment due to high faecal coliform counts.

In Latin America, the Reconquista and Matanza-Riachuelo rivers in Argentina, the Choqueyapu-Reni rivers in Bolivia, the Tiete river in Brazil, the Magdalena river in Colombia, the Bio-Bio and Maipo rivers in Chile, the Guayas river in Ecuador, the Rimac river in Peru, and the Tuy river in Venezuela, amongst others, receive serious levels of toxic industrial pollution due to untreated factory discharge. The majority of these rivers not only provide water to small settlements along their course, they are also sources of water supplies for major metropolitan areas (CEPIS, 1989).

Poor storage of industrial and other waste also results in groundwater and surface water pollution. Major causes include the poor design of storage facilities, leakage from damaged stores and the seepage from treatment ponds. At Modinagar, Uttar Pradesh, an industrial complex for textile, steel, sugar, varnishes, paints and chemical factories discharges untreated waste into a 32 kilometre drain. Of the three handpumps and one dug well analyzed near the drain, three were seriously contaminated by such elements as rubidium, copper and zinc. In the Punjab, industrial waste water is allowed to percolate from unlined drains and shallow depressions (Handa et al, 1983). Seepage of pollutants from open storage in drains appears a common problem in India.

In Ludhiana, Punjab, many industries discharge their waste effluents in unlined drains, which during the heavy rainy seasons, spread over a large area. After running for two kilometres, one such drain empties into a shallow depression with no visible outlet. Handpumps drawing domestic and livestock water in the surrounding region were seen to produce yellow-green water. People and livestock drinking this water had been known to suffer severe health effects. A detailed chemical analysis was undertaken of the handpumped shallow groundwater and amongst other things, heavy concentrations of nickel, chromium, copper and cyanide were discovered (Handa et al, 1983).

Soils and rock are often relied upon to process industrial effluent by filtering through chemical reactions. However, this cannot be assumed universal and depends on both the character of the effluent and of the soil and rock, its texture, clay and organic content, pH, mineralogy, redox capacity, bio-chemistry and the depth of the unsaturated layer (seasonally variable).

Accidental release is a growing threat, particularly as developing world industries grow to larger capacities. The example of Bhopal provides one end of the spectrum. The other end is represented by the thousands of petrol, oil and other toxic hydrocarbon stores that can be found in most small towns. Many of these have been built without effective planning guidelines or adequate supervision. Ruptures of these tanks which are often evacuated into the ground can have serious consequences for regional aquifers (Foster et al, 1987). Poor safety procedures, errors by untrained staff, the use of unreliable technologies, and the lack of maintenance of installations all contribute to a high risk factor for release. Risks are multiplied in zones prone to natural disasters such as earthquakes or landslides.

While accidental events in the developed world are well documented in the media and unsafe installations or practices are monitored and protested against by vocal interest groups, such watchdog activities are underdeveloped elsewhere. Insufficient documentation is available on a country-by-country basis on what could happen and what has happened, and what the effect has been on the aquatic environment. However, the known effects of purposeful and accidental industrial pollution are the presence of a growing number of toxic chemicals in the surface and groundwater supply, the deterioration of the aesthetic quality of water supplies and the onset of health problems among user communities including skin diseases, ulcers, cancers and birth defects. Insufficient data exists to quantify the scale of the problem and the role played by the wastes of different industries. There is evidence, however, that small-scale industries processing agricultural products are contributing considerably to water pollution and lack the technology and the financial means to modernize their production process and to decrease pollution.

4.3   Use of pesticides, fertilizers and other chemical pollutants in agriculture

There are two types of pollution from pesticides and fertilizers: point pollution and non-point pollution. Point pollution refers to the concentrated input of chemicals into the water source from a distinct place such as a storage area, from the direct discharge of pollutants into the water, or from spraying on the water source itself. Non-point pollution occurs due to the gradual influx of low-concentrations of chemicals into the water source, for instance from irrigated farmland. Through time, the washing of chemicals into surface water and the leaching of chemicals into the groundwater results in gradually increasing concentrations of contaminants to toxic levels.

An example of a point problem is the disposal and storage of pesticides by farmers. In Chaing Mai province, Thailand, rural villagers take water from irrigation canals downstream from locations where pesticides are regularly used (Perry and Dixon, 1986). Seepage from pesticide containers or from fertiliser bags cause contamination of both surface and groundwater. Similar point pollution of water sources is experienced from land-fill sites (Ngainayo, 1986), unlined pits where chemical drums are stored, and sealed tanks for oil and gasoline (Myhrstad and Haldorsen, 1984).

Pesticides are also used to control waterborne diseases such as malaria, bilharzia and onchocerciasis. The effects of those pesticides on the people who drink water from the

treated sources have received little attention so far. Onchocerciasis has been controlled in many countries by eradicating the fly vector from streams using DDT. Malaria vector control of the Anopheles mosquito is carried out by spraying an insecticide film onto the edges of ponds and lakes (Khamala, 1977). These insecticides can be expected to affect the health of the water users downstream (de Koning, 1987. WHO, 1968. WHO, 1985b). In Tanzania, pesticides, in particular DDT, are sprayed directly onto water sources to control waterborne insect vectors. Copper sulphate is used to control bilharzia in the irrigation canals and ditches of sugar and other large estates. These sources are used by small communities (Ghebtsawi-Tsighe, 1990).

> In Munuki Area, Juba, a Sudan Council of Churches study (1986) found that the problems of pollution of groundwater with faecal material due to poor pit latrine siting and construction were further aggravated by the fact that 23% of householders regularly emptied pesticides into their latrines to protect against fly and mosquito breeding. The predominant pesticide used was named as DDT, with some householders using Gammatox. The two boreholes and three waterholes used by villagers were tested and showed groundwater pesticide levels exceeding the WHO limit for DDT by 6 to 50 times. The use of DDT was officially banned in Sudan in 1980 but villagers appear to have quantities in store, are given it by local officials, or are able to buy it.

Non-point pollution, although not widely detected as yet in developing country water supplies, can only be on the increase. The use of fertilizers and pesticides is growing. In Guatemala, the improper use of chemical concentrates by small farmers causes contamination of local drinking water (Hoy and Belisle, 1984). Spraying by light planes was common in the Banana growing areas of Urabá in Northern Colombia. Surface water was delivered to the users without treatment (Heynen, 1981). The Asian Development Bank issued a handbook on the use of pesticides in the Asia-Pacific Region (1987). They specifically mention the contamination of local water supplies from rice padi's where pesticides have been applied and have leached down into the groundwater. For instance, in Sri-Lanka, drinking water wells are often placed adjacent to padi-fields and the potential for pesticide pollution locally and in the regional aquifer is acute (Boot, 1989 personal communication). In Thailand many rural people take their water from irrigation canals (Chainarong, 1977), which can be assumed to contain high concentrations of leached fertilizers and pesticides.

The growing threat from pesticides are a definite concern for WHO. Health studies have shown that increasing pesticides in the environment can result in effects such as DDT appearing in the milk of lactating women (WHO, 1985b). As pesticide use increases, the concentration of carcinogenic substances in the water supply and food chain will also increase (de Koning, 1987). Although there is considerable literature and data on this and other sources of environmental pollution (see the references in de Koning, 1987 and WHO, 1985b), in most developing countries this is still a largely unknown problem due to the fact that little monitoring takes place. A continuing worry is that many pesticides banned in the developed world are still exported and used extensively in developing countries (UNIDO, 1983), often in an uncontrolled manner (WHO, 1985c. Copplestone, 1985).

4.4　Sewage discharge

The situation in developing countries with regard to sewage treatment is currently that a large percentage of waste water goes directly into water sources without treatment. Only a few countries have primary treatment facilities to remove about 40-50% of the organic load (BOD) and very few use any secondary treatment process to remove more than 80% of the BOD (Laugeri and Hespanhol, 1990). Many urban centres and large towns have no treatment facilities at all or ones that are antiquated or poorly maintained. In Central and

South America, CEPIS (1989) estimates that 50% of the urban population does not have access to sewerage systems, and over 90% of the sewage water collected from those that do, is still discharged into waterways without any treatment.
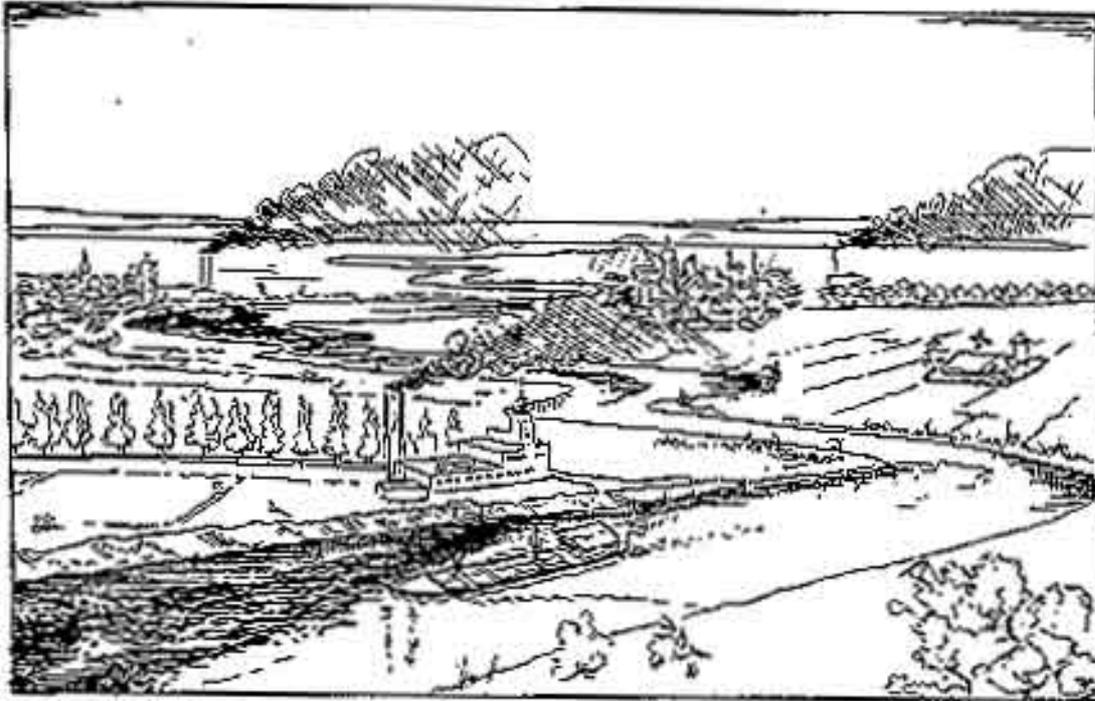
Figure 7:   Over 90% of sewage discharged without treatment

Users of river water downstream from Bogota, Colombia must contend with enormous concentrations of faecal coliforms resulting from discharge of untreated sewage into the water (UNEP, 1986). The city has installed sewers in the urban area, but they flow directly into the Rio Bogota untreated. Among other uses, water is taken from the heavily polluted river for irrigation of cash crops, resulting in serious health consequences for unwary consumers (Okun, 1990). Purposeful discharge of raw sewage into the nations water bodies is a common characteristic in developing countries, as it still is in a number of European countries which rely on the diluting effect of large river estuaries and the sea. In Guatemala, water contamination from dumping raw sewage into the nations waterways is a major problem; contaminating the water supplies of local settlements which have no treatment facilities (Hoy and Belisle, 1984). In Tanzania, sewage treatment plants in all the major towns except Morogoro and Dodoma fail to produce acceptably safe effluent, mostly due to lack of proper operation and maintenance of the systems (Ghebtsawi-Tsighe, 1990). This kind of picture is repeated in many countries throughout Africa and Asia. This problem is most severe for downstream users when treating the water is not feasible or not affordable and when no alternative sources are available.

One way water users are exposed to sewage water is where communities are sited next to sewage spreading areas, where their water supplies can be directly contaminated. Chauhan et al (1984) studied the pollution of groundwater by irrigation of sewage water from a treatment plant onto sandy soil with high permeability. Seepage of water from the sewage stores has polluted local groundwater, turning it hard and brackish. Water in five wells in the irrigated area and nineteen wells outside the area was examined. Most of the wells were uncovered open wells. The four shallow wells inside the sewage farm had high levels of dissolved solids, very high hardness, coliforms, faecal coliforms and faecal streptococci (up to 9000 MPN per 100 ml faecal coliforms). Nitrate and nitrite concentrations met permissible Indian limits. The fifth borehole had negligible contamination due to the

filtering effect of the soil. As the distance from the irrigated area increased, the bacterial count and dissolved solids decreased, indicating that the pollution is mainly due to waste water percolation rather than direct contamination by users.

As with many Indian rivers, exceeding assimilative capacity coupled with high frequency of contact between riverine communities and pilgrims carrying out ritual bathing creates a major health problem.

> Along every kilometre of the River Ganges in Uttar Pradesh, Bihar and West Bengal, cities and towns use the river as a sewer. An investigation carried out by the Central Board for Prevention and Control of Water Pollution indicated that none of the large cities and towns had a sewage treatment plant, although most had partial sewerage facilities. In all, 48 class I cities, and 66 class II towns dump largely untreated sewage into the river each day. At Kanpur, the River Ganges receives a massive input of sewage from three main sewage outfalls (Jajmau, Guptar and Sisamau) of 147 million tonnes of suspended solids per day (Chattopadhya et al, 1984), the average bacterial counts of E. Coli indicated the water to be a potential source of enteric diseases for the villages consuming this water downstream. Sewage combines with industrial waste, half-burnt corpses, eroded catchment soil, fertilizers, pesticides and religious mass bathers to produce an unhealthy cocktail of contamination (Sinnarkar et al, 1987). The pollution is most serious during the summer months when the water flow is reduced. The consequence at the bathing Ghats at Varanasi is a massive growth of pathogenic bacteria and fungi (Tripathi and Sikandar, 1981). The water is unfit for body contact let alone for use as drinking water. However, during crisis periods, the Ganges water is used by large communities without any proper treatment, exposing drinkers to densities of faecal coliforms of over 20000 MPN (Ram Bilas et al, 1981). It is used regularly by small riverside communities.

4.5   Over-extraction of groundwater

In almost every developing country there are examples of long-term problems of groundwater depletion due to the lack of control on private pumping by ineffective or poorly implemented legislation (Bosscher, 1989 personal communication). Clear examples of falling groundwater levels exist for Pakistan (Bosscher, 1990) and the Yemen (van der Gun, 1986, 1987) as well as for a number of different states in India including Gujerat (Shukla, 1984), Maharashtra, Karnataka and Andhra Pradesh (Bandyopadhyay, 1987). In Baluchistan, groundwater levels have been falling by 26 cm/year since the 1960s (Bosscher, 1990). Over-grazing on the surrounding hillslopes has reduced recharge levels, and intensive groundwater extraction by motorized pumps for irrigation in the valleys has occurred. The kareze chain-wells have run dry and only deep boreholes owned by the more wealthy families provide water now.

> Until recently in the Yemen Highland Plains, the use of groundwater was restricted by technological constraints, but the introduction of drilling rigs and powered pumps has brought about drastic changes in a short period (van der Gun, 1986). Since the 1960s, the number of wells has increased to around 10,000 with pumping levels estimated at several hundred million cubic metres annually. Monitoring on the Sana'a Plain has shown groundwater levels have fallen by 20 metres in ten years (Charalambous, 1982). An almost equal rate of decline has been seen in the Sadah Plain (van der Gun, 1985). The rate of natural groundwater recharge at Sadah is estimated at one million m^3/year whereas by 1983, groundwater abstraction by newly introduced bored wells and diesel pumps was approximately fifty seven million m^3/year. This mining of groundwater is a serious threat to the quantity, reliability and cost of water in the future. Public water supply is becoming increasingly difficult. The viability of groundwater-irrigated agriculture is gradually declining and the water sources might finally be exhausted. Since there is no potential for artificial recharge of aquifers due to the lack of surface water resources, the only feasible strategy for preserving the groundwater resources of the Yemen Highland Plains is to reduce and control groundwater extraction rates. Although it is agreed that this will be extremely difficult to manage, it is essential (van der Gun, 1986).

The striking problem of the over extraction of groundwater affects all users, but particularly small communities dependent upon low-cost shallow wells with handpumps. The causes are several fold:

- lack of yield potential and recharge data from which sustainable extraction levels can be determined and used in planning;
- uncontrolled and unsustainable use coupled with a lack of regulations;
- ineffective and inadequate enforcement of legislation to maintain sustainable extraction;
- lack of water recycling and conservation strategies as tools for pollution control and increasing efficient use;
- lack of adequate alternative surface water resources partly due to pollution of these sources by industrial and municipal waste;
- absence of an effective large-scale artificial recharge programme;
- lack of integrated water management policies.

The result is that many of the Village Level Operation and Maintenance (VLOM) handpump and shallow well systems are not sustainable. Many wells have run dry. Where the lowering of the water table below wells is a seasonal event, the reliability of the water source is seriously affected for user groups dependent on shallow groundwater. The development and promotion of low-cost technology options for water supply and community-based maintenance systems is rendered ineffective by a general lowering of the water table (Danida, 1988).

India has invested heavily in the low-cost VLOM handpump technology as a major means of achieving International Drinking Water Decade targets and providing potable water for its people. Traditionally, groundwater has been the main drinking water source in almost all its rural areas. In the last few decades it has been exploited substantially for irrigation based on financial support given for the installation of motorised pumps. These are creating water shortages for poor peasants by draining down the water table below the reach of their dug wells and shallow bored wells. Many of the VLOM pumps are not capable of pumping from deeper depths. This is particularly true in the hard rock areas of Maharastra, Karnataka and Andhra Pradesh. Depletion of shallow aquifers results in dug wells being dry part of the year and storage tanks being less effective. This is often blamed on poor rainfall, but evidence has shown that it is over-exploitation, not climatic change, that is the cause of this problem. An example of the problem is Maharashtra, where sugarcane cultivation has lead to severe problems. Processing factories have invested in deep borewells. Rapid groundwater depletion in the two years since 1985 has resulted in an increase of villages with no permanent source of drinking water from 1,800 to 23,000 (Bandyopadhyay, 1987). Public and private shallow wells have all run dry. The Indian Planning Commission on the Task Force on Ground Water Resources earlier estimated that the total usable groundwater available in the whole country would have been tapped by 1989 and that recharge rates must be increased.
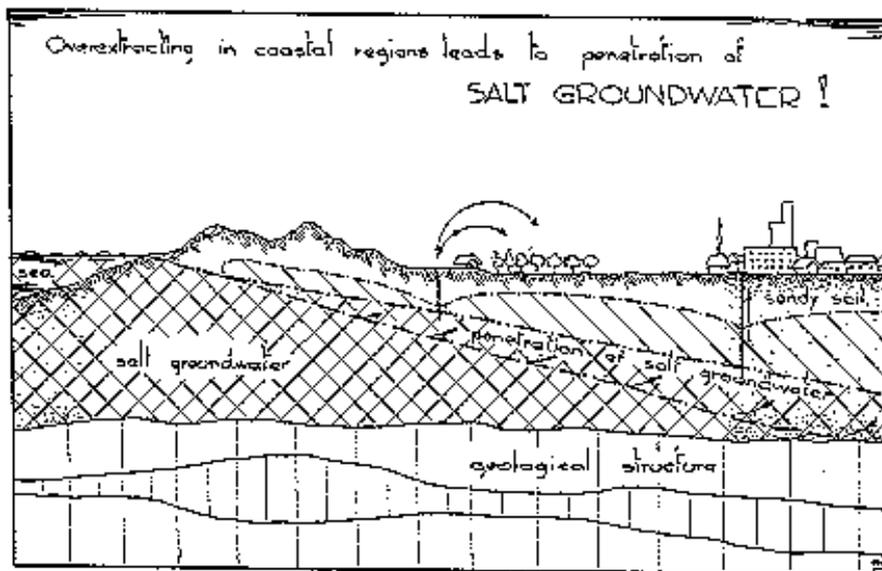
Figure 8:   Intensive pumping of freshwater aquifers adjacent to saltwater sources, results in
saltwater intrusion

Unsustainable extraction of groundwater can also lead to quality problems when coastal aquifers are involved. A frequently reported problem is the intrusion of saline or brackish water. It occurs in two main hydro-geological settings:

> in coastal areas and river deltas where fresh and saltwater reserves are adjacent to each other. Intensive extraction from freshwater aquifers results in saltwater intrusion from the adjacent saltwater source. This is particularly serious problem in the coastal zone of Gujerat State, India (Vos, 1989 personal communication. Shukla, 1984).
> in geological complexes with horizontal layers of fresh and salt water in different sedimentary strata. Sinking of a borehole or deep well into the freshwater aquifer and local draw-down can disturb the equilibrium between the two layers and cause vertical mixing, as the saline water is forced upwards by the downward hydraulic pressure of the higher water table either side.

The problems of saline intrusion have been discussed extensively for both developed and developing countries in the meetings of the Salt Water Intrusion Group organised as part of the International Hydrological Programme (de Breuck, 1983) from which a comprehensive source of references can be obtained. The experiences of managing coastal aquifers in the Netherlands are generally applicable to problems experienced in developing country coastal areas such as Thailand and Indonesia (Kop, 1989 personal communication).

> Along the coastal region of Saurashtra in Gujerat State, the switch to mechanised pumping of groundwater has lead to a lowering of the water table from 10 to 35 metres and saline water intrusion due to a reversal of the hydraulic gradient (Shukla, 1984). The increase in extraction from deepened, drilled wells was used for sugar-cane irrigation and processing. The consequence has been the decreasing quality of drinking water for both rural and urban communities reliant on shallow dug wells. Over 12,000 wells were estimated to have been put out of use affecting 280,000 people.

One cause of unsustainable extraction of coastal groundwater is the failure to allow for reduced recharge inland. Systems may well have been designed to function up to a given yield level based on historical pumping tests. However, as recharge is reduced inland by deforestation and increased surface flow, drawdown and depletion may occur as current pumping levels cannot be sustained. Hydraulic gradients are reversed and seawater flows into the freshwater aquifer.

Another major problem associated with groundwater depletion is when large urban areas pump water from highly porous aquifers below, subsidence occurs as soil pores collapse. A clear example of this problem is the city of Bangkok.

Depletion and contamination of groundwater around the urban concentration of Bangkok is continuing at an alarming rate, with water levels dropping 10-12 metres in three years since 1985 (Nair, 1988). With many of the thousands of wells drilled in the metropolis and surrounding provinces, no records are kept of pumping levels. However, it is forecast that over 1 million cubic metres are pumped per day (UNEP, undated). The cost of pumping is increasing rapidly. The environmental effect has been wider than just water resource depletion. Land has subsided on a massive scale resulting in flooding of sewage and storm drainage systems at high tides. Pipelines are breaking and industrial and domestic waste is finding its way into the aquifer from these various sources. A serious threat to quality is through seawater intrusion, causing the abandonment of thousands of shallow wells and their replacement with deep wells. The rate of intrusion varies from 100 to 200 m inland per year. Chloride concentrations in municipal wells have increased five times up to 1,000-1,250 mg/l.

4.6　Land-use changes in large source catchment areas

Deforestation and erosion is increasing in many developing countries at a rapid rate. As forests are cleared, water rushes unimpeded down slopes, carrying with it valuable soil and causing flooding in the lower areas. Wells increasingly dry up during the dry season because less water was retained in the soil to percolate into water tables (see Figure 9). Increasing populations force the rural poor to clear more forests on marginal farm land. Large-scale plantation oriented concerns contribute to the problem by clearing large tracts of upland catchments.

On the island of Madagascar, commercial logging of rainforests has resulted in perennial rivers and streams becoming seasonal. This has lead to disruption of rice production, making the island dependent on imports for its staple crop. In India, deforestation and soil erosion cause the disappearance of water points, lowering of groundwater, flash-floods and decreased dry-period flow (Das and Pandey, 1989). In Guatemala, widespread deforestation results in soil erosion and degradation. Soils cannot retain water leading to rapid floods and subsequent depletion of groundwater and dry season surface water levels (Hoy and Belisle, 1984). In Uttar Pradesh, there are increasing threats of water scarcity in the villages of the Himalayan region. While the Monsoon rains run off and flood the plains below as a consequence of forest destruction, there is a scarcity of water in post-monsoon periods as springs dry up due to lower groundwater levels and perennial streams become seasonal (Bandyopadhyay and Shiva, 1988).
The conversion of catchment forest reserves into mono-culture plantations has had the largest effect (Bandyopadhyay, 1987). The Indian experience shows clearly that disrupted water cycles can result in the loss of a renewable natural resource. A similar story can be told for Africa. In Tanzania, tobacco production in Iringa and Tabara regions results in large tracts of woodland being deforested by small-holders practising shifting cultivation to avoid nematode infestation (Mgeni, 1988). This alters the hydrological regime leading to the exacerbation of water scarcity during the dry season.
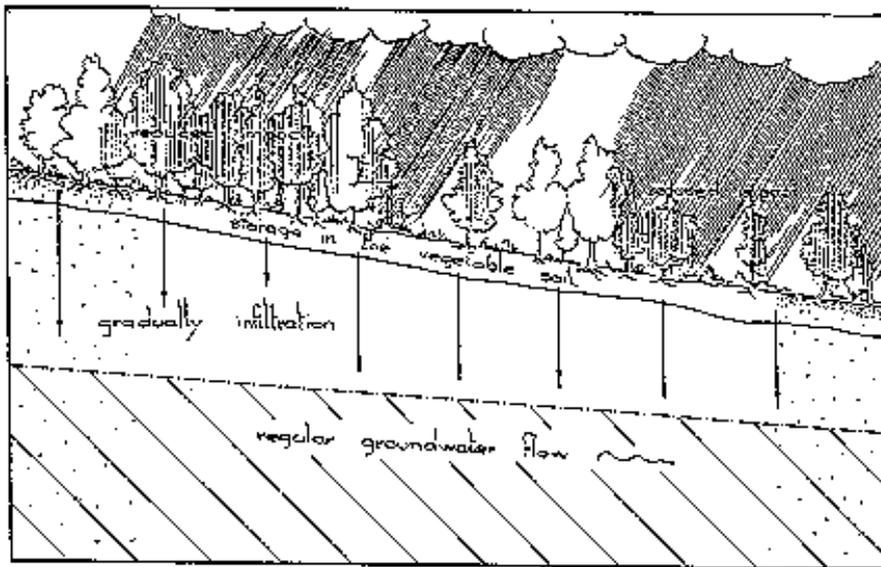
Before deforestation
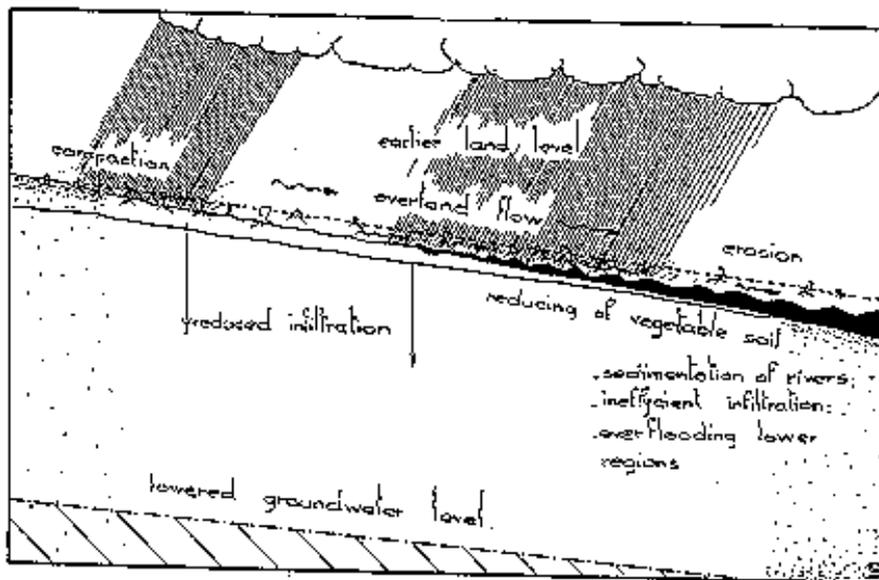
After deforestation

Figure 9:   The effects of deforestation

The effects of deforestation are aggravated by over-grazing, soil degradation, and settlement construction. They contribute to soil erosion by weakening the physical structure of the soil, exposing the surface to direct impact of raindrops, and reducing the resistance to overland flow leading to more rapid flooding of streams and rivers.

Over-grazing often occurs around improved water sources, as more people can be supported by the available drinking water and move into the region. This is the case in Sudan where deep wells provide water for people and cattle. Additionally, provision of a more reliable and convenient water source allows users (particularly women) more time to expand their agricultural activities and the demand for fuelwood and farmland increases accordingly (Boot, 1989 personal communication).

Urbanization can cause significant changes to the downstream flow of rivers and streams. Soil degradation creates a largely impermeable surface, providing fast drainage channels down which stormwater can flow, changing natural flood patterns. Less water infiltrates into the ground. Downstream users experience greater probabilities of heavy floods followed by low surface water retention and groundwater yields fall. Dam construction and river-works also alter the regime of rivers and lakes, reducing or increasing water levels at different intervals. The consequence of lower river levels is that access to surface water by

gravity becomes difficult, sources dry up, and bank-side users experience greater difficulties hauling water up the banks.

The effects of deforestation and soil degradation are most strongly felt in semi-arid and arid areas. They seriously limit the reliability of groundwater and surface water sources in large geographic areas and greatly increase time and energy burdens for women and children who collect water and fuel wood for the family. The limited reliability of the sources is becoming most obvious in areas with rapid population increase. This problem is particularly acute for local aquifers, which receive only limited recharge and act as temporary underground storage reservoirs.

The effects of increased seasonal flooding is often disastrous. This can have a direct effect on water supply reliability and water quality. Floods can pollute surface and groundwater sources and cause health hazards. This phenomenon was reported in Bangladesh after the floods of 1988. Flood damage can have an instantaneous and disastrous effect on surface water supply by washing away restraining dams that would otherwise have stored the dry season drinking water supply for settlements. This is most commonly a problem for earth dams in arid or monsoonal climates. Dams are usually constructed to withstand the forces of a given probability of flood, for instance, that which can be expected to occur every 10 to 25 years. Changing catchment conditions through deforestation and soil erosion can intensify peak flow and lead to more frequent breaches and subsequent destruction of dams.

Decreased vegetation cover has implications for water sources through its effect on soil degradation, erosion and consequent siltation. Raised turbidity levels leads to decreases in reservoir capacity as sediments silt out in water stored behind small or large dams as shown in Ghana (de Jager, 1989). Treating the water becomes more difficult and more expensive. Soil erosion in parts of Africa during the seventies was estimated to be in the range of 600 to 1500 tonnes per hectare per year (Edwards, 1977). It is certainly no less of a problem today. The fall in storage capacity reduces the reliability of the water source, which results in wells being increasingly prone to drying up.

5.   Experience in Better Water Resource Management

5.1   Risk assessment

Risk assessment strategies are receiving growing attention from planners of small community water supply systems. It is recognized that water quality can be ensured more effectively when avoiding the risk for contamination by human waste, agricultural chemicals, livestock faeces and industrial discharge (Hubbs, 1985). This is particularly important in rural areas where it is preferable to minimize the necessity for water treatment (Okun and Ernst, 1987). Assessing the risk of source problems requires knowledge of the possible causes of such problems under local conditions at the source and in the catchment area.

Risk assessment is preferably carried out in the planning stage of a water supply system development in which the objectives are to select sites with the lowest risk factor and to plan for preventive actions. Experience has been reviewed in three main areas to date: Source and site selection, catchment protection, and sanitary surveying.

Source selection and siting intakes
Field experience shows that good source selection and adequate siting of intakes contribute to the reliability of the water supply system. Various field manuals and handbooks have been developed for the design of gravity water supply systems, which include basic procedures for source selection and siting of intakes (for instance, Archambault et al, 1987; Jordan, 1980). Often these procedures concentrate on the determination of a safe source yield or the design of the intake structures, rather than on present and future risks to be avoided. Sustainable use of sources requires site and source selection allowing subsequent protection of the source and catchment area (Sundaresan et al, 1982). Lloyd (1982) stresses the environmental factors affecting sources and recommends the following procedure for the selection of surface water sources:

- take water as near to the watershed as possible;
- choose sources with catchments as sparsely inhabited as possible;
- choose supplies that consistently yield low-turbidity water;
- frequently inspect catchment areas for pollution sources; and
- avoid activities that may pollute upstream locations.

The Tanzanian temporary water standard guidelines (Sechu, 1986) state that river intakes should be constructed upstream from villages and industries, and the intake should be in deep water close to a stable bottom. Lake intakes should avoid shore water and be positioned deeper in the lake towards the centre of the depression. This minimises both the chances of pollution and the risks of dry periods.

For the selection of groundwater sources, in particular for small point source supplies, procedures could be more systematic, both in terms of locating high-yielding sites and in terms of avoiding sites with high potential for contamination by seepage from the surface. Low success rates in drilling small diameter wells, and early deterioration of boreholes have caused rural water supply programmes and water agencies to give more attention to this point. However, there are still many projects haphazardly selecting sites for well construction and drilling. Nevertheless attempts are being made to

develop more reliable and more economical ways to select groundwater sources. For

instance, Poyet and Detay (1988) developed computer software to assist projects in siting and designing wells.

For the siting of shallow drilled and hand-dug wells, the risks associated with faecal contamination from on-site sanitation are still poorly understood and quantified. Where water supply points are located within or adjacent to settlements, two elements have not been adequately addressed with respect to possible contamination by existing sanitation units and/or waste disposal practices. The first element concerns contamination risks to drinking water sources from waste. The lack of criteria for the establishment of safe distances between the water source and possible contamination points is the second element.

Ward (1989) suggests that contamination risk cannot be determined without monitoring groundwater conditions, especially given that research has shown pollution of groundwater is negligible under certain hydro-geological conditions (Lewis et al, 1982). Problems are so site-specific that general guidelines are often ineffective. Ward sees monitoring as indispensable to groundwater development projects where on-site sanitation is also practised. He also considers monitoring within the capacity of developing countries given clearly defined objectives and the elaboration of a simple methodology (Ward and Foster, 1981). Participation of the user communities in the assessment of possible intake and well-sites is important for two reasons. First, local communities have knowledge about variations in water levels and water and land use activities, which are of use in selecting sources that can remain adequate in terms of both quality and quantity. Secondly, source discussions promote a dialogue with the users on environmental risks and protection, which raises community awareness and can develop or problem-solving actions.

With increasing population pressures and expansion of human activities into previously undisturbed catchment areas, risk assessment must take into account both current and projected activities within the catchment area. Awareness of the changing nature of catchment areas is very important, particularly for safeguarding untreated gravity systems, springs and mountain streams.

One of the most successful gravity piped water supply programmes is considered to be the rural water supply programme in Malawi. Sources were located in forest reserves with low risk of contamination. In spite of this, contamination of an increasing number of sources is raising concern. Some of the Malawi rural self-help gravity systems are now being examined by IDRC (1989) to determine the nature of water contamination. Appropriate measures to remedy existing contamination as well as future source protection and site selection criteria are being investigated.

In Danida supported water supply programmes, greater yielding, distant gravity sources are generally selected at higher costs in an effort to meet the future water demand of the target population and to minimize risks of pollution. In principle, these sources are less affected by the user communities and their livestock. Nevertheless, some of the sources have a lower yield than expected or have been found to be contaminated. Lack of long-term data on spring characteristics at the time of selection and rapidly changing conditions in the catchment areas have contributed to this problem. In some areas, the programme installed handpumps because groundwater sources were evaluated as being more reliable than surface sources (Jensen 1989, personal communication). Undisturbed catchment areas for spring development with relatively lower risk and lower exploitation costs are threatened as land is increasingly brought under production. Similar problems are reported from the Punjab in Pakistan and from Colombia. In Colombia, pollution of highland springs feeding gravity

pipes has increased the necessity for slow sand filtration systems managed by villagers (van Wijk, 1989 personal communication). These examples show that it is important to assess the effects of changes which are likely to take place in the future. Site and catchment risk assessment enables planners and managers to compare source problem risks for different alternatives.

Catchment protection

Clearly from the above examples, more active protection of catchment areas is required. This involves a systematic appraisal of catchment areas for surface or groundwater sources and the identification of environmental factors, related to land- use. There is a need for practical experience to develop checklists for small sources to be effectively managed by local communities. Such checklists were developed in Sri Lanka, where the Sarvodaya organization prepared yield measurement procedures in addition to using colouring agents to determine pollution risks.

On a larger scale, PAHO/CEPIS has established procedures for the identification and evaluation of pollution risk for regional aquifers in Latin America and the Caribbean (Adams, 1990). Many of the aquifers in the region are vulnerable to pollution from discharge of effluent, solid waste and toxic chemical disposal, and the expansion of agriculture. As groundwater is used to provide drinking water to an estimated 140 million people in urban and rural areas, the protection of aquifers is of critical concern. Important considerations mentioned are:

- Groundwater pollution has a long lasting effect;
- Remedial action is often not feasible or very expensive;
- There are not only immediate, but also chronic health implications from pathogenic or toxic pollutants.

The groundwater pollution risk is the product of the contaminant load applied to the subsurface environment by human actions and the natural pollution vulnerability of the aquifer (Foster et al, 1987). To protect aquifers, it must be clear by which pollutants and pollution sources they are most affected. This knowledge forms the basis for the delimitation of protection zones in which human activities must be regulated.

Protection zones are conceptually important for the design, prioritization and distribution of water resources protection measures. The zones can be delimited with respect to the level and nature of risk, resulting in more coherent and incisive protection strategies. However, those zones may be established even when risk information is incomplete. The following zones are defined as follows:

- the inner zone, defined as the area in which there is a direct risk of contamination,
- the outer zone, defined as the area in which the water may be at risk from indirect contamination,
- the catchment area, the whole area from which water flows to the intake.

Existing water resource protection legislation can be incorporated into zoning to elaborate protection strategies. An example of such effort is a SIDA sponsored study in Botswana carried out in the early 80's resulting in a proposal for new domestic water legislation (Hawerman et al, 1983). The issue of protection areas for drinking water sources is presented in the proposal, but the information lacks detail.

In Sri Lanka, the Sarvodaya organization mentioned earlier, requires communities to establish protection zones of at least one acre surrounding the source before the construction of a system is considered. Often larger areas are set aside of 4 to even 10 acres. The protection zone is demarcated by a fence or shrubs. Mixed tree seedlings are planted within this demarcated area (Heynen, personal communication 1990).

The effectiveness of protection zones relies on local people's commitment to protection measures established. Protected areas are obviously increasingly vulnerable as population densities increase. Local people must therefore be motivated to take effective measures to protect the catchment area. Motivation will be partially a function of their perceived value of the resource. The boundaries of high risk zones can be identified by physical surveys, discussions with community members, and aerial photographs. Areas can be demarcated by fencing or planting a particular variety of tree to act as a differentiating line (Jensen, 1989 personal communication).

Sanitary surveying
Sanitary surveys are a form of risk assessment which examine the technical quality of a water supply point, the manner of use by consumers, the surrounding environmental hygiene conditions and the potential causes of contamination. Their purpose is to minimize the level of risk of on-site contamination by identifying remedial measures that can quickly and easily be taken. Preventive measures may already have been implemented in the planning and construction stage as part of site selection, risk assessment and system construction. Coupled with bacteriological analysis, sanitary surveys provide a methodology on which successive improvements can be made to water supply conditions. The method can also identify where off-site problems contribute to contamination and where remedial catchment protection is urgently required. This is illustrated in the experiences of Lloyd and his colleagues who have developed a sanitary survey strategy in collaboration with WHO (Lloyd, 1990; Lloyd and Suyati, 1989).

Through the Java pilot project, Lloyd and his colleagues, have developed cost-effective methods for sanitary inspection and water quality monitoring that are now being applied in UNEP/WHO projects in Peru, Colombia, Nicaragua, Zambia, Nepal and Vanuatu (Lloyd, 1990. WHO, 1989). A sanitary survey was developed which could be rapidly and accurately completed at the same time as bacteriological sampling and field-testing. The survey report has a checklist of potential contamination sources and quantifies the level of overall risk by a cumulative yes/no score. A sketch of the risks to be left at the site so users can see the site protection measures is elaborated. The strategy classifies the water point on the basis of the sanitary risk, graded from high to low. The survey reveals the sources of highest contamination risk. The sanitary surveys are a tool to enable inspectors to play an active role in the improvement of water sources by undertaking on-site evaluation and providing clear instructions on remedial protective measures. The approach provides a scientific basis for prioritizing remedial actions to protect the consumer from the risk of waterborne disease. Remedial measures relate to actions taken at the site by the user community, either to make physical repairs or to improve unhygienic practices causing

contamination. Continued surveillance allows drinking water sources and supply systems to be improved gradually so they can achieve satisfactory survey results.

To provide a more meaningful assessment of the sanitary status of water sources and the level of risks for waterborne disease transmission, a more appropriate grading of faecal contamination was deemed necessary. Because of the adoption of a realistic and more elaborate grading system (i.e. more than just 0=safe, > 0=unsafe), as well as a quantitative evaluation of potential pollution risks, it is possible to more accurately assess the health risk attributable to every drinking water installation in order to prioritise remedial action (Lloyd, 1990). The grading is based on increasing orders of magnitude of faecal coliform contamination:

Grade of Risk		E.coli-Faecal coliforms/100ml	Risk Factor
A	=	0 (WHO Guideline);	no risk
B	=	1-10;	low risk
C	=	11-100;	intermediate to high risk
D	=	101-1,000;	gross pollution; high risk
E	=	> 1,000;	gross pollution; very high risk

Sanitary risk is plotted against bacteriological risk to give a clear indication of the worst water supply points. Where a low sanitary risk is paired with a very high bacteriological risk, this may well indicate remote source problems such as pit-latrine seepage. When this probable remote contamination is detected, a wider catchment risk assessment is required as explained previously. At a recent IRC meeting on drinking water source protection, participants recommended that the sanitary survey be adopted more universally; preferably in combination with risk assessment in the catchment area and the formulation of protection zones in which human activities are regulated and preventive steps taken (Lee, 1990). Especially for small and scattered community-managed water supply systems, it is essential that community members take a active part in such sanitary surveys, as their help will usually be needed to improve sanitary conditions and to change practices which cause contamination of water sources.

In some countries community-based monitoring systems of the water quality of small community systems are under development. For instance in Colombia, a simple quality testing device has been developed and village water operators are being trained to regularly monitor and record turbidity and E-coli levels as part of a demonstration project on simple treatment methods supported by IRC.

5.2   Technical solutions

Possible solutions to source problems include improved sanitation, physical protection, soil and water conservation, waste water treatment and recycling, artificial recharge and tree planting. In many cases, these must be combined to respond to problems that have more than one cause.

Improvements in sanitation

As mentioned earlier, the problem of user contaminated water supply through poor sanitation and hygiene is widespread. Use of latrines and other sanitary systems reduce faecal pollution risk by excluding contamination of the topsoil or ground surface so that excreta is not washed into surface water or transported by animals (Nordberg and Winblad, 1990). The design of the latrine should in principle ensure that there is no direct sub-surface link between the excreta and the groundwater supply which involves consideration of siting, soil type and depth, and seasonal or daily water levels (Lewis et al, 1980a). Given well designed latrines, adapted to local conditions, improved sanitation requires broad acceptance as well as high use rates by the population.

Figure 10:   Users polluting their water source

Figure 11:   Users protecting their water source.

Physical protection of wells and intakes

Users pollute their water sources due to the lack of awareness about ways and means to ensure adequate physical protection of the supply point (Figures 25 and 26). Community water supply projects engaged in groundwater development through well construction, recognize the importance of simple site protection against pollution. The addition of well-aprons, soak-away drains, covers and hand pumps protect water quality by preventing the inflow of contaminated water back into the well. In addition, the direct input of contaminants is excluded while extracting the water (Boschi, 1982. Nyangeri, 1986. Rogers, 1985. IRC, 1988. Archambault et al, 1987). The benefit of providing well-heads, walls and aprons was clearly observed in Sierra Leone where bacteriological contamination was lower than in traditional shallow wells and fluctuated less seasonally (Wright, 1985). Because proper construction and maintenance of these improvements is required to safeguard water quality through time, it is essential that communities, and women as first users, are involved in the decision regarding the construction and design of aprons, drains etc., and are trained in its relevance for the cleanliness of their drinking water.

The use of wells for clothes washing, bathing and cattle watering and nearby open defaecation, are other sources of water contamination. Absolute prohibition of these practices is often no solution as it forces women and children to either increase time necessary for water collection or limit water-use for hygiene. In many areas, such problems can be prevented by discussing the need for additional washing, bathing and/or cattle watering facilities and coming to clear agreements regarding the design, siting, financing and management of additional facilities for these purposes.

Figure 12:   Neighbourhood washingfacility near water point in Tanzania

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Pollution also occurs due to the direct use of surface water sources by livestock. This can be prevented by constructing fencing using branches, thorny scrub or hedges of cacti or thorn-bushes, provided there is a watering trough for animals outside the fence. This form of protection is illustrated in the sketches from the SIDA funded HESAWA project (SIDA, 1987) in Tanzania.
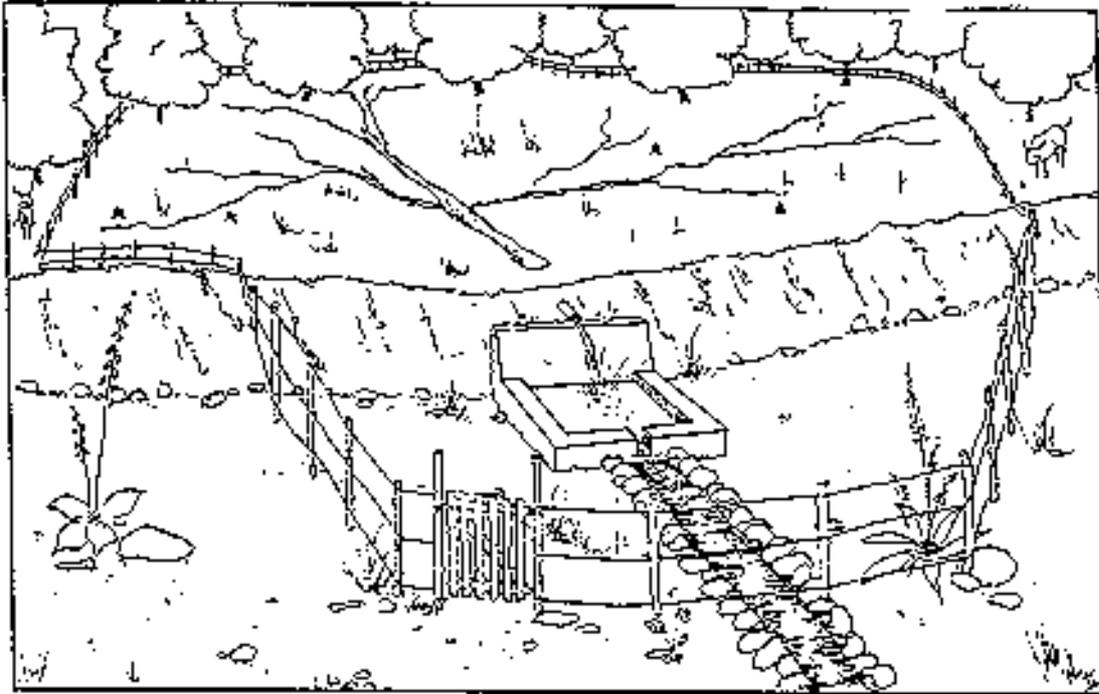
Figure 13:   Fencing as well as hedges can be an effective protection measure

Experiences in Haiti, Rwanda, Zaire and Burundi show that physical protection has to be combined with community oriented training and education related to system-use and maintenance, and catchment protection (Archambault et al., 1987; Klomberg, 1988 personal communication).

Soil and water conservation techniques
Soil and water conservation activities can decrease turbidity by preventing sediment transport, increasing groundwater recharge and decreasing surface flow peaks by increasing infiltration. A full range of erosion control techniques and strategies have been pioneered for developing countries and applied with considerable success. Methods include terracing, contour ploughing, infiltration buffers, earth bunds, stone-lines, trash-lines as well as various forms of runoff farming (Wenner, 1981; Morgan, 1981; Morgan, 1985). A prominent example of soil and water conservation to preserve watershed environments and increase agricultural activity is the EEC-assisted Machakos Integrated Development Project in Kenya (Harrison, 1987).

However, soil erosion has expanded at a faster pace than most national governments have been able to cope with. A large proportion of soil erosion problems have resulted from the expansion of shifting cultivation techniques into marginal areas. Additionally, they result from the settling of previously semi-nomadic people who have little history of terrace building or other traditional forms of soil stabilisation. Concentration of livestock around newly developed water supply points such as earth dams has also caused serious soil degradation through over-grazing. Erosion results in rapid siltation and subsequent

reduction of the reservoir capacity of dams. A more widespread application of soil and water conservation techniques is clearly required. Institutional capacities and community programs must be stimulated, if control is to keep pace with the growth in population and new land brought under production. These elements have been incorporated in a forthcoming innovative rural water supply programme in the Dodoma region of Tanzania (Stanislawski, 1990 personal communication).

Waste water treatment

Both industrial effluent and domestic sewage should be treated to minimize pollution risk. For domestic sewage, different on-site and off-site technical options are available, but they are not always applied. For developing countries, sewage lagoons and oxidation ditches are among the more economical methods. Automated sewage treatment plants are more difficult and expensive to operate and maintain. It is often technically difficult and expensive to process industrial waste. A variety of techniques exist for mechanical purification and chemical and biological treatment. GTZ commissioned a handbook on waste water technology (Fresenius et al, 1989), which discusses the treatment of domestic, commercial and industrial waste water.

Little experience exists in using simple and effective, low-cost treatment technologies for small-scale industrial polluters; especially for small rural agro-industries. Suitable technological solutions and a system of incentives against discharging untreated waste into national and local waterways appear to be lacking. Many toxic elements originating from industries and the misapplication of fertilizers have no feasible treatment possibilities. Therefore, preventive measures against contamination from industrial and agricultural activities are crucial.

Waste water Recycling

Waste water treatment is complementary with waste water recycling. As such, sewage waste may only need partial treatment to be used on farmland for irrigation or in a range of industrial processes where water quality standards are not critical. Waste water recycling if carried out correctly, can be a form of water source protection as well as conservation. Contamination risk of water sources is decreased through proper recycling and increases the efficient use of the water source. Water is treated by less expensive methods because treatment is to a lower quality level, since only coliforms and helminths need be removed. Less expensive waste treatment ponding is one technology recommended for developing countries. These ponds are adapted to existing technical skills and socio-economic conditions (Laugeri and Hespanhol, 1990). The cost of treatment is reduced compared to that necessary to safely release treated waste into surface water. However, there is always the prospect of groundwater contamination by infiltrating waste water irrigation. In the irrigated area, the most susceptible water supply systems are shallow wells (Laugeri and Hespanhol, 1990).

Several benefits can be derived in groundwater dependent areas for irrigation by recycling waste water. Recycled water, supplements the existing water source by decreasing the use of groundwater. In some cases, waste water can be substituted for fresh water for non-essential uses. Recycling of waste water reduces the risk of contaminating water resources. Health risks to down stream users would be reduced.

The two major financial benefits are the reduction in water supply costs by supplementing waste water for limited supplies of fresh water, and revenues for sewerage works processing

the waste water for sale to re-users (Laugeri and Hespanhol, 1990). To effectively and safely carry out waste water recycling, developing countries must considerably improve their operation, maintenance and surveillance practices in relation to waste management.

Artificial Recharge

Groundwater resources can be managed to decrease water table recession and saltwater intrusion by artificial recharge. A range of techniques are available and depend on the geological and topographic conditions of the location, and the size of the aquifer to be recharged (Rushton and Phadtare, 1989). At the small and medium-scale, recharge is predominantly from infiltration ditches, ponds and basins, through retention of river underflow using sub-surface dams, and through retention of river flood-water. Sand storage dams can also be used to increase the dimensions of the shallow groundwater reservoir (Nilsson, 1988).

Siting individual or batteries of wells adjacent to rivers may be effective in filtering out contaminants, as opposed to using water directly from the river. (Huisman and Kop, 1988). General information on small and medium-scale artificial recharge has been provided, for example by Hofkes and Visscher (1987).

In irrigated zones of Punjab in Pakistan, artificial recharge was applied on a considerable scale. In certain areas brackish groundwater can not be used for drinking water. Wells were situated at regular distances along main irrigation channels to draw from the freshwater aquifer around the channel. The water was pumped electrically into a piped system for a rural town and villages. This solution was preferred over pumping directly from the canal in order to combine a safe yield with better water quality.

Recharging groundwater has possibilities in arid zones where potential evaporation and runoff is high. The success of the method obviously depends on local conditions such as the porosity of the aquifer, the depth of the capillary zone through which water can be drawn up to the surface and evaporated, and the retention of the soil and rock.

Reforestation

Reforestation programmes coupled with anti-erosion and soil and water conservation techniques are considered essential to the amelioration of many source problems. However, for the moment many more trees are cut than planted. For example, it is estimated that in South America the rate of tree planting to cutting is approximately 1:10 (Gaskin-Reyes, 1988).

It is important to remember that while it takes only a short time to clear forests to cause soil erosion and to disrupt hydrological processes, it takes a much longer period to counteract these problems. In addition, the environmental benefits accruing from reforestation are not easily recognized by the local population. Their overriding concern is bringing new land under cultivation to increase food production. Short term needs often have priority over long term benefits. Nevertheless there are encouraging experiences. In India, the Chipko movement is considered successful (Bandyopadhyay and Shiva, 1988) and protection of forest areas has helped reduce the intensity of floods and soil erosion, ensuring a perennial water supply from previously threatened local sources. Elsewhere, social forestry programmes have contributed to environmental stabilisation while meeting local resource needs for food, firewood, fodder, building materials and income (Gaskin-Reyes, 1988). Village forestry has also been promoted to help regulate water flows in streams and rivers

and prevent siltation in dams and reservoirs.
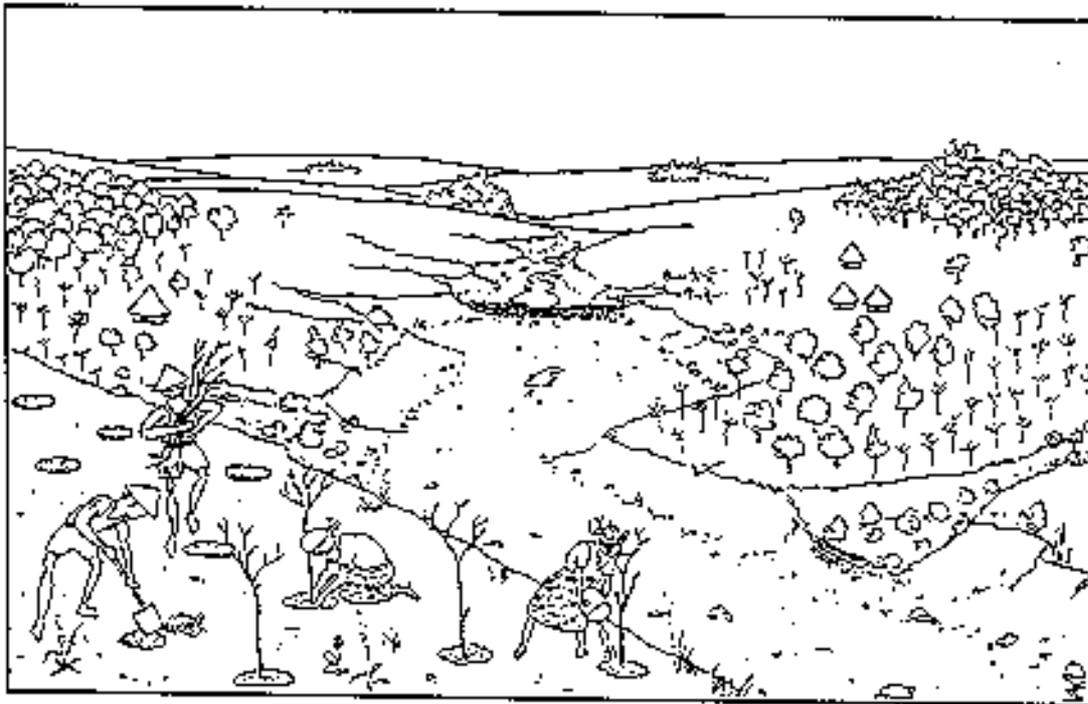
Figure 14:   Village forestry

Comprehensive solutions
A single technical approach is often not enough to remedy or protect water sources. Effective drinking water source protection may need to adopt a multiple intervention strategy because usually, gross pollution of drinking water supply has more than one cause. A comprehensive water source protection assessment must be carried out, identifying actual and potential problems, for which protection measures can be suggested (Nordberg and Winblad, 1990).

For example, a high-level committee was established by the Government of Gujerat to report on the causes of increased salinization of groundwater, consequent deterioration of irrigated land and possible remedial measures. The cause was clearly over-pumping of groundwater. The comprehensive remedial measures recommended were: to change crop patterns (to less water-dependent crops); to regulate ground water extraction; to increase artificial recharge with check dams, recharge wells, and recharge tanks; to block salt water intrusion with tidal regulators, fresh water barriers and extraction carriers; and to reforest the upland catchments (Shukla, 1984).

5.3   Institutional and legal aspects of source protection

Community motivation and awareness
Many water pollution problems are due to a lack of awareness of the causes of health problems among local communities (Wihuri, 1989 personal communication). The link between water, hygiene and illness is not strongly perceived since water is assumed to

be beneficial and cleansing rather than a potential avenue for infection (Boot, 1984). Local community awareness raising is often an essential prerequisite to stimulating their motivation for undertaking protection activities.

For example, the Al-Baghari Spring in the Yemen (Ansell and Burrowes, 1981) was polluted by users washing laundry and allowing their donkeys to stand in the water while filling jerry-cans. The spring was believed to have been formed by the prophet striking the ground with his sword and pronouncing it to be self-cleansing. Local village people saw no need to modify their behaviour, considering the water to be free, plentiful, and pure. Much time and effort was required on the part of field workers to involve the community in a strategy to protect the spring and pipe water down to the village. This illustrates the importance of cultural factors and the need for community awareness of the real nature of problems affecting their health and welfare.

Health and hygiene education activities help prevent many water source contamination problems through measures such as:

- preventing open-air defaecation;
- disposing safely of human waste by the introduction and regular use of sanitation systems, such as pit latrines;
- using clean buckets and ropes to extract water;
- excluding washing of laundry, bathing and livestock watering in the drinking water source;
- improving people's understanding of the mechanisms that transmit and cause diseases.

Health and hygiene education methods and experiences are described extensively in IRC publications (for instance, Boot 1984). However, there is little information concerning training of community members and water committees, enabling them to play a more active role in the protection of their drinking water sources.

Partnership between communities and governmental agencies
Reliably functioning water supply systems may greatly contribute to the protection of water sources. Community-based maintenance and management of water supply systems is a good starting point for a more integrated approach to water source protection and environmental conservation. As explained earlier, poor functioning of supply systems limits reliability, and makes sources inaccessible for unacceptable periods. As a result, users may alternatively adopt less sanitary methods of extracting water, which in itself can cause pollution.

There are a few examples of community-based management comprehensively addressing water source problems. An example of effective community management developed with little external assistance was found in Botswana, where a policy of constructing small dams for local rural groups was adopted in 1974. Each dam was intended to water 400 head of cattle and in some cases, provide domestic water (Fortmann, 1983). This was later re-evaluated because planners felt that the risks of water source deterioration were too high. Specifically, they worried about escalating cattle concentrations around dams leading to severe damage and contamination leading to possible health hazards. However, planners found their concerns already accounted for by the local community. The rural groups had developed a four-fold system of source protection in an attempt to maintain water quality and reliability. The following are elements of the community designed water management strategy:

- limiting the number of users to members of the group and occasional non-members

from the same community;

- restricting use to domestic purposes and the watering of calfs either permanently or seasonally;
- controlling the manner of use by preventing animals from taking water directly from the dam by fencing and providing watering troughs; and
- rotating reservoir use by exploiting shorter lived sources first.

Similar highly motivated management actions can be found among communities in Asia. In the mountainous Himalayan region of Uttar Pradesh, there is an increasing threat of water scarcity in the rural villages due to the clearing of natural broad-leaved forests (Bandyopadhayay and Shiva, 1988). Rapid runoff of monsoonal rains create floods which are followed by post-monsoonal drying up of springs and streams. The impact of this seasonal water fluctuation has been felt strongly by women who must now walk long distances each day for the family water supply. Inspired by the Chipko (hug-a-tree) movement, village women have begun to protect and regenerate forests in the vicinity of their village to help improve their water, and at the same time, their firewood and fodder situation. In the Song river catchment of the Saklan region, villages have protected and regenerated the oak forests which have reduced the intensity of river floods, inhibited soil erosion, and ensured that springs and streams provide a year-round water supply (Shiva, 1989). In developing effective community-based environmental management, more attention should be paid to local knowledge and traditional management systems already existing in the areas concerned. Local men and women know their environmental socio-economic and cultural conditions well, and can therefore often advise whether a certain strategy is likely to be appropriate. In a Colombian mountain village where an intake was affected by cattle and soil erosion the villagers rejected the idea of fencing or grazing cattle elsewhere. They predicted that the wire would be stolen, and that they did not have enough land and cash to make proper pastures. Instead, they provided voluntary labour to plant prickly vegetation upstream from the intake. This effectively forced the cattle to drink water at lower places along the river and solved the problem.

With regard to traditional management systems, there are indications that regulations on management and use of water sources exist especially in areas with a shortage of water, a high water culture and/or sharing of water points by a relatively small group of families. Women often play an important role in this source management (van Wijk, 1985). Asking users about *how* they manage traditional water sources was found to be the best way of identifying such traditional management patterns (Roark, 1984).

Although community water management strategies are possible, there must generally be direct links between the community and the water source. Communities must be users of the water source or derive some other benefit from the protective action such as commercial benefits from tree-planting or increased crop production following soil conservation. Conflict of interests between upstream and downstream users is a serious problem worldwide. This is true for the next village farming further up the mountain hillside as well as for the industry discharging its waste upstream from a water intake. Neither sees the need to change its polluting or over-exploiting activities since neither experiences the negative effects these activities create. Reconciling conflicts of interest and instituting environmental protection in these situations is the role of the national, regional or local authorities. Government institutions and regional and local authorities should support community efforts to manage and protect their drinking water sources. Support to community-based environmental management can be formalized in regulations and control procedures.

Greater information is required to enable governments to formulate water management policies. Information creates the basis on which planning and legislative decisions can be made. For international support agencies and national governments there is a need to better identify issues and priorities as a basis for strategy development. The development of country profiles of major environmental problems affecting drinking water sources was called for at the recent review meeting at IRC (Lee, 1990).

A recent attempt to formulate a strategy comes from West Java where the Government of the Republic of Indonesia has set up a Water Resources Management Office (GOI/Cowiconsult, 1989). This organization issues licences for water source developments which are used to enforce the Environmental Management Act of 1982 and in particular, the 1988 Control of Groundwater and Surface Water Exploitation and Disposal of Waste Water. To obtain a licence, information must be provided in the form of a "Presentation of Environmental Information" (PIL). The information required consists of general information on the water source, its geological and morphological characteristics, present environmental conditions, and the anticipated changes in the catchment area and source characteristics as a result of exploitation. The sensitivity to pollution is expressed in five relative terms from safe to very sensitive. For each source examined, protection requirements are illustrated on a topographic map showing the source location and the proposed protection area. For springs and small streams, the entire catchment is protected in which polluting activities are to be controlled. For big rivers or irrigation canals, the immediate upstream areas from the intake are designated as a protected zone. For boreholes/wells, the protective area is both the immediate area surrounding the well and the catchment area for groundwater flow.

Legislation and enforcement

Currently, water resource and environmental legislation in most developing countries has evolved through time in response to particular water management problems that have developed with associated economic and demographic growth (UN, 1984). They are directed towards the control of water use from major rivers or lakes which are of economic significance and do not currently provide a good basis for protection of drinking water sources.

From their work on the legal and financial aspects of community water supply development, WHO has listed several legal issues that have recently come to the forefront (Laugeri and Hespanhol, 1990; Laugeri, 1990):

- regulations are needed to ensure that the source exploited for community water supply is the most favourable in terms of quality, quantity and access. The rights and needs of drinking water users should be protected. For example, if there is a deficit in community water supply due to industrial extraction, industry should bear a real share of the cost to the community for having to use more distant or polluted sources;
- regulations are needed to ensure health and environmental protection for waste water use since there are obvious public health hazards. Guidelines are currently being elaborated by WHO based on available experience;
- legal provisions are required to ensure that potential water sources are adequately protected from the deteriorating effects of waste water infiltration;
- fundamental legislation and regulations are needed to ensure that community water supply and sanitation costs are recovered from all water source users, especially those

consumers who access common-property sources through privately-owned facilities. This is particularly true where the better sources have been monopolized by a few privileged consumers at the expense of public access.

Some developing countries have prepared new water resource legislation. However, there has been difficulty in the enforcement of these laws. Government staff have insufficient training to carry out their tasks and have little reliable data with which to formulate activities. In general, there is a low awareness on the part of government and the population concerning water source problems. Finally, water source problems are often linked to population growth and subsequent expansion of agricultural activities into marginal catchment areas.

Legal measures need to take into account existing appropriate technologies as well as institutional capacities. Government can enhance awareness of the benefits of improving the living environment, for instance through land-use planning or decreasing pollution risks when developing land for government use and by effectively ensuring the emptying of septic tanks.

It is recognized that environmental regulations remain ineffective if locally perceived interests are not taken into account. For instance, subsistence agriculture may lead farmers to continue clearing more land for agriculture, even being aware of the negative environmental effects and that it is against the law (Smet, 1989 personal communication). It is essential to recognize and address these needs and develop more effective agricultural methods with agro-forestry and soil and water conservation activities. For instance, in Malawi with a population density of nearly a hundred inhabitants per sq km, agricultural exploitation is at carrying capacity. Wood gathering by women is becoming more burdensome due to deforestation. However, fuelwood scarcities are related more directly to agricultural activities than fuelwood collection itself. Consequently, food deficiency appears to be the critical problem, and it is difficult to stop deforestation caused by agricultural activities (Hirschman, 1990).

An important constraint on the enforcement of legal measures is the lack of political priority for drinking water source protection (Nakai, 1989 personal communication). Greater priority is given to the development of the economy. Source problems are felt more directly by those without access to a sophisticated piped water supply service. Consequently, drinking water sources for smaller and medium sized settlements and low-income groups in urban fringe areas are increasingly affected by the pollution caused by larger settlements and economic activities.

Costs and benefits

In many developing countries, national authorities are aware of some of the basic problems affecting drinking water sources. However, in many cases, the solutions are not politically acceptable, especially where they relate to major industries or agricultural producers. The short-term aspect of production or profitability appears to be of higher priority than the long-term effect on drinking water supplies.

It is difficult to measure the cost for example, of allowing farmers to overexploit aquifers for cash-crop irrigation, or allowing industries to dump waste products into a river with respect to environmental damage. The burden of water sources deterioration is usually borne by the users and must include the time lost walking to a safer, or more distant source,

or the number of days spent ill and unable to work due to diarrhoea. It is often overlooked that in an economic sense there are costs to the country and the government due to decreased productivity. In some extreme cases, there may also be a financial cost when the government has to bowse in water daily from tens of kilometres away (Bandyopadhyay, 1987).

Unless the benefits of good environmental management and water source protection are perceived, it is difficult to expect developing country governments to improve and enforce water resource legislation. Therefore, it seems appropriate to give high priority to community roles in water source protection. The prospects for effective protection seem best where communities cause their own water source problems. The impact of drinking water protection measures is felt more directly and the communities can weigh the costs in terms of time, money and effort against the benefits they receive in increased quality, quantity and reliability of their water supply.

Helping involve women to attend and speak out during community water planning meetings may be important as they often feel most directly the impacts of deteriorating water quality and quantity. This usually requires special steps, including support from male leaders. Holding meetings for women at suitable times and places, informing and encouraging women to attend, and facilitating their input, e.g. by using local languages, inviting spokes women, encouraging internal discission, or holding separate meetings for women (van Wijk, 1985).

6.   *Conclusions and Wider Considerations*

6.1   Need to address water source protection more systematically

Based on the information received and the documentation reviewed, there is a definite need to address source protection problems and their underlying causes more systematically. Water related environmental problems have received much attention in recent years because they affect the sustainability and the effectiveness of drinking water supply improvements and other development efforts. Donors, including Danida, Unicef, SIDA, Finnida and others have or are developing policy documents concerning the broader environmental issues. However, there is no clear overview of the problems, and causes of source problems are not systematically identified and analyzed.

6.2   Causes of local and regional water source problems

Water source problems concern both the quality and the quantity of the water. Both these aspects determine the reliability of drinking water sources. Small communities are affected by both local and regional water source problems, as they largely depend on small water supply systems without treatment.

Environmental factors affecting small water sources such as springs and local aquifers most seriously are pollution by source users, contamination from on-site sanitation, regular supply-site malfunctioning, competing demand for a limited water supply and the effects of local land-use changes. Larger water sources such as major rivers or regional aquifers are mainly affected by discharge of industrial pollutants, growing and widespread use of pesticides and fertilizers, discharge of sewage waste water, over-extraction of groundwater and effects of large-scale land-use change.

6.3   Lack of reliable information

There are insufficient reliable data on the magnitude and nature of drinking water source problems. Lack of information is possibly one of the main reasons why few countries have formulated overall policy objectives concerning environmental protection of drinking water sources, and fail to make appropriate legal and institutional provisions.

Field experience in local water source management mainly concerns technical approaches to source protection to solve source problems in small catchments. Other essential elements to protect drinking water sources appear to be land-use planning and control, legislation and regulations, source selection and siting procedures, and community management. However, there is very little documented evidence of successful experience in developing such an integrated concept.

6.4   Legislation not enforced

Environmental legislation and water laws mostly concern large basins, and so do not provide a basis for the protection of many of the smaller water sources. Enforcement of laws and regulations is hampered by lack of awareness of environmental problems affecting drinking water sources and the costs and benefits associated with environmental protection. It is critical that future legislation should be resource management oriented and take a sustainability approach.

6.5   Lack of awareness

There is a general lack of awareness of these environmental issues among planners and decisions makers, and often among the water users themselves. In many cases, both the people and the authorities give priority to meeting short term needs and give lower priority to the long term benefits of protecting land and water resources. More attention is needed for the training of local staff and users, enabling them to play an active role in water source protection. According to participants at the IRC working meeting on drinking water source protection, water source problems are currently ignored because there is insufficient priority given to source protection and a lack of political commitment to tackle the issues.

6.6   Wider considerations

Strategy development
There is a definite need for developing countries to come to terms with the range of causes and effects of drinking water source problems. Presently they lack the information and the means to formulate guidelines for land-use management and catchment protection. They also need to collect accurate information on the sustainable yield of groundwater sources and on the public and private extraction and use of water as a basis for planning and regulations. Consequently, there are no operational strategies, even where the policy framework largely exists.

More independent and detailed analysis of environmental data and greater effort by international organizations is required to set standards, provide workable guidelines and promote water source protection at all levels in developing countries, would contribute to developing such national strategies. Possible activities by the international organizations could include:

- Developing checklists and general guidelines to identify, prevent and remedy water source problems;
- Preparing country inventories to establish the nature and magnitude of water source problems and identify possible protective actions;
- Reviewing legislative and economic aspects of water source protection and enhancing support to governments in this area;
- Identifying cases and diffusing information on successful community management of water sources;
- Preparing environmental impact assessments for all activities that can affect drinking water quality and quantity.

Environmental profiles and monitoring indicators
Profiles of different types of water sources in different environments and their vulnerability to environmental factors could form a basis for decision-making. Establishing parameters for the monitoring and evaluation of surface and sub-surface sources under different catchment conditions and developing checklists of remedial and preventive solutions would form a starting point for engineers and planners. These decision making tools are considered essential for the enhancement of water source protection.

Simple tools and methods

Small water sources could be protected by using simple tools and methods and using community resources and skills. Practical examples may help to promote the idea of water source protection and trigger the development of local solutions. Detailed studies on water source problems in selected developing countries would help to develop these simple tools and methods which can be applied at the community level.

Community and local government involvement in the management of water resources

Community-based water source protection can be both feasible and effective on a small-scale and should be promoted wherever possible. Establishing exactly how and what communities should do in specific situations would be a useful step forward. Problems appear to be worsening because agencies, projects and local institutions are not equipped to support and advise communities in this area. Institutions lack the physical infrastructure and manpower skills to implement action-oriented environmental research and the implementation of management programmes. Staff does not always have the right attitudes and skills for working in a non-directive problem-solving way with rural communities. It would therefore be appropriate to increase efforts to train technical and extension staff, and develop procedures to support, advise and train community members to promote drinking water source protection as an integrated part of the management and improvement of drinking water supply and sanitation facilities.

Role of women

Lack of adequate water sources heavily affect women. They are therefore additionally motivated to solve or prevent problems. Women's daily visits also make them appropriate for monitoring local water points. Often, they already manage such points and monitor environmental hygiene. More documentation of these roles, and training of staff on women's involvement in planning and water source management can help disseminate and improve community water activities.

Costs and benefits

Costs and benefits of water source protection need to be investigated by collecting data on the nature and the magnitude of water source problems. A thorough understanding of the incentives and disincentives of protecting or not protecting water sources could encourage developing country governments and industries to control major deterioration of water sources.

Low-cost techniques for waste management

Low-cost technologies for waste water treatment and the management and control of industrial waste could be applied more often, in particular by small and medium size industries, and by public institutions like hospitals. Some are already in existence whereas others must be installed. It would be important therefore to identify and promote existing appropriate and low-cost processing technologies, to identify where the necessities currently exist, to promote research on new treatment methods, and to develop adequate maintenance programmes for existing methods.

Pesticides and chemicals

Little detailed information is available for developing countries on the effects on the health on water users related to pesticides and chemicals discharged into water sources. Monitoring of these substances in water supplies is not widespread. Many new substances are created by industrial chemists each year, for which little is known about the toxicology (Lloyd, 1990 personal communication). An increasing array of chemicals are imported and used in the developing world and many countries do not have a registry of toxic imports. Recommendations include:

- information on pesticide and chemical use practices should be collected so that guidelines can be drawn up to enable planners to determine high-risk water sources, and situations where contamination of sources is likely;
- information on the health effects of pesticides and chemicals should be compiled to determine the scale and magnitude of the risks involved and this should be made freely available; and
- registers should be compiled of all toxic substances imported by a country and regulations issued concerning those which can be used with a high degree of safety, and import bans placed on those with unacceptable risks.

References

Adams, B. (1990). *Groundwater pollution risk assessment in Latin America and the Caribbean : working meeting on drinking water source protection, 30 June - 1 July, 1990.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Andersson, I. (1982). *Wells and handpumps in Shinyanga region, Tanzania : level of service from scale water supplies.* (Research Paper; no. 7). Dar es Salaam, Tanzania, Bureau of Resources Assessment and Land Use Planning.

Ansell, C. and Burrowes, R. (1981). *Communicating hygiene/sanitation messages to villagers : an experiment in Wadi Ayyan.* Westport, USA, American Save the Children/Yemen.

Archambault, J., Cédou, C. and Camphuis, N. (1987). *Le captage des sources.* (Le Point Sur; no.10). Paris, France, Association Française des Volontaires du Progrès/GRET.

Asian Development Bank (1987). *Handbook on the use of pesticides in the Asia-Pacific Region.* Manila, Philippines, Asian Development Bank.

Bandyopadhyay, J. (1987). 'Political ecology of drought and water scarcity - need for an ecological water resources policy'. In : *Economic and Political Weekly*, December 12, 2159-2169.

Bandyopadhyay, J. and Shiva, V. (1988). 'People's control over forest resources in the Himalayas'. In : *Appropriate Technology,* vol.15, no.1, p.8-10.

Bastemeijer, T. (1982). *An overview of environmental problems in Tanzania : teaching manual.* Dar es Salaam, Tanzania, Ardhi Institute, Department of Urban and Rural Planning.

Bastemeijer, T.F., Gondwe, H.A., Magonya, S.N., Majumdar, J. Smet, J.E.M. and Wijk-Sijbesma, C.A. van (1987). *The DANIDA financed rural water supply programme in Iringa, Mbeya and Ruvuma Regions of Tanzania.* Copenhagen, Denmark, Danish International Development Agency.

Bastemeijer, Teun and Visscher, Jan Teun (1988). *Maintenance systems for rural water supplies.* (Occasional Paper; no. 8). The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Bastemeijer, T.F. (1990). *Evaluation a mi-parcours du projet eau et assainissement 1988-1992 (MLI/022) : rapport de la mission d'évaluation conjointe.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Bhargava, D.S. (1987). 'Exploitability of the River Kali, the most polluted tributary of the Ganges'. In : *Asian Environment*, vol.9, no.3, p.28-37.

Blackie, J.R. et al. (1980). *Environmental effects of deforestation : an annotated bibliography.* (Occasional Paper; no. 18). UK, Freshwater Biological Association.

Blaikie, P. (1985). *The political economy of soil erosion in developing countries.* UK, Longmann Development Studies.

Boot, M. (1989). *Personal communication.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Boot, M. (1984). *Making the links : guidelines for hygiene education in community water supply and sanitation.* (Occasional Paper; no.5). The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Boot, Marieke and Heijnen, Han (1988). *Ten years of experience : community water supply and sanitation programme, Pokhara, Western Development Region, Nepal.* (Technical Paper Series; no. 26). The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Boro, G. (1984). *Industrial waste water discharges with special reference to the leather industry in Kenya.* (Publication Series B; no.4). Tampere, Finland, Tampere University of Technology Department of Water Supply and Sanitation.

Boschi, I. (1981). *Health and technical data for water supply projects : interregional project for planning, organisation and execution of special public works programmes.* (Technical Instructions 5). New York, NY, USA, United Nations Development Programme.

Boschi, I. (1982). *Construction of hand dug wells and protection against pollution : interregional project for the implementation and evaluation of special public works programmes.* (Technical Instructions 7). New York, NY, USA, United Nations Development Programme.

Bosscher, A. (1990). *Land-use changes and groundwater depletion : the role of vegetation : working meeting on drinking water source protection, 30 June - 1 July, 1990.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Bosscher, A. (1989). *Personal communication.* Enschede, The Netherlands, ITC.

Breuck, W. de (1983). *Salt water intrusion meetings 1968-1981 : a review.* Delft, The Netherlands, International Hydrological Programme.

Cairncross, S. (1988). *Small scale sanitation.* (Bulletin; No. 8). London, England, Ross Institute of Tropical Hygiene.

Cairncross, S. and Tayeh, A. (1988). 'Guineaworm and water supply in Kordofan, Sudan'. In : *Journal of the Institute of Water and Environmental Management*, vol.2, June, p.269-274.

Cessti, Rita (1989). *Water resources : problems and issues for the water sector.* Washington, DC, USA, World Bank.

CEPIS (1989). *Health conditions in the Americas.* Lima, Peru, Centro Panamericano de

Ingenieria Sanitaria y Ciencias del Ambiente. Leaflet.

Chainarong, L. (1977). 'Water for domestic use in rural areas - Thailand'. In : *Water Development and Management, United Nations*, p.1835-1845.

Charalambous, A.N. (1982). 'Problems of groundwater development in the Sana'a basin, Yemen Arab Republic'. In : *Proceedings of the symposium on Improvement of methods of long term prediction of variations in groundwater resources and regimes due to human activity, Exeter, July 1982*. (IAHS Publication; no.136). Wallingford, UK, International Association of Hydrological Sciences.

Chathopadhya, S.N., Routh, T. and Sharma, V.P. (1984). 'A short term study on the pollutional status of River Ganga in Kanpur Region'. In : *Indian Journal of Environmental Health*, vol.26, no.3, p.244-257.

Chauhan, L.I., Bhatt, N.M. and Parhasarathy, G.S. (1984). 'Groundwater quality in and around the area irrigated by waste water'. In : *Journal of the Indian Water Works Association,* vol.XVI, no.4, p.371-378.

Christiansson, Carl (1986). 'Soil erosion and conservation in the drylands'. In : Boesen J., Havnevik K.J., Koponen J. and Odgaard R. *Tanzania : crisis and struggle for survival.* Uppsala, Sweden, Scandinavian Institute of African Studies, p.143-157.

Committee on Development Planning (1990). *Water, the fundamental resource.*

Conré, N. and Babo, M. (1989). *L'eau dans les villages : etude des mesures d'hygiène et d'assainissment du milieu.* Bamako, Mali, UNICEF.

Cook, J.M. and Das, D.K. (1980). *Semra village : case study of groundwater pollution in central India.* (Report No. WD/OS/80/16). London, UK, ODA.

Copplestone, J.F. (1985). 'Pesticide exposure and health in developing countries' In : Turnbull, G. *Occupational hazards of pesticide use.* London, UK, Taylor and Francis, p.67-78.

DANIDA (1988). *Environmental issues in water resources management : a strategy for water resources management.* Copenhagen, Denmark, DANIDA.

Das, D.C. and Pandey, C.M. (1989). *Soil conservation for perspective water management, environment and land productivity : paper presented at national seminar on 'new perspectives in water management',* New Delhi, India, Indian National Academy of Engineering and Central Water Committee.

Dhaneshwar, R.S., Basu, A.K., Biswas, A.K., Ganguly, A.K. and Sanyal, P.B. (1985). 'Evaluation of rural water supply in hill regions of West Bengal'. In : *Journal of the Indian Water Works Association*, vol.XVII, no.2, p.187-192.

Dikshit, V.P. and Nigam, K.K. (1982). *An overview of pollution from tannery wastes : paper presented at the 17th Tanners get-together, Madras, Jan 31 - Feb 4.*

Doppenberg, A. (1989). *Personal communication.* Rotterdam, The Netherlands, IWACO.

Edwards, K.A. (1977). 'Water resources and soil conservation : the Kenyan situation'. In : Castelino, J.B. and Khanala, C.P.M. *The role of water resources in development : proceedings of the 13th annual symposium of the East African Academy, September 1977.* Nairobi, Kenya, National Academy for Advancement of Arts and Science, p.167-176.

Falkenmark, M. (1980). *Rural water supply and health : the need for a new strategy : summary of papers and discussions for the UNited Nations Interregional Seminar on Rural Water Supply, Uppsala, Sweden, 6 - 17 October 1980.* Uppsala, Sweden, Scandinavian Institute of African Studies.

Feachem, R. et al. (1978). *Water, health and development : an interdiscliplinary evaluation.* London, UK, Tri-Med Books.

Fortmann, L. (1983). 'Managing seasonal man-made water sources : lessons from Botswana'. In : *Waterlines, .* vol.1, no.4, p.22-25.

Foster, S.S.D. (1987). 'Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy'. In : Duijvenboden, W. van and Waegeningh, H.G. van. *Vulnerability of soil and groundwater to pollutants.* The Hague, The Netherlands TNO Committee for Hydrological Research.

Foster, S.S.D., Ventura, M., and Hirata, R. (1987). *Groundwater pollution : an executive overview of the Latin America-Caribbean situation in relation to potable water supply.* Lima, Peru, Centro Panamericano de Ingenieria Sanitaria y Ciencias del Ambiente.

Fresenius, W., Schneider, W., Bohnke, B. and Pöppinghaus, K. (1989). *Waste water technology : origin, collection, treatment and analysis of waste water.* Berlin, Germany, Springer-Verlag.

Gaskin-Reyes, C. (1988). 'Forests in Latin America's future'. In : *Development and Cooperation*, vol.2, no.88, p.13-15.

Ghebtsawi-Tsighe, T. (1990). 'Drinking water source protection problems : the case of Tanzania'. In : *Working meeting on drinking water source protection, 30 June - 1 July, 1990.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Goodland, R. (1990). 'Environmental aspects of dam and reservoir projects : the World Bank's new policy'. In : *Waterlines*, vol.8, no.4, p.7-10.

Goetsch, O. (1989). *Evaluation of water points and wells constructed from 1964 to 1989.* Yaounde, Cameroon, CD/Helvetas.

GOI/Cowiconsult (1989). *Preliminary report on catchment and water resources protection.* Bandung, Indonesia, GOI, Ministry of Public Works, Directorate General of Cipta Karya.

Groen, J., Schuchmann, J.B. and Geirnaert, W. (1988). 'The occurrence of high nitrate concentration in groundwater in villages in Northwestern Burkina Faso'. In : *Journal of African Earth Sciences*, vol.7, no.7/8, p.999-1009.

Guo, P. (1989). *Personal communication.* Kuala Lumpur, Malayasia, PEPAS.

Gun, J.A.M. van der (1985). *Water resources of the Sadah area.* Delft, The Netherlands, Delft University of Technology, Unpublished main report WRAY-3.

Gun, J.A.M. van der (1986). 'High rates of groundwater abstraction in the Yemen Highlands'. In : *Proceedings of the 19th Congress of the Int. Assoc. Hydrogeologists.* Karlovy Vary 8, Czechoslovakia.

Handa, B.K., Goel, D.K., and Kumar, A. (1983). 'Pollution of natural waters by industrial waste effluents in some parts of North and Northwestern India'. In : *Asian Environment,* vol.5, no.4, p.13-19.

Hanson, B.D. (1985). *Water and sanitation technologies : a trainer's manual.* (Training Manual; no. T-32). Washington, DC, USA, Peace Corps.

Harrison, P. (1987). *The greening of Africa : breaking through in the battle for land and food.* UK, Paladin Books.

Hawerman, B., Naeslund, G. and Wilkinson, G.K. (1983). *Domestic water legislation : final report.* Stockholm, Sweden, SIDA.

Hemmings-Gaiphan, G.S. and Freitas, M. (1990). 'Health benefits of water and sanitation in San Antao, Cape Verde'. In : *Water Quality Bulletin*, vol.15, no.1, p.18-22.

Heynen, H.A. (1981). *Watervoorzienings- en rioleringsprojecten : verslag van een missie uitgevoerd ten behoeve van de Inspectie Ontwikkelingssamenwerking te velde.* The Hague, The Netherlands, Ministry of Foreign Affairs, Dirctorate for International Cooperation.

Hirschman, D.(1990). 'Malawi's 'captured' peasantry : an empirical analysis. In : *The Journal of Developing Areas,* vol.24, no.4, p.467-488.

Hofkes, E.H. and Visscher, J.T. (1986). *Artificial groundwater recharge for water supply of medium-size communities in developing countries.* (Occasional Paper; no.9). The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Hofkes, E.H., Huisman, L., Sundarsen, B.B., De Azevedo Netto, J.M. and Lanoix, J.N. (1986). *Small community water supplies.* (Technical Paper Series; no. 18). The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Holmes, J.R. (1984). *Managing solid wastes in developing countries*. Chichester, England, John Wiley.

Hoy, D.R. and Belisle, F.J. (1984). 'Environmental protection and economic development in Guatemala's Western Highlands'. In : *The Journal of Developing Areas*, vol.18, no.2, p.161-176.

Huisman, L. and Kop, H. (1986). 'Artificial recharge of ground-water'. In : *Nature and Resources*, vol.XXII, no.1&2, p.6-12.

Hubbs, S.A. (1985). *Understanding water supply and treatment for individual and small community systems*. Washington, DC, USA, Volunteers in Technical Assistance.

Hutton, L.G. and Lewis, W.J. (1980). 'Nitrate pollution of groundwater in Botswana'. In : Pickford, John and Ball, Susan (eds.). *Water and waste engineering in Africa : 6th WEDS Conference 24-28 March 1980 : proceedings*. Loughborough, UK, Loghbourough University of Technology, WEDS Group, p.112-115.

IDRC (1989). *Project summary of pollution load in the Msimbazi Stream (Tanzania)*. Ottawa, Canada, IRDC. Unpublished File 3-P-87-0173.

IRC and IDRC (1988). *Handpumps : issues and concepts in rural water supply programmes*. (Technical Paper Series; no. 25). The Hague, The Netherlands, IRC International Water and Sanitation Centre.

IWSA (1987). *Protection of resources : how to work in water supply*. (Booklet; no.1.7). London, UK, International Water Supply Association.

Jager, A.L. de (1989). *Village water reservoirs project, Tamale, Ghana : models for the prediction of soil erosion and silt sedimentation in artificial lakes in Northern Ghana in order to determine life time*. Utrecht, The Netherlands, SAWA.

Jensen, H. (1989). *Personal communication*. Copenhagen, Denmark, DANIDA.

Jordan, D.J. (1980). *Handbook of gravity-flow water systems*. Kathmandu, Nepal, UNICEF.

Kalbermatten, J.M., Julius, D.S., Gunnerson, C.G. and Mara, D.D. (1982). *Appropriate sanitation alternatives : a planning and design manual*. (World Bank Studies in Water Supply and Sanitation; no.2). Baltimore, USA, Johns Hopkins University Press.

Katko, T. (1989). *Personal communication*. Tampere, Finland, Tampere University of Technology.

Kauzeni, A.S. (1981). *Villagers' expectations and attitudes towards traditional and improved water supplies and pre-conditions for successful rural water development programmes : the case study of Rukwa region*. (Research Report; no. 50). Dar es Salaam, Tanzania, Bureau of Resources Assessment and Land Use Planning.

Kebede, H. (1978). *Improving village water supplies in Ethiopia : a case study of socio-economic implications*. Addis Ababa, Ethiopia, United Nations Economic Commission for Africa.

Khamala, C.P.M. (1977). 'Insects of medical and veterinary importance associated with water resources and some aspects of their control by water resource management'. In : Castelino, J.B. and Khamala, C.P.M. *The role of water resources in development proceedings of the 13th annual symposium of the East African Academy, September 1977*. Nairobi, Kenya, National Academy for Advancement of Arts and Science, p.130-135.
Klomberg, A. (1989). *Personal communication*. The Hague, The Netherlands,

SNV-Netherlands Organization for International Cooperation.

Koning, H.W. de (1987). *Setting environmental standards : guidelines for decision-making.* Geneva, Switzerland, World Health Organization.

Kop (1989). *Personal communication.* Delft, The Netherlands, Delft University of Technology, Vakgroep Gezondheidstechniek en Waterbeheering.

Lal, R. and Russell, E.W. (1981). *Tropical agricultural hydrology.* Chichester, England, John Wiley.

Lane, J. (1989). *Personal communication.* Katmandu, Nepal, Wateraid.

Langenegger, O. (1987). *Groundwater quality in rural areas of western Africa.* Abidjan, Ivory Coast, World Bank Regional Water and Sanitation Group.

Laugeri, L. (1990). *Legal issues in community water supply and wastewater disposal : paper presented at the Consultation on Legal Issues in Health Oriented Water Management, 24-28 September. Draft.* Geneva, Switzerland, World Health Organization.

Laugeri, L. and Hespanhol, I. (1990). *Waste water reuse : some management, economic and legal issues : working meeting on drinking water source protection, 30 June - 1 July, 1990.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Lee, M.D. (1990). *Drinking water source protection : problems, causes and needs : working meeting report.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Lee, M.D. and Visscher, J.T. (1990). *Water harvesting in five African countries.* (Occasional Paper Series; no. 14). The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Lewis, W.J., Foster, S.S.D. and Drasar, B.S. (1980a). *The risk of pollution by on-site sanitation in developing countries : a literature review.* (IRCWD Report; no.01/82). Duebendorf, Switzerland, International Reference Centre for Waste Disposal.

Lewis, W.J., Farr, J.L., and Foster, S.S.D. (1980b). 'The pollution hazard to village water supplies in eastern Botswana'. In : *Proceedings of the Institute of Civel Engineers.* Part2, vol.69.

Lewis, W.J., Foster, S.S.D., Read, G.H. and Schertenleib, R. (1981). 'The need for an integrated approach to water-supply and sanitation in developing countries'. In : *The Science of the Total Environment*, vol.21, p.53-59.

Lloyd, B. (1990). *Diagnostic surveillance for risk assessment, protection and improvement of drinking water sources in Indonesia : working meeting on drinking water source protection, 30 June - 1 July, 1990.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Lloyd, B. (1982). 'Water quality surveillance'. In : *Waterlines*, vol.1, no.2, p.19-23.

Lloyd, B. and Suyati, S. (1989). 'A pilot rural water surveillance project in Indonesia'. In : *Waterlines*, vol.7, no.3, p.10-13.

Lloyd, B. and Helmer, R. (1990). *Surveillance of drinking water quality in rural areas.* Harlow, UK, Longmans.

Maanen, van (1989). *Personal communication.* Amersfoort, The Netherlands, DHV.

Mandia (1987). *Personal communication.* District Water Engineer's Office, Songea Rural District, Ruvema Region, Tanzania.

Mgeni, A.S.M. (1988). 'Woodlands going up in smoke : tobacco and the environment in Tanzania'. In : *Development and Cooperation*, no.2, p.17-18.

Mishra, B.K. and Ramakrishnan, P.S. (1983). 'Slash and burn agriculture at higher elevations in north-east India : 1. sediment, water and nutrient losses'. In : *Agriculture and Environment*, vol.9, no.1, p.69-82.

Morgan, R.P.C. (1981). *Soil conservation.* Chichester, UK, John Wiley.

Morgan, R.P.C. (1985). *Soil erosion and conservation.* Soil Science Society of America.

Mosha, A.C. (1989). *Urban environment mismanagement in Tanzania : paper presented at the seminar on the environment in Tanzania, 23-25 October.* Dar es Salaam, Tanzania, Goethe Institute and Ardhi Institute.

Mowli, P.P. and Seshaiah, K. (1988). 'Nitrate contamination of groundwater in an unsewered town : a case-study of Tirupati'. In : *Asian Environment,* vol.10, no.1, p.23-26.

Myhrstad, J.A. and Haldorsen, O. (1984). 'Drinking water in developing countries : the minimum treatment philosophy : a case study'. In : *Aqua,* . no.2, p.86-90.

Nair, C. (1988). 'Bangkok's deteriorating groundwater: environmental issues'. In : *14th WEDC Conference : water and urban services in Asia and the Pacific : Kuala Lumpur, 11-15 April 1988* Loughborough, UK, Loughborough University of Technology, WEDC group, p.67-70.

Nakai, J. (1989). *Personal communication.* Nairobi, Kenya, UNEP.

Ngainayo, C.M. (1986). *Disposal of solid wastes in Moshi and Arusha towns, Tanzania.* (Water Supply and Sanitation Publication; no. 30). Tampere, Finland, Tampere University of Technology.

Nillsson, A. (1988). *Groundwater dams for small-scale water supply.* London, UK, Intermediate Technology Publications.

Norconsult, (1981). *Water master plans for Rukwa and Kigoma regions : interim report : part IV : selected working papers.* Hovik, Norway, Norconsult.

Nordberg, E. and Winblad, U. (1990). *Environmental hygiene in SIDA-supported programmes in Africa : review and recommendations.* Stockholm, Sweden, Swedish International Development Authority.

Nyangeri, E.E.N. (1986). *Rehabilitation of hand-dug wells and protected springs in Kisii, Kenya.* (Water Supply and Sanitation Publications; no. 29). Tampere, Finland, Tampere University of Technology.

Okun, D. (1990). 'Water reuse in developing countries'. In : *Water and Wastewater*, vol.5, no.1, p.13-21.

Okun, D.A. and Ernst, W.R. (1987). *Community piped water supply systems in developing countries : a planning manual.* (Technical Paper; no. 60). Washington, DC, USA, World Bank.

Perry, J.A. and Dixon, R.K. (1986). 'An interdisciplinary approach to community resource management : preliminary field test in Thailand'. In : *The Journal of Developing Areas*, vol.21, no.1, p.31-48.

Pickford, J. (1984). 'The solid waste problems of poor people in Third World cities'. In : Holmes, J.R. *Managing solid wastes in developing countries.* Chichester, England, John Wiley, p.29-45.

Poyet, P. and Detay, M. (1988). *Un système expert d'aide à l'implantation de forages en hydraulique villageoise.* (Rapports de recherche; no. 936). Le Chesnay, France, Institut National de Recherche en Informatique.

Raay, H. van, Laar, A. van de, Broek, J. van den, Bosscher, A., Lucasse, C. and Roux I. le (1980). *The environment and the Netherlands programme for bilateral development cooperation : a report commissioned by the Netherlands Minister for Development Cooperation.* The Hague, The Netherlands, Institute of Social Studies.

Rahman, A.F. (1987). *Groundwater pollution from on-site sanitation in Dhaka, Bangladesh.* Bangkok, Thailand, Asian Institute of Technology, MSc Thesis, no. EV-87-10.

Ram Bilas, Tripathi, B.D. and Singh Ranga, P.B. (1981). 'Problems of Ganga water pollution in Varanasi : a study of environmental planning'. In : *Proceedings of symposium on ecology and resource management in the tropics, Bhopal, India, 5 - 10 October.*

Reddy, T.V.K. (1987). 'Effects of distillery waste water discharges on rivers : a case study of Neeva River, Chittoor District, Andhra Pradesh, India'. In : *Asian Environment,* vol.9, no.2, p.20-22.

Roark, P. (1984). 'Women and water'. In : Bourne, P. (ed.). *Water and sanitation, economic and sociological perspectives.* Orlando, FL, USA, Academic Press, p.49-68.

Rogers, N. (1985). *Water sources and their protection : a guide to community water source protection and designs for a spring protection and well digging programme.* Oxford, UK, Oxfam.

Rushton, K.R. and Phadtare P.N. (1989). 'Artificial recharge pilot projects in Gujarat, India'. In : Sahuquillo, A., Andrew, J. and O'Donnell, T. *Proceedings of symposium on groundwater management : quantity and quality, Benidorm, Spain 2-5 October, 1989.* (IAHS Publication; no. 188). Wallingford, UK, International Association of Hydrological Sciences, p.533-545.

Sechu, L.M. (1986). *Drinking water quality control in Mtwara and Lindi Regions, Tanzania.* (Water Supply and Sanitation Publication Series; no. B. 20). Tampere, Finland, Tampere University of Technology.

Shiva, V. (1988). *Staying alive : women, ecology and development.* London, UK, Zed Books.

Shukla, B.V. (1984). 'Drinking water problem in coastal region of Saurashtra'. In : *Journal of the Indian Water Works Association*, vol.XVI, no.1, p.59-63.

SIDA, (1987). *Afya kutoka na usafi wa mazingira na maji. Mpango wa mafunzo kwa vikundi. Sehemu ya kwanza.* Hesawa Project (in Swahili).

Sinnarkar, S.N., Kesarwani, S.K. and Bhat, S.G. (1987). *River Ganga : an overview of environmental research.* Nagpur, India, NEERI.

Smet, J. (1989). *Personal communication.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Stanislawski, D. (1990). *Personal communication.* Dar es Salaam, Tanzania, UNDP/ILO Special Public Works Programme.

Strauss, M. (1989). *,Personal communication.* Duebendorf, Switzerland, IRCWD.

Sudan Council of Churches (1986). *Water and sanitation situation Munuki area/Juba, 1986 : survey.* Khartoum, Sudan, Sudan Council of Churches.

Sundaresan, B.B., Paramasivam, R., and Mhaisalkar, V.A. (1982). *Technology choice for rural water supply : paper presented at the Commonwealth Science Council Workshop on Rural Drinking Water Supply, 10-13 May, Madras.* Nagpur, India, NEERI.

Suresh Chandra and Krishna, G. (1983). 'Effect of tannery waste disposal on the quality of the River Ganga at Kanpur'. In : *Pollution Research,* vol.2, no.2, p.63-64.

Tripathi, B.D. and Sikandar, M. (1981). *Pollution load on Ganga water at Varanasi : proceedings of symposium on Ecology and Resource Management in the Tropics, Bhopal, India, 5 - 10 October.*

UN ACC Task Force on Rural Development, Panel on Monitoring and Evaluation (1984). *Guiding principles for the design and use of monitoring and evaluation in rural*

development projects and programmes. Rome, Italy, International Fund for Agricultural Development.

UNEP (undated). *Asian environmental resources for development : part I : Asian Environment*, Nairobi, Kenya, UNEP.

UNEP (1986). *The state of the environment : environment and health.* Nairobi, Kenya, UNEP.

UNEP (1989). *The state of the world environment, 1989.* Nairobi, Kenya, UNEP.

UNIDO (1983). *Formulation of pesticides in developing countries.* New York, NY, USA, UNIDO.

Vos, J. (1989). *Personal communication.* Wageningen, The Netherlands, ILRI.

Wandiga, S.O. (1977). 'Analysis of chemical pollution in some Kenyan water systems with special reference to Lake Nakuru'. In : Castelino, J.B. and Khamala, C.P.M. *The role of water resources in development : proceedings of the 13th annual symposium of the East African Academy, September 1977.* Nairoby, Kenya, National Academy for Advancement of Arts and Sciences. p120-123.

Ward, C.F. (1989). 'Groundwater quality monitoring in relation to on-site sanitation in developing countries'. In : *Journal of the Institute of Water and Environmental Management*, no.3, p.295-302.

Ward, C.F. and Foster, S.S.D. (1981). *On-site sanitation and groundwater quality : a methodology for monitoring.* Duebendorf, Switzerland, International Reference Centre for Waste Disposal.

Wellings, F.M., Lewis, A.L., Mountain, C.W. and Pierce, L.V. (1975). 'Demonstration of virus in groundwater after effluent discharge onto soil'. In : *Applied Microbiology*, vol.29, no.6, p.751-757.

Wenner, C.G. (1981). *Soil conservation in Kenya.* Nairobi, Kenya, Soil Conservation Extension Unit, Ministry of Agriculture.

WHO (1968). *Research into environmental pollution.* (Technical Report Series; no. 406). Geneva, Switzerland, World Health Organization.

WHO (1985a). *Drinking water quality control in small community supplies : guidelines for drinking water quality : vol.3.* Geneva, Switzerland, World Health Organization.

WHO (1985b). *Environmental pollution control in relation to development.* (Technical Report Series; no. 718). Geneva, Switzerland, World Health Organization.

WHO, (1985c). *Safe use of pesticides.* (Technical Report Series; no. 720). Geneva, Switzerland, World Health Organization.

WHO, (1989). *UNEP/WHO project on control of drinking water quality in rural areas : report of a review meeting at the WHO Collaborating Centre for the Protection of Drinking*

Water Quality and Human Health, Robens Institute, Guiltford, 31 October to 4 November 1988. Geneva, Switzerland, World Health Organization.

WHO (1990). *Proceedings of the Meeting of the Operation and Maintenance Working Group, vol. I : report of the meeting.* WHO/CWS/90.14. Geneva, Switzerland, World Health Organization.

Wihuri, H. (1989). *Personal communication.* Helsinki, Finland, FINNIDA.

Wijk-Sijbesma, C. van (1984). *Participation and education in community water supply and sanitation programmes : a literature review.* (Technical Paper Series; no. 12). The Hague, The Netherland, IRC International Water and Sanitation Centre.

Wijk-Sijbesma, C. van (1985). *Participation of women in water supply and sanitation : roles and realities.* (Technical Paper Series; no. 22). The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Wijk-Sijbesma, C. van (1989). *Personal communication.* The Hague, The Netherlands, IRC International Water and Sanitation Centre.

Winblad, U. and Kilama, W. (1985). *HESAWA sanitation study.* Stockholm, Sweden, SIDA.

Woldeye (1990). *Personal communication.* Catholic Diocese of Nakuru, Kenya.

World Commission on Environment and Development (1987). *Our common future.* Oxford, UK, Oxford University Press.

Water Research Centre (1989). *Disinfection of rural and small-community water supplies : manual for design and operation.* Medmenham, UK, Water Research Centre.