UNIVERSITY OF CAMBRIDGE

Institute for Manufacturing

Water Supply and Sanitation in India

2002 MET II Long Project

Tristan Fletcher

Contents

Summary

This report represents information gathered from a five-week expedition to India, investigating the problems associated with water supply and sanitation and how various organisations find solutions to these problems.

The main problems associated with water and sanitation are:

- Lack of water and sanitation availability, both in rural and urban areas
- Poor water quality due to chemical and bacterial contamination
- Low cultural priority traditionally given to hygiene
- Lack of education and hence awareness concerning sanitation
- The poverty trap which compounds all these problems

The organisations visited which are concerned with tackling these issues can be classed as being:

- Strategic, high level players

through to more

- Low level, hands-on engineering NGO's,

backed up technologically by

- Scientifically minded research organisations.

It appears that water quantity is, on the whole, more of a problem than water quality – it not being sensible to try to solve the problem of the latter without first sorting out the former.

In many cases solutions have been found by NGO's operating in the sector. These are most successful when an integrated approach is taken to tackle poverty, hygiene and water supply issues simultaneously. Furthermore, community involvement right from the beginning of any project is also very important if it is to be sustainable and continue when the NGO is no longer present. These are lessons which the Government has learnt from the many NGOs in the sector after making mistakes itself.

While there are still vast social and economical disparities within India there will continue to be inequality in terms of water supply, sanitation and hence health throughout the country.

Approach

This project has evolved from a product idea for purifying water[1]. This water purifier was to function using a renewable and independent power supply and be robust and inexpensive – all characteristics rendering it applicable in the developing world. Having conducted experiments to prove the technology and created rough conceptual designs for the product it was decided to investigate the context within which such a water purifier could be used. It was with this aim in mind that a trip to India was organised: to investigate water supply and its requirements in a developing world environment with particular reference to the efficacy of the product design.

Contact was made with various organisations, both governmental and non-governmental (NGO's), before arrival in India. However, once in the country each meeting yielded further contacts and hence meetings. It became increasingly obvious that it would be inappropriate to consider water supply without also investigating sanitation. Furthermore, it was also progressively more evident that a great deal of insight would be needed into the environment within which I wished my water purifier product to operate. The project therefore moved from a technology and marketing focus to a much more strategically and even politically orientated view to investigate this context.

This report draws together information gathered during a five week excursion around the Indian sub-continent visiting the various organisations involved with water supply and sanitation. In some instances I was also able to visit projects that the organisations were involved in out in the field and gain first hand experience of the issues involved with my project's topic. In others I held long discussions and obtained relevant documentation.

The organisations visited and described here represent different levels of operation, from top-down strategic, advocacy organisations to more technological, hands-on NGO's operating at the village level. India is a huge country and hence contains an immense amount of diverse organisations concerned with water supply and sanitation. The few organisations described here are the ones I feel most important at their level of operation. They are: the Department for International Development (DFID), the UN Children's Fund (UNICEF), the Centre for Science and Environment (CSE), the Organisation for Rural Sustainable and Environmental Development (ORSED), WaterAid, the Society for Community Organisation and People's Education (SCOPE and the Industrial Toxicology Research Centre (ITRC).

I decided that the best way to compile the final report was to put all the extracted information in a framework first describing what the main problems associated with water supply/sanitation are in India and then describing how the different organisations go about finding solutions to these problems. These organisations are depicted in order of decreasing strategic level, i.e. the high level, strategic bodies first and the village level, hands-on NGO's last.

[1] See Appendix A

Global Issues

Of the many essential elements for human existence, water is of the greatest importance. Over two-thirds of the human body is constituted of water. No form of life, be it plant, animal or human, can exist without water. Civilisations have evolved and developed around water bodies as most human activities, including agriculture and industry, depend on water. At the same time water is also a source of conflict and problems.

Over 70 per cent of the Earth is covered with water. Nearly 97 per cent of the world's water is salty or otherwise undrinkable. Another two per cent is locked up in ice caps and glaciers. That leaves just one per cent for all humanity's needs – all its agricultural, residential, manufacturing, community and personal needs.

About one-fifth of the world's population lacks access to safe drinking water, and with present consumption patterns two out of every three persons on the earth will live in water-stressed conditions by 2025. Pollution, scarcity of water resources and climate change will be the major emerging issues in the next century.[2] Water pollution adds enormously to existing problems of water scarcity by removing large volumes of water from the available supply. The pollution threat is particularly serious when it affects ground water supplies, where contamination is slow to dilute and purification measures are costly.

Indian Overview

Most of the rainfall in India takes place under the influence of South West monsoon between June and September. Rainfall in India shows great variations, unequal seasonal distribution, still more unequal geographical distribution, and frequent departures from the normal. India is also criss-crossed by a large number of small and big rivers.

Table 1: National Water Resources[3]	*Quantity (cu km)*
Annual Precipitation Volume (inc. snowfall)	4000
Average Annual Potential flow in Rivers	1869
Estimated Utilisable Water Resources:	
Surface Water Resources	690
Ground Water Resources	432
Total	**1122**

In the five decades since independence, India has witnessed phenomenal development of water resources and has, in the main, successfully met the demand of water for many of the diverse uses in the country. Investments made during the last fifty years

[2] Global Environment Outlook 2000: Environment Program's Millennium Report, *UN* (2000)
[3] The Water and Environmental Sanitation Sector in India, *DFID India* (2001)

in water related infrastructure in the country have resulted in rapid expansion in the urban, energy and industrial sectors. Infrastructure for safe drinking water has been provided to about 85 per cent of India's urban and rural population.[4] However, there remain significant challenges in providing sustainable services, especially for the poorest and hard to reach.

India's irrigated agriculture sector has been fundamental to its economic development and poverty alleviation. The rapid expansion of irrigation and drainage infrastructure has been one of India's major achievements. From 1951 to 1997, gross irrigated areas expanded four-fold, from 23 million ha to 90 million ha.[5] However, this achievement has been at the cost of groundwater depletion, water-logging and in increasing salinity levels affecting large areas.

With the rapid population growth since independence, water is becoming an increasingly scarce resource in the country. Despite this, water continues to be used inefficiently on a daily basis in all sectors. At independence, the population was less than 400 million and per capita water availability over 5,000 cubic meters per year (m^3/cap/yr). Today, fifty years later, the population has grown to 1 billion and water availability has fallen to hardly more than 2,000 (m^3/cap/yr).[6]

India's finite and fragile water resources are stressed and depleting, while sector demands (including drinking water, industry, agriculture, and others) are growing rapidly in line with urbanisation, population increases, rising incomes and industrial growth. This has resulted in declining per capita availability and deteriorating quality. Inter-sector allocations, planning, and management of increasingly fragile water resources have thus emerged as a major challenge before the nation.

Problems

One can break up the main problems associated with water supply into two categories: those of quantity and those of quality.

Quantity
To describe how accessible a water source is to a person one needs to make several definitions:[7]

- A usage of 40 litres per capita per day (lpcd) of safe drinking water for humans.
- 30 lpcd for their livestock.
- The water source exists within a distance of 1.6km in plains or 100m elevation difference in hills.
- Safe water is defined as free from bacteria carrying water borne disease and chemical contamination.

[4] Inter-sectoral Water Allocation, Planning & Management: India Water Resources Management, *World Bank & Ministry of Water Resources, Government of India* (1999)
[5] The Irrigation Sector: India Water Resources Management, *World Bank & Ministry of Water Resources, Government of India* (1999)
[6] ibid.
[7] Guidelines on Accelerated Rural Water Supply Programme, *Department of Drinking Water Supply, Ministry of Rural Development, Government of India* (2000)

Rural

Using these definitions the current level of coverage of drinking water supply amongst India's rural inhabitants is 86% 'fully covered', 12% 'partially covered' and 2%'not covered'.[8]

These shortage problems persist even though there is a backbone of at least 3 million boreholes with hand-pumps and over 150,000 piped water supplies throughout the country. In fact, investments in the water supply and sanitation sector presently constitute about 3% of the national budget, with 60% of this being earmarked for rural areas.[9]

Hand-pumps and bore-wells are the primary source of drinking water, used by 42 % of the population.[10] The traditional open well[11] serves about 27 % and 5 % of people still collect drinking water from exposed sources such as rivers, lakes and ponds. In many parts of the country, however, an open well is still the main source of water.[12]

As in most developing countries, in India it is mostly women who are responsible for collecting water and managing its household use. A 1989 Knowledge, Attitudes and Practices (KAP) study showed that women in rural India spent between one and four hours a day collecting water. [13] They make an average of nine trips to a water source, collecting 192 litres of water for an average six-member household (32 lpcd). Carrying water is hard physical labour, studies show that a reduction of three hour's work fetching water resulted in a saving of 350 kilo calories. Bringing water closer, therefore, has important nutritional and other health benefits, especially for the malnourished.

However, national guidelines and investments in the rural water supply and sanitation sector, which have traditionally focused on extending coverage to rural areas, neglected to ensure that the quality of services to rural areas remained adequate. The Accelerated Rural Water Supply Programme (ARWSP)[14] was totally government run without the participation of stakeholders. This created a scenario in which users considered water a free commodity with the government having the entire responsibility for running the operation. This has stifled the development of more efficient, low cost options for service delivery and denied users as consumers the opportunity to demand better services.

Furthermore, due to the lack of consumer participation, users did not feel they owned their water extraction equipment and hence did not adequately maintain it. When maintenance was needed, government mechanics would have to be called out. These mechanics would be covering hundreds of villages each, so a broken pump could have to wait months to be fixed, leaving without water the community dependent on its use.

---

8 Rapid Assessment of Government Subsidy to Rural Water Supply in India, *World Bank Water and Sanitation Program* (1998)
9 The Water and Environmental Sanitation Sector in India, *DFID India* (2001)
10 See photo in Appendix C.6
11 See photo in Appendix C.5
12 WATSAN India 2000, *UNICEF* (2000)
13 ibid.
14 Guidelines on Accelerated Rural Water Supply Programme, *Department of Drinking Water Supply, Ministry of Rural Development, Government of India* (2000)

Often a water supply may only be available to the better off or the higher castes in a village who either own the land on which the supply is based or pay for its upkeep somehow. It is up to the discretion of these people to allow others to use the water and in many cases this does not happen – an example of the disparity between the rich and poor in terms of water access.

A further issue is that with the electrically operated pumps, the very unreliable electricity source available in rural areas means that water is only sporadically made available. Farmers, who often use electrically pumped water supplies for irrigation are given this electricity and hence the water free. This means that there is no incentive for them to use their water economically, for example using drip irrigation instead of pumped irrigation, and the rest of the community depending on the water supply suffer.

Another issue is that during the monsoon, there is a huge amount of rainfall, with some areas of the country receiving as much as 32 inches of rain a month. However, as the rainfall occurs over such a concentrated period, a large majority of it does not have time to seep into the water table and much water is lost either in run-off (specially in coastal areas) or in evaporation.

Urban

The situation is not much improved in the piped water supplies of the urban areas. One study ranked Delhi, Mumbai and Chennai among the four worst cities in Asia in terms of water availability.[15]

Table 2: Water Supply Coverage in India's Cities

City	**Coverage (%)**	**Availability (Hours)**	**Consumption (Ltrs/Cap.)**	**Demand (Mill. Ltrs per day)**	**Supply (Mill. Ltrs per day)**
Bangalore	70	2.5	105	970	680
Calcutta	66	10	209	1,125	1,125
Chennai	97	4	80	600	400
Delhi	86	4	200	3,600	2,925
Mumbai	100	5	178	3,200	2,700

In areas where demand is greatly exceeding supply, the water table is falling as much as a few metres a year.

There are many reasons for the poor state of urban water supply. A great deal of the piped water supplies are subject to heavy losses through leakage. Furthermore, lots of the supplies have water tapped off them illegally so that the water does not reach the intended consumer. These losses mean than up to 55% of water in some cities is unaccounted for.[16]

[15] *Asian Development Bank* (1997)
[16] Water: Midsummer Nightmare, *Outlook Magazine, India* (3/6/2002)

Another problem is that the owner of a building, and hence a plot of land, is allowed to extract water from anywhere on or below that land. This means that the discrepancy that already exists between the rich and poor is exacerbated in terms of water supply as owners of large plots of lands have access to greater bodies of water, and as the water is free to them (apart from the cost of its extraction) they may use it very inefficiently.

The water shortages in the cities has also spawned water purification industries and companies producing bottled water, many of them unlicensed and thus not guaranteed to produce safe drinking water. In Delhi the government water board, the Delhi Jal Board (DJB), has identified at least 15 such illegal plants operating in the city.[17] This means that people who think they are drinking clean water may in fact be being mislead and hence are even more likely to be affected by water-borne diseases.

Quality
Unregulated and overexploited ground water extraction has resulted in groundwater depletion and the resultant decline in water quality. Furthermore, excess fluoride, arsenic, nitrate, iron and salinity are causing health hazards for large numbers of people. It is estimated that 5% of all water supplies throughout the country are affected by water quality.[18]

Table 3: Habitations Effected by Water Quality Problems (1999)[19]

Nature of Quality Problem	**No. of affected habitations**
Excess Iron	138,670
Excess Fluoride	36,988
Excess Salinity	32,597
Excess Nitrate	4,003
Excess Arsenic	3,553
Other Reasons	1,400
Total	**217,211**

Though excess fluoride and arsenic are not the most common forms of poor quality, their effects are the most insidious and therefore represent the problems focused on here.

Arsenic
Contamination of ground water used for drinking purposes with arsenic has emerged as a serious public health threat in recent years in India. The main affected area is West Bengal and more recently Madhya Pradesh. The total population at risk from arsenic contaminated water could be as high as 1.5 million.

Arsenic is a naturally occurring element, which is widely distributed throughout the earth's crust. It is introduced into water through the dissolution of minerals and ores,

[17] ibid.
[18] Rural Drinking Water Supply Programme, *Rajiv Gandhi National Drinking Water Mission* (2000)
[19] ibid.

from industrial effluents and from atmospheric depositions. Elevated concentrations of arsenic in groundwater in some areas are a result of erosion from local rocks.

Chronic exposure to arsenic results in ‘arsenicosis’: hyper-pigmentation, depigmentation, keratosis and peripheral vascular disorders are the most commonly reported symptoms. Skin cancer and a number of internal cancers can also result. Cardiovascular and neurological diseases have also been found to be linked to arsenic ingestion.

Arsenic poisoning takes a heavy social toll – making many people suffer silently for fear of ridicule or stigmatisation. There are reports of girls not being able to marry because of arsenicosis. With accompanying morbidity, its economic impact on people’s livelihood too remains unknown.

In 1997, the World Health Organisation acknowledged that arsenic drinking water was a ‘major public health issue’ in the subcontinent, which would be dealt with on an ‘emergency basis’. The best remedial action for controlling this impending catastrophe is prevention of further exposure by providing arsenic safe drinking water to the populations at risk.

Fluorosis

Fluorosis is caused by ingestion of excess fluoride over a long period. It affects multiple tissues, organs and systems of the body, and results in a variety of clinical manifestations, culminating in a crippling condition and/or damaged and discoloured teeth.

Dental fluorosis, which affects children, sets in if the foetus, infant or child is exposed to excess fluoride during the period when its teeth are developing. Persons with fully developed teeth will not be affected by dental fluorosis, even if they are exposed to fluoride. Skeletal fluorosis and non-skeletal (soft tissue) fluorosis affect people of all ages. The damage caused due to dental and skeletal fluorosis is irreversible. Only non-skeletal fluorosis can be reversed. Dental and skeletal fluorosis have no treatment or cure. Prevention is the only solution, provided the disease is detected in the early stages.

The main occurrence of fluorine in rocks is in the form of fluoride-bearing minerals like fluorite and fluoroapatite. India has among the largest resources of these minerals. In such areas, ground water drawn through wells, hand-pumps and especially tube wells, is likely to contain excess fluoride due to the dissolution of fluoride from fluoride bearing minerals. Therefore, these areas are generally endemic.

The problem of excess fluoride in ground water was detected in many states of India as early as the 1930s. Till 1999, as many as 17 states had been identified with the problem of excess fluoride in ground water sources.[20] Rajasthan and Andhra Pradesh are the most severely affected states. Rural populations, which depend mainly on groundwater for their drinking water supply are the worst affected. Vulnerability to

[20] Excess fluoride concentration is defined as greater than 1.5mg/litre concentration by the WHO.

fluorosis is higher if the nutritional status is poor – malnourished children or lactating mothers are especially vulnerable.

An estimated 66 million people are at risk from Fluorosis in India.[21]

Microbiological Contamination
When surface water is used as a supply it is often contaminated with harmful microbial pathogens. These are usually in the form of faecal choliforms where animals and sometimes people have excreted into the water supply that is being used for drinking. Diseases such as diarrhoea, dysentery, typhoid, cholera and hepatitis are caused by consuming water contaminated in this manner. With increased provision of biologically safe drinking water, mortality rates among children under five have declined from 236 per 1000 in 1960 to 105 in 1998. However, half a million children under five still die in India due to water-borne diseases.[22]

In some circumstances, communities partially filter water to remove any visually noticeable sediment but leave the more dangerous microbial contaminants intact. For example locally available *nirmali (Strychnos potatorum)* seeds can be rubbed in a pot containing turbid water, the chemical these seeds release causes the dirty particles in the water to coagulate together and sink to the bottom of the pot. This makes the water look clean, as if it came from a safe supply, and hence lulls users into a false sense of security concerning the purity of the water they drink.

Sanitation

Population coverage in rural areas by sanitary latrines is at about 16% and overall in the country coverage is about 48%.[23] Most people in rural India defecate outdoors, near the village itself or in the fields. Some people believe it is more hygienic than using a latrine because excreta is deposited away from their homes. However, the majority of people who defecate outside do not cover or dispose of their excreta. This causes serious problems in the rainy season.

In densely populated rural areas the lack of privacy and the need to walk long distances to find a suitable spot to defecate are also a recognisable problem. It is difficult to defecate outdoors during the rainy season or at night. Nevertheless, many women must go early in the morning before it is light or wait till night time to urinate or defecate to ensure privacy. Some women avoid drinking during the day, even in the scorching summer months, because they have no place to urinate in privacy.

Furthermore, it is fair to say that sanitation is not really a cultural priority in India. Even when facilities exist for improved hygiene they are not always taken advantage of. Studies have shown that about two-thirds of the rural population think that exposed excreta are harmful to health, yet less than a quarter understands the faecal-oral danger. Most people think that children's faeces are not harmful, which explains

[21] Mitigating Fluorosis through Safe Drinking Water, *UNICEF*
[22] WATSAN India 2000, *UNICEF* (2000)
[23] Rapid Assessment of Government Subsidy to Rural Water Supply in India, *World Bank Water and Sanitation Program* (1998)

why they are often disposed of close to the household. Most people in India wash their hands after defecating, although it is estimated that about one-quarter wash without any form of soap.[24]

The problem is therefore not just of a lack of latrines and soap but also of creating demand for them - educating people in the importance of washing their hands, of using latrines etc.

[24] WATSAN India 2000, *UNICEF* (2000)

The Government's Role

Obviously the organisation with the most responsibility and the largest budget with respect to water supply and sanitation is the Indian Government. Under the Indian Constitution, drinking water comes within the domain of the state governments (provincial governments). The 73rd constitutional amendment mandates that responsibility for drinking water and sanitation service should be with local governments. Various states in India are at different stages of giving effect to this constitutional mandate.

Sector Reform
The Sector Reform Project and the World Bank funded Rural Water Supply and Environmental Sanitation projects are helping the states to move in this direction. This programme is based on the subsidiary principle, and recognises that services should be delivered by the lowest appropriate level.

Its priorities are:

- Supporting effective and inclusive decentralisation by empowering local communities in rural areas.
- Building and implementing consensus on key policy and institutional reforms.
- Funding investments in rural infrastructure linked to reforms in service delivery.
- Using NGO's and alternative service providers.
- Targeting the poorest and most vulnerable groups.
- A focus on village level capacity building.
- The maintenance of an integrated approach to water supply, sanitation and hygiene promotion.
- A requirement for partial capital cost recovery and full operations and maintenance financing by users.
- The promotion of groundwater conservation and rainwater harvesting.

The programme challenges the previously described ARWSP traditional top-down model of delivery of water supply services by state government owned engineering departments and agencies. It forms a reaction to the previous method of providing schemes that are often unsuited to meeting the requirements of those whom they are designed to serve and are therefore unsustainable.

The Role of NGO's and Donors

Donor development organisations approach the issue of water from several inter related and overlapping viewpoints. The various approaches focus on particular components and cover a large area or adopt a more incorporated approach and focus on a small area. However, the trend in these organisations is to have a more integrated approach. The movement is from project-based support to programme based support. Within programme support, the movement is from sub areas (drinking water, irrigation, watershed development, etc.) to a holistic management of water resources.

All the programmes are aligned to or complement the Government of India programmes and schemes in water resources. Almost all the programmes place an overwhelming emphasis on people's participation.

Department for International Development (DFID)

DFID operates mainly in a strategic manner, addressing all the problems associated with water supply and sanitation, as well as other related issues, at a high level. It works bilaterally, government to government, in an advocacy role. It supplies money for training government staff to deal with water supply issues at a strategic level. It also raises awareness of water related issues trough organisations such as UNICEF and does operate at lower levels through 'Water Shed' programmes.

DFID makes agreements with the government concerning its budgetary aid and then puts the money straight into the states. It audits what this money has been spent on, insuring that isn't siphoned off through corruption, but otherwise has little control once the money is donated.

In India, DFID's main philosophy is to help people to find long-term solutions to poverty. The provision of the basic services of water, sanitation, health and education are seen as key elements in the elimination of poverty. DFID prioritises its work towards:

- Strengthening the capacity of the Indian Government to develop and implement pro-poor policies; and strengthening the accountability of this government to those it represents.

- Promoting increased investment in education, health and clean water.

- Supporting programmes which help poor people improve their own livelihoods, and which give poor people a bigger say in decisions affecting their lives.

- Promoting sustainable management of the earth's resources.

Water and sanitation form an integral part of DFID India's state programmes. Within these state programmes, priorities in water and sanitation focus on the need to:

- Recognise water as both a social and economic good.
- Increase support for programmes that bring clean, safe water to poor people in a sustainable manner.
- Encourage all those who have an interest in its allocation and use, particularly women, to be involved in decision-making and management of water resources.
- Adopt a comprehensive framework that takes into account impacts of water use on all aspects of social and economic development.

The main focus of DFID India's work in water and sanitation is:

- Promoting the adoption of a demand-based approach which is participatory and based on offering appropriate technology choices.
- Promoting the principles of cost recovery for operation and maintenance, and cost sharing for capital works.
- Promoting the importance of improving the quality of both drinking water supply and waste-water discharges.
- Working with project partners to increase understanding of the need for integrated water resources management.
- Working with project partners to bring about institutional reform which makes services providers more efficient, more accountable and more responsive.

In 2000, India received £106 million of aid from DFID, making it the largest recipient of bilateral assistance from the department.[25]

United Nations Children's Fund (UNICEF)

UNICEF has been operating in India since 1966 - longer than any other NGO. It allocates about $5 million per year in 'General Resources' and $7 million in 'Supplementary Funds' to carry out its various projects in India.[26]

Water Supply
UNICEF were originally involved with drilling boreholes for local water supplies: developing local capacity to drill water locally and encouraging local manufacture of the drill parts. As these drilling services became available, irrigation became possible.

[25] Development Counts: Selected Statistics on International Development, *DFID/Office of National Statistics* (2001)
[26] The Water and Environmental Sanitation Sector in India, *DFID India* (2001)

UNICEF helped solve the problem of hand-pump maintenance by developing the concept of the "hand-pump caretaker", a person to act as a link between village pump users and block level authorities. This was a very important step on the way to community participation in the rural water supply programme – it was also the point at which women began to be brought actively into the programme.

A three-tier maintenance system introduced in 1976 is still in use in many parts of the country today. It consists of a mobile repair team (a truck with a mechanic and helpers) at district level, responsible for 500 pumps; a trained mechanic at block level, responsible for 100 pumps; and a hand-pump caretaker at village level, responsible for one pump.

Sanitation

UNICEF's focus has now changed from drought prevention to education on health and sanitation topics. The Indian Government and UNICEF collaborate to work towards the goal of assuring every child the right to safe drinking water and a clean environment. The collaboration is instituting social mobilisation and behavioural change, using schools as important centres for creating new norms of hygiene in the community.

UNICEF has been working in sanitation since late 1982, when it assisted three NGO's in setting up rural sanitation schemes in West Bengal and Orissa. Hygiene awareness was an integral part of the programme even then, for it was recognised that it was cheaper and easier to change unsanitary practices – such as allowing garbage, cow dung and stagnant water to collect near a house-hold – than to build a latrine.

As part of this programme, UNICEF produced a number of educational materials on the relationship between water, dirt and health for use by health educators, community development officers, teachers and *anganwadi* (mother/child centre) workers.

UNICEF's Central Rural Sanitation Programme (CRSP) promotes sanitation as a seven-component package, focusing on:

- Handling of drinking water
- Village sanitation
- Personal hygiene
- Home sanitation and food hygiene
- Disposal of human excreta
- Disposal of garbage and animal excreta
- Disposal of waste water

More recently school sanitation projects have been instigated to develop sanitary habits among school children, particularly in the primary grades. Teachers and students are focal points for promoting a sanitation package to the student's household and to the community, allowing not just child-to-child relaying of sanitation messages, but child-to-parent as well. Hygiene education is becoming an integral part of the school curriculum.

One very notable success of UNICEF's sanitation work, in collaboration with the Indian Government, is the eradication of Guinea worm from 34,000 cases in 1984 to the present day where almost no cases are reported .[27]

Arsenic Mitigation
In August 1999 UNICEF and the government of West Bengal initiated a comprehensive $3 million joint plan of action with the support of DFID for dealing with the unfolding arsenic situation in the state.

Under the plan, each community drinking water source is tested bi-annually using field test kits in the affected districts. The owners of private sources are also encouraged to get their sources tested at a nominal cost decided by the community. The objective is to progressively cover all drinking water sources, both private and public, in the affected districts.

All community sources testing negative are re-tested for arsenic in a laboratory to ensure complete reliability and correctness of test results. Only those drinking water sources that have arsenic less than 0.05 ml/lit are marked as safe.

In the villages where most or all of the hand-pumps yield excess arsenic, the project provides hand-pumps which are installed on extra deep wells tapping aquifers free of excess arsenic. These sources are also tested for arsenic. Where no safe aquifers can be tapped, horizontal-roughing/slow sand filters are provided. In villages that have many sources with excess arsenic, home-based arsenic removal filters are introduced. In some cases arsenic removal filters are attached directly to hand-pumps.

Awareness is generated amongst people in affected areas about adverse health affects of arsenic and preventative measures. People are advised to drink water only from certified safe sources. Training of personnel in the use of the field test kits and the filters also constitutes a major part of the programme.

Fluorosis Mitigation
UNICEF works closely with the Government of India and other sector partners to assess fluoride level safety conditions and implement mitigation programmes. Some of the key areas of intervention have been in the strengthening of water-quality monitoring systems, facilitating research and development of household water treatment systems and advocating alternative water supplies when necessary. Education is key to UNICEF's strategy, with emphasis on grass-root implementation of water safety procedures.

Some of the initiatives include:

[27] WATSAN India 2000, *UNICEF* (2000)

- Strengthening district water-quality laboratories by supplying Ion meters and training water analysts

- Developing improved fluoride field test kits and domestic defluoridation kits[28] (using activated aluminium)

- Enhancing local manufacturing capacity to manufacture these kits

DFID – UNICEF Partnership

As mentioned before, there is considerable overlap between organisations operating in the water supply and sanitation sector in India. This overlap often leads to collaboration between the bodies concerned, a notable one being the partnership between DFID and UNICEF. This is characterised by:

- Joint workshops – UNICEF has participated in a series of workshops on human resource development in the sector organised by DFID.

- Programme development – DFID collaborates on the evaluation of various UNICEF projects and regularly consults UNICEF on its various development strategies

- Country-level partnership – DFID and UNICEF hold meetings to 'develop a memorandum of understanding, which captures the partnership in the format of a logical framework'.[29]

- Joint reviews – DFID participates in all quarterly and annual reviews of UNICEF's Sanitation, Hygiene and Water Supply Project.

- Support for drought mitigation – DFID and UNICEF have worked closely to contribute to emergency relief, most notably for drought mitigation in Madhya Pradesh and Rajasthan.

- High Level Visits – Claire Short, British Minister for International Development, has visited UNICEF twice in India.

Organisation for Rural Sustainable and Environmental Development (ORSED)

ORSED is a small NGO based in the town of Pondicherry in Tamil Nadu. It is mainly concerned with improving village competencies in terms of the maintenance of local water 'tanks'. Tamil Nadu has very concentrated rainfall during the monsoon and much of this rain is lost in run-off to the sea. ORSED is encouraging the usage of large reservoirs to hold and contain this water so that it can be stored and used

---

[28] See Appendix B.1 and B.2
[29] Child's Environment: Sanitation, Hygiene and Water Supply Project, *UNICEF* (1998)

throughout the year. Many of these large reservoirs have existed in the area for a long time but have a reduced capacity due to silting and the growth of vegetation in the reservoir basins when dry. ORSED's role is to train the users of these 'tanks' to maintain them to ensure that they are maximising their capacity. A typical reservoir starts filling in July and is completely full by the end of September, to be gradually emptied again by the end of April.

First ORSED does a survey of the empty reservoir, and estimates how much it will cost in labour and materials to maximise the tank's capacity.[30] ORSED then organises a meeting with a previously formed committee from the village who will be using this tank.[31] This committee will be composed of representatives of all the different castes and social groups within the village. At this meeting ORSED will discuss the estimated cost for the maintenance of the tank and ask the village to pay 30% of the cost, the other 70% being born by ORSED. A typical fee is of the order of $10,000 in total. Asking the users to pay towards the maintenance ensures that they take an interest in what is going on. Once the initial maintenance has been done, ORSED will start to train members of the committee to do it themselves so that the maintenance is sustainable.

WaterAid

WaterAid has been supporting water and sanitation projects in India since 1985. In 1992 it opened a South Indian Office in Tiruchirappalli, Tamil Nadu. An annual budget of £0.5 million currently supports projects run by over 100 partner NGO's in five states - Tamil Nadu, Andhra Pradesh, Maharashtra, Orissa and Karnataka and there are plans to expand this.

Community Development

Project work reflects WaterAid India's overall strategy, integrating water supply, sanitation, and hygiene education, and introducing appropriate technologies within a framework of community management.

WaterAid operates in schools giving education on sanitation[32]; it creates demand and then implements a response to this demand, e.g. shows why latrines are important and then builds some. In schools, WaterAid forms committees and parent-teacher associations – working bottom-up. All the knowledge and hence power is slowly transferred to the teachers and the process is thus sustainable. Furthermore, the children are encouraged to go to other villages and spread the word as ambassadors of hygiene.

One method that WaterAid has employed to encourage usage of latrines amongst children is to develop Child Friendly Toilets (CFTs)[33]. These are aimed at 'providing

[30] See photo in Appendix C.2
[31] See photo in Appendix C.1
[32] See photo in Appendix B.3
[33] See photo in Appendix C.7

a safe and friendly atmosphere to the children for defecation'[34] and consist of ten seats arranged in two rows over a raised platform in an un-enclosed structure. Colourful paintings adorn the sides of the CFTs explaining how to use the latrines and to wash one's hands afterwards. Usage of CFTs has been reported as being as high as 90% in some of the slums in which the scheme has been implemented, with a resulting reduction of diarrhoea cases amongst children from 73% to 10%.[35]

At the village level Community Based Organisations (CBO's) are also formed and households and families are taught about hygiene. These committees become responsible for all the maintenance and repair problems associated with their water supply and sanitation needs. Federations of 10 or more CBO's each have a stockpile of spare parts and tools which they lend out when maintenance is needed.

A typical implementation plan involves first educating people about how important hygiene/sanitation is, and then a team of women is put together to plan and manage (Self Managed Team) the construction of the latrines.[36] Women are favoured in such a role as they are thought to be less greedy and selfish in their usage of the power and money that such a team is in control of. Putting women in charge requires major social upheaval and is initially difficult. However, once the menfolk see the benefits they soon relent.

Loans from WaterAid are used for the building of the latrines. Once built, people are charged half a rupee to use the latrines and detailed accounts of the income generated are kept.[37] They often show that almost the entire population of the slum/village goes to the loo daily, furthermore people from neighbouring areas come to use them too. The money is used to pay for keeping the loos clean, to pay back the loan and to start other projects.

An immense sense of pride in what the groups have achieved develops and they start various 'cottage industries' with their money such as tailoring and selling compost. The heads of the self managed teams also start to get involved with local politics and encouraging other such schemes.

It appears that in many of the situations, money was initially the main motivator - once people were shown they could make money they became more interested.

Pond Purification[38]

In instances where a community is using a contaminated body of surface water for its supply[39], WaterAid instigates the following action plan:

- Increase the depth of the pond to reduce the surface area to volume ratio and hence comparative evaporation loss.

[34] Child Friendly Toilet – Innovation in Sanitation, *WaterAid India*
[35] A Study on the Reduction of Diarrhoea in the Urban Slums of Tiruchirapalli, *WaterAid India* (2001)
[36] See photo in Appendix C.9
[37] See photo in Appendix C.8
[38] Pond Purification, *A. Kalimuthu - WaterAid India* (2001)
[39] See photo in Appendix C.10

- Prevent any plant growth in the pond to avoid growth of germs.
- Increase inlet-flow by providing cement concrete pipes, connected to the feeder channel, and also to provide an outlet on the opposite side.
- Disallow cattle and people into the pond for watering, washing or bathing.
- Fence the pond to prevent entry of cattle and other animals.
- Introduce filtration systems compromising of horizontal roughing filters and slow sand filters to avoid faecal contamination.
- Add a settling or sedimentation pond to avoid turbidity.
- Train villagers in the management of the filter systems.

Typical results of such a scheme show marked decline in diarrhoea and other water-related diseases. Furthermore, contribution and participation by the villagers creates a sense of ownership in the community.

Society for Community Organisation and People's Education (SCOPE)

SCOPE is one of WaterAid India's main partner NGO's and represents a typical organisation working in collaboration with WaterAid. It promotes similar self-help groups composed of women and creates demand for sanitation through education then meets this demand in a similar fashion.

SCOPE's aim is 100% latrine coverage (i.e. 1 latrine per household) in the villages within which it operates and this has been done for many villages. It places a great emphasis on water preservation - for example waste water from washing the latrines, having bucket showers and washing clothes all flows onto herb gardens. It ensures washing places are kept away from the loos as separate compartments.

In some villages, the latrines have sections which connect with manure to produce biogas from the combined faeces. This is pumped into houses for cooking. Also some of the manure is used to make compost which is then sold. Some villages even grow mushrooms on the compost.[40] Villagers are also encouraged to develop cottage industries such as sewing and gemstone polishing.[41] Furthermore, some of the materials to construct the latrines are made by the villagers themselves along with hygiene products such as soap.[42]

[40] See photo in Appendix C.13
[41] See photos in Appendix C.11 and C.14
[42] See photo in Appendix C.12

SCOPE operates the following credit scheme for the construction of sanitation structures such as latrines:

- WaterAid provides a revolving loan of $2,000 to SCOPE
- SCOPE lends up to $400 to individual village *sangams* (committees) which make regular re-payments over 10 months.
- The village *sangam* considers applications from households and administers loans, taking responsibility for repayment through personal passbooks. Only poor families are eligible, the maximum loan being $13.

Three months after starting the scheme demand proved so great that SCOPE sought a further $1,200 from the local People's Bank (formed by a federation of 38 self-help groups), which makes limited investments in schemes for special needs. A typical latrine with hollow brick superstructure and bath extension purchased under this scheme would cost:[43]

WaterAid subsidy for substructure	$13	
Village *sangam* loan	$13	(interest free loan)
People's Bank loan	$2	(commercial loan)
Family Contribution	$2	
Total Cost	$30	

To date SCOPE has been responsible for constructing over 6000 individual latrines, 50 school sanitary blocks and 10 community latrines in a total of 70 villages.[44]

Research Organisations

There are many research organisations in India involved with water supply and sanitation providing information and documentation for practical application through the hands-on engineering related NGO's. The two described here represent typical research bodies operating in the sector.

Industrial Toxicology Research Centre (ITRC)
Established in 1965, the ITRC is a research and development organisation based in Lucknow, Uttar Pradesh dedicated to providing health safeguards to industrial and agricultural workers through its knowledgebase. Its mission statement is to 'achieve the highest international standards in toxicological research to ensure safety to human health and environment and help regulatory agencies in prescribing safe limits of chemicals.'[45]

[43] India: Making Government Funding Work Harder, *WaterAid India* (1998)
[44] 25 Toilets in 24 Hours: Catharapatty Experience, *SCOPE*
[45] http://www.itrdindia.org

The ITRC generates new methods for testing water for purity and for eliminating toxins in unclean water. Any methods developed are usually patented and then sold on to a relevant organisation for practical implementation. It places an emphasis on using locally available materials for meeting solutions. An example of one of these 'appropriate technologies' is a system utilising a mixture of used tealeaves and small amounts of silver to coagulate toxic particulates in turbid water.

Other products that the ITRC has developed include:

- A water analysis kit - a one-piece kit for physico-chemical and bacteriological analysis of water to determine the drinking water quality from a public health point of view in rural areas.

- A mobile laboratory van - a mobile water quality-testing laboratory for physico chemical and bacteriological assessment of potable water in villages and remote areas.
- *Amrit Kumbh* - a household low cost water filtration assembly to combat the problems of water borne diseases particularly in rural areas.

- *Bact-O-Kill* - an electronic device for disinfection of water.

Centre for Science and Environment (CSE)
The Centre for Science and Environment was established in 1980 by a group of engineers, scientists, journalists and environmentalists to increase public awareness of vital issues in science, technology, environment and development. The Centre is involved in producing an information service on science and society-related issues such as energy, environment, health, human settlements and the impact of science and technology at the grassroots level. Its programme is built around the objectives of awareness raising, policy research, advocacy, education and training and documentation.
Its relevance to water supply and sanitation is mainly in rainwater harvesting. The kind of schemes it tries to promote are:[46]

- Construction of permanent/portable storage structures for *in situ* collection of rainwater.

- Usage of farm ponds for collection of runoff, either for supplemental irrigation or for augmentation of groundwater.

- Checking of dams for storing runoff in first order (small) streams.

- Reclamation/revitalisation of traditional water harvesting structures.

- Enhancement of runoff through mechanical and chemical treatment in the catchment area.

- Building of sub-surface dams to arrest base-flow of groundwater.

[46] Water Links-2: Water Harvesters Directory, *CSE* (2001)

- Control of seawater incursion in coastal aquifers/prevention of subsurface discharge of groundwater to sea.

- Control of transpiration without affecting normal plant growth.

CSE's main focus is to augment traditional techniques with appropriate, locally available technology: for example improving the capacity of already existing reservoirs by raising mud banks or using bamboo chutes to channel water for drip irrigation.

Rainwater harvesting is a very powerful technology. A hectare of land in Barmer, one of India's driest places, still receives an average of 100mm of water a year. This equates to as much as one million litres of water – enough to meet drinking and cooking water needs for 182 people at 15 lpcd.[47] Even if all the water is not captured, depending on the nature of rainfall events and type of runoff surface amongst other factors, at least half a million litres a year could be captured using even rudimentary technology. Furthermore, rural density loosely follows intensity of annual rainfall, so that in areas where there is relatively less rainfall, more land is available per person to collect the water.

Table 4: Potential of Water Harvesting to meet India's Drinking Water Needs[48]

ASSUMPTIONS:			
Population			1 billion
Average annual rainfall			1,100 mm
Land area for which land-use records are available			304 mill. hectares
Average household water requirement nationwide			100 lpcd
Annual Water Requirements	**Water collection efficiency (%)**	**Land Requirement**	**% of India's Land needed for harvest**
36,500 bill. litres	100	3.32 mill. hectares	1
36,500 bill. litres	50	6.64 mill. hectares	2

[47] Making Water Everybody's Business, *CSE* (2001)
[48] Dying Wisdom: Rise, fall and potential of India's traditional water harvesting systems, *CSE* (2001)

Conclusions

Overall, the excursion to India proved extremely fruitful in obtaining an insight into the problems associated with water supply and sanitation in a developing country. The problems of water supply and sanitation are deeply tied to India's social and political growth. It is futile to make assumptions about how water is to be supplied or purified in purely technical terms when it is social and political issues that need to be deeply examined. This is particularly relevant in India where the population is massive, extremely culturally diverse, continuously changing in terms of demographics and where politics at many different levels play a major role. India is the world's largest democracy, has one of the most clearly defined forms of classism in its caste system and has vastly varying attitudes to women and the role of the family. All of these have implications on the management of water and sanitation.

The Government wields the most power with regards to water supply in the country. Having made mistakes in providing water blindly without instigating community participation it has learnt from various NGO's that decentralisation is the most effective method for sustainable improvements in water availability. The provision of free electricity and hence water to farmers is unlikely to change, as no government is likely to remove this benefit from potential voters. However, this issue may be resolved if electricity is privatised in the country, which due to external international pressure, may be a possibility in the future.

From the limited experience that was obtained from visiting the different levels of organisations involved in the water and sanitation sector in India, it seemed that the more strategic, higher-level organisations such as DFID and the Indian Government exerted a disproportionate amount of influence on the sector as a whole. While many of the smaller NGO's actually doing the work out in the field have an immense influence in small localised areas, it appeared that at the end of the day a new amendment passed by the government or new recommendations made by DFID would have far more effect on people's access to water and sanitation than any NGO could achieve in a decade. This could prove to be extremely demoralising for any organisations that did have aspirations contrary to governmental policy. For example when the Accelerated Rural Water Supply Program was introduced by the Government any plans that local NGOs had to provide water supply schemes fell by the wayside, even though they would have been more suitable in the long term. Its is unlikely that villagers would want to pay a small amount to have a new locally maintained well in the village when the government would provide a less sustainable alternative for free.

Water supply and sanitation programmes have been shown to be an immense success when the community is involved right from the start of any project. Schemes also seem to be most successful when integrated solutions to water supply and sanitation are found, instead of just one of the problems being considered in isolation. Furthermore, when consumers are made to pay in some way for the provision of water they are much more attentive to issues such as maintenance and hence such projects are more likely to continue sustainably. In cases where profits are actually generated, from paying for latrine usage for example, the money can be fed-back into the community to start other income generating ‘cottage industries’. This virtuous cycle has a marked positive effect on the psychology of the community. This is particularly important because problems like arsenicosis and fluorosis associated with water quality are augmented by the conditions of poverty and malnourishment within the areas which they most occur.

It is my feeling after having experience of the water supply and sanitation sector in India that all the problems are really still to do with a lack of quantity in terms of water supply. There is enough water available in the country for everyone to have an adequate supply of the element. However, social, economic and geographical disparity compounded by bureaucracy, corruption and in some cases mis-management mean that while some people have more than enough water others barely struggle to survive. I don’t believe that it is sensible to consider quality of water supply until the problem of quantity has first been resolved. However, there are instances where quality is more important than quantity – for example where chemical infiltration or bacterial infection of drinking water would be more harmful than dehydration.

It was due to the idea of a product able to purify water in a developing world context that this project was started. Having conducted experiments with the first prototype purifier it was clear that the product would work in theory, i.e. it would be possible to kill microbiological pathogens in infected water using a renewable power source in a robust package. However, it does not make sense to try and develop a product for consumers without first investigating the environment within which they live and hence their desire to use such a product. It was for this reason that the excursion to India was originally planned. As has been mentioned before, problems associated with a lack of quantity rather than a lack of quality in terms of water supply are more prevalent in India. However, in many situations that I witnessed, the effects of consuming water from a dirty surface water body, infected with bacteria or helminths, far outweighed those of dehydration. In these cases, if the product could be made sufficiently inexpensive then it could perhaps be used to clean water and make it suitable for consumption. Furthermore, in cases where a microbiologically associated disease epidemic occurs in an area, the purifier could be used in an emergency relief capacity. Continued research on improving the design and ensuring a low manufacturing cost will therefore continue on the water purifier.

Bibliography

Arranged alphabetically by publishing organisation. Some of the publishing dates are unknown.

Making Water Everybody's Business, *CSE* (2001)

A Water Harvesting Manual for Urban Areas: Case Studies from Delhi, *CSE*

Water Links-2: Water Harvesters Directory, *CSE* (2001)

Dying Wisdom: Rise, fall and potential of India's traditional water harvesting systems, *CSE* (2001)

The Water and Environmental Sanitation Sector in India, *DFID India* (2001)

Development Counts: Selected Statistics on International Development, *DFID/Office of National Statistics* (2001)

Indian Reform Initiatives in the Water Sector, *Keynote Address by the Minister for Rural Development Government of India* (May 2002)

Water: Midsummer Nightmare, *Article in Outlook Magazine, India* (3/6/2002)

Developing and Managing Community Water Supplies, *J. Davis, G. Garvey and M. Wood - Oxfam* (1993)

Rural Drinking Water Supply Programme, *Rajiv Gandhi National Drinking Water Mission* (2000)

25 Toilets in 24 Hours: Catharapatty Experience, *SCOPE*

Fresh Water for India's Children and Nature, *UNICEF/WWF* (1998)

WATSAN India 2000, *UNICEF* (2000)

Water Quality Surveillance: A Community-based Approach, *UNICEF* (1996)

Mitigating Fluorosis through Safe Drinking Water, *UNICEF*

Arsenic Contamination in India, *UNICEF*

Manual on Construction and Maintenance of Household Based Rooftop Rainwater Harvesting Systems, *UNICEF*

Child's Environment: Sanitation, Hygiene and Water Supply Project, *UNICEF* (1998)

Water Supplies for Rural Communities, *C. and M. Ball - VSO* (1991)

Handbook for Field Workers on Water, Health and Sanitation, *WaterAid India*

India: Making Government Funding Work Harder, *WaterAid India* (1998)

Child Friendly Toilet – Innovation in Sanitation, *WaterAid India*

Rural Water Harvesting: Eastern Coastal Plains – Pond Purification, *WaterAid India*

Schools: The Channels of Hygiene Promotion, *WaterAid India*

Integrated Hygiene Promotion in Schools: A Manual for Health Workers and School Teachers, *WaterAid India*

A Study on the Reduction of Diarrhoea in the Urban Slums of Tiruchirapalli, *WaterAid India* (2001)

Integrated Hygiene Promotion: Action Plans and Strategies, *WaterAid India*

WaterAid India Annual Report 2000-2001: Scaling Up Success, *WaterAid India* (2001)

Water for India's Poor, *UNDP – World Bank Water and Sanitation Program* (1999)

Rapid Assessment of Government Subsidy to Rural Water Supply in India, *World Bank Water and Sanitation Program* (1998)

Learning What Works: A 20 year Retrospective View on International Water and Sanitation Co-operation, *UNDP – World Bank Water and Sanitation Program* (1998)

Rural Water Supply and Sanitation Report (India), *World Bank* (1998)

Contact Details

Below are the addresses of the major organisations that were visited in India.

DFID India
B28 Tara Crescent
Qutub Institutional Area
New Delhi 110 016
Tel.: *(0091) 11 6529123*
URL: *www.dfid.gov.uk*

UNICEF – India Country Office
UNICEF House
73 Lodhi Estate
New Delhi 110 003
Tel.: *(0091) 11 4690401*
URL: *www.unicef.org*

ORSED
29 Nethaji Nagar
2 Ouppalum
Pondicherry 605 001
Tamil Nadu
Tel.: *(0091) 413 623385*
E-mail: *orsed@rediffmail.com*

WaterAid India
PO Box 850
Tiruchirappalli 620 020
Tamil Nadu
Tel.: *(0091) 431 422276*
E-mail: *waindia@satyam.net.in*

SCOPE
PI17 6th Cross
Ahmed Colony
Rahamalinganagar
Tiruchirappalli 620 003
Tamil Nadu
Tel.: *(0091) 431 774144*
E-mail: *scope@eth.in*

CSE
41 Tughlakabad Institutional Area
New Delhi 110 062
Tel.: *(0091) 11 6081110*
URL: *www.cseindia.org*

ITRC
PO Box No. 80
M.G. Marg
Lucknow 226 001
Uttar Pradesh
Tel.: *(0091) 522 227586*
URL: *www.itrcindia.org*

Note of Thanks

Sponsors
It would not have been possible either for me to do my initial research on the water purifier product idea or for me to have visited India without the financial help of sponsors. I would like to thank the following organisations and people who contributed to the expenses of the initial research on the product idea or the trip itself and therefore made the project possible:

- CambridgeFlava, Cambridge University
- The Cambridge Commonwealth Trust, Cambridge University
- Gonville and Caius College, Cambridge University
- Department of Engineering, Cambridge University
- Cavendish Physics Laboratory, Cambridge University
- Mrs Doreen Fletcher
- Miss Simin Bagheri

Assistance
I am also extremely grateful to Dr Siddharth Saxena, Dr Richard Carter and Dr Claire Barlow for their assistance and encouragement in undertaking this project.

Appendix A

The first part of the appendix briefly describes the product idea that formed the initial motivation for this project.

Contents:

A.1 Original Product Idea

Problem:

- Billion people worldwide are without access to safe drinking water.
- 80% of diseases in the developing world are related to unclean water.

Aim:

- To bring clean safe water to everyone regardless of where they are and what infrastructure exists near them.
- To provide this water cheaply, portably and using a renewable energy source.
- To possibly add a desalination capability in the future

Market
There are three main market areas:

- The main market is international aid agencies operating in the third world such as Oxfam and Medicins Sans Frontiers. The use is intended for both emergencies and for ongoing development.
- For travellers to areas with unsafe water.
- For people who stock up resources due to a fear that there will be some kind of international disaster, e.g. a nuclear holocaust, rendering access to a previously reliable water supply impossible

Market growth
All these markets will grow:

- The first will grow as the world's population will increase mostly in areas which already have poor access to clean water, e.g. India and many countries in Sub-Saharan Africa.
- The second market is growing because of the increase in disposable income in the developed world, the reduction in travel costs and the opening-up of many previously closed countries.
- The last market is also growing as even though nuclear stockpiles are on the decline, it appears that other non-conventional weapons such as chemical and biological are on the increase. There is also an increasing perception that the international political environment within which we live is becoming more volatile.

Once the product is established in at least the first market, there is the possibility of expanding the product range to include a product with a desalination function.

Technology
Present methods for removing bacteria from water are: filtration, boiling, chemical, reverse osmosis and using UV light. There are problems associated with each of these:

- Filtering requires expensive/high precision mesh's to get rid of organisms which are of the micron-scale in size. Furthermore, these filters have to be regularly cleaned or changed as they get clogged up.

- Boiling will kill most bacteria but requires a great deal of energy to boil any useful amount e.g. to heat 1 litre of water to boiling from 20^0C would require 336KJ. (5 litres, what a person is estimated to need a day, would require 1.68MJ to boil)

- Chemicals have the problem of being toxic to humans as well as bacteria, are not biodegradable – harm the environment, would need to be topped up when they ran out and may only be specific to certain bacteria. Furthermore, some bacteria are becoming immune to previously popular chemical methods used to kill them, e.g. Iodine tablets. Water that has been chemically treated often does not taste or look very pleasant.

- Reverse Osmosis techniques produce a high percentage of waste water. Furthermore, the membranes required are subject to the same limitations of cost and replacement that micro-filters are.

- UV light is comparatively better as a method for killing bacteria. It does however suffer some minor problems: Currently UV bulbs are relatively expensive, they also have a short life span.

Competitors
Manufacturers of water purifiers using many of the different forms of filtration already exist. However, there are only a few which manufacture a portable water-purification system which can be operated from a stand alone renewable power supply, e.g. Photo-voltaic solar cells or a rechargeable battery . Due to their design, these are both expensive and have parts which require replacement over a shorter life-time. These factors render them inapplicable for wide-spread use in the developing world.

A.2 Experimental Procedures

Experimental Procedure for determining the germicidal potency of a UV-C bulb under different conditions

Experiment 1
Pour infected water into cylinder and let it sit still
Power bulb from mains continuously
Measure % of bacteria which survive after treatment
Varying:
Time bulb remains on
Initial concentration of live bacteria in sample

Experiment 2
Run water through cylinder at a given flow rate
Power bulb from mains continuously
Measure % of bacteria which survive after treatment
Varying:
Different flow rates of the water
Initial concentration of live bacteria in sample

Experiment 3
Run water through cylinder at a constant flow rate
Power bulb from mains but strobe on at different frequencies
Measure % of bacteria which survive after treatment
Varying:
Strobe rate of bulb

Experiment 4
Run water through cylinder at a constant flow rate
Power bulb from independent PSU but strobe on at different frequencies
Measure % of bacteria which survive after treatment
Varying:
Strobe rate of bulb

Specifications:

UV-C bulb

Uses 4W power at 29V, 017A (170ohms) produces 0.7W UV-C radiation at a wavelength of 253.7nm. Light emitting region is 106mm long, bulb is 16mm in diameter

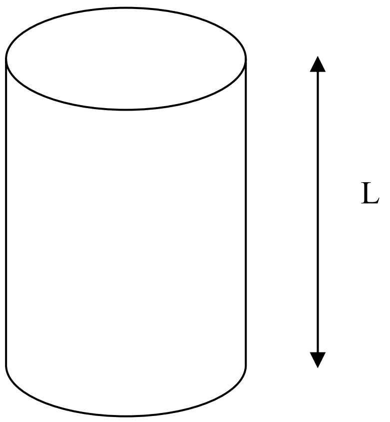
Bulb Holder

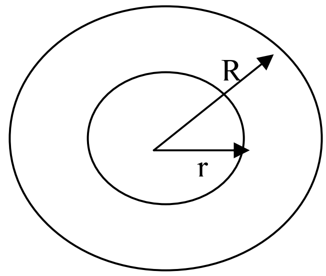
Fixture is made from plastic, and the protruding ends are 20mm in diameter and 6mm long.

Undetermined

- Size and material for cylinder, how it is lagged internally
  - Needs to be about 50mm internal diameter, have reflective coating on the inside, be waterproof, stiff and we must be able to drill into it for later experiments and mount end plates on.
- How cylinder attaches to bulb holder
- How water flows through cylinder
- How flow rate will be altered
- How bacteria concentration in sample will be controlled, how it will be measured after passage through cylinder
- What the independent PSU is capable of delivering (what power, for how long and at what voltage) and how it will interface with the bulb

A.3 Theory





To kill bacteria furthest away from the bulb, i.e. at **R**, an intensity over the area **2ΠRL** (cm^2) is needed = **I**:

Intensity required = **I** ($mW\ cm^{-2}$)
The time a volume of water remains illuminated by the bulb, its residence time = **T** (s)
The power of light in the UV-C region emitted by the bulb = **P** (mW)

$I = P / 2\Pi RL$

The dosage that a sample of infected water receives, $\mathbf{D} = \mathbf{PT / 2\Pi RL}$ ($mW\ s\ cm^{-2}$)

The volumetric flow rate of the water sample, **F** = Volume of cylinder / **T**

$\mathbf{F = \Pi L (R^2 - r^2) / T}$

Therefore, $\mathbf{D = P\Pi L (R^2 - r^2) / 2\Pi RLF}$

To ensure that a sample of infected water receives an adequate dosage:

$\mathbf{D \leq P (R^2 - r^2) / 2RF}$

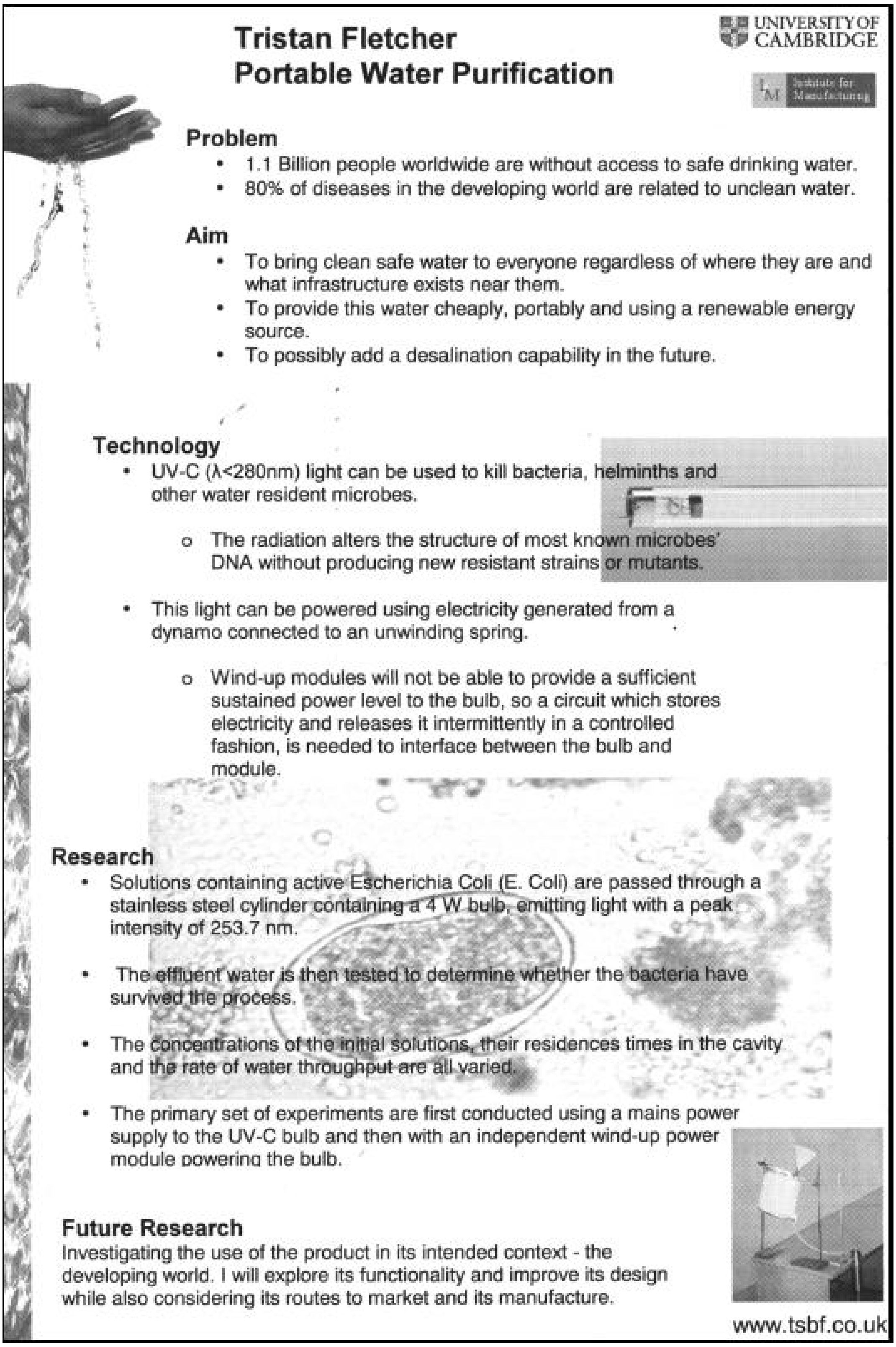
Or

$\mathbf{P/F \geq 2DR / (R^2 - r^2)}$

N.B.
These equations don't take into account the absorption of UV-C light by the water
They also assume very good mixing of bacteria within sample so that all bacteria receive similar UV-C radiation

A.4 Poster

This poster describing my initial product idea was presented to MPs at the Houses of Commons' on 18th March 2002 at an event called SET for Britain.

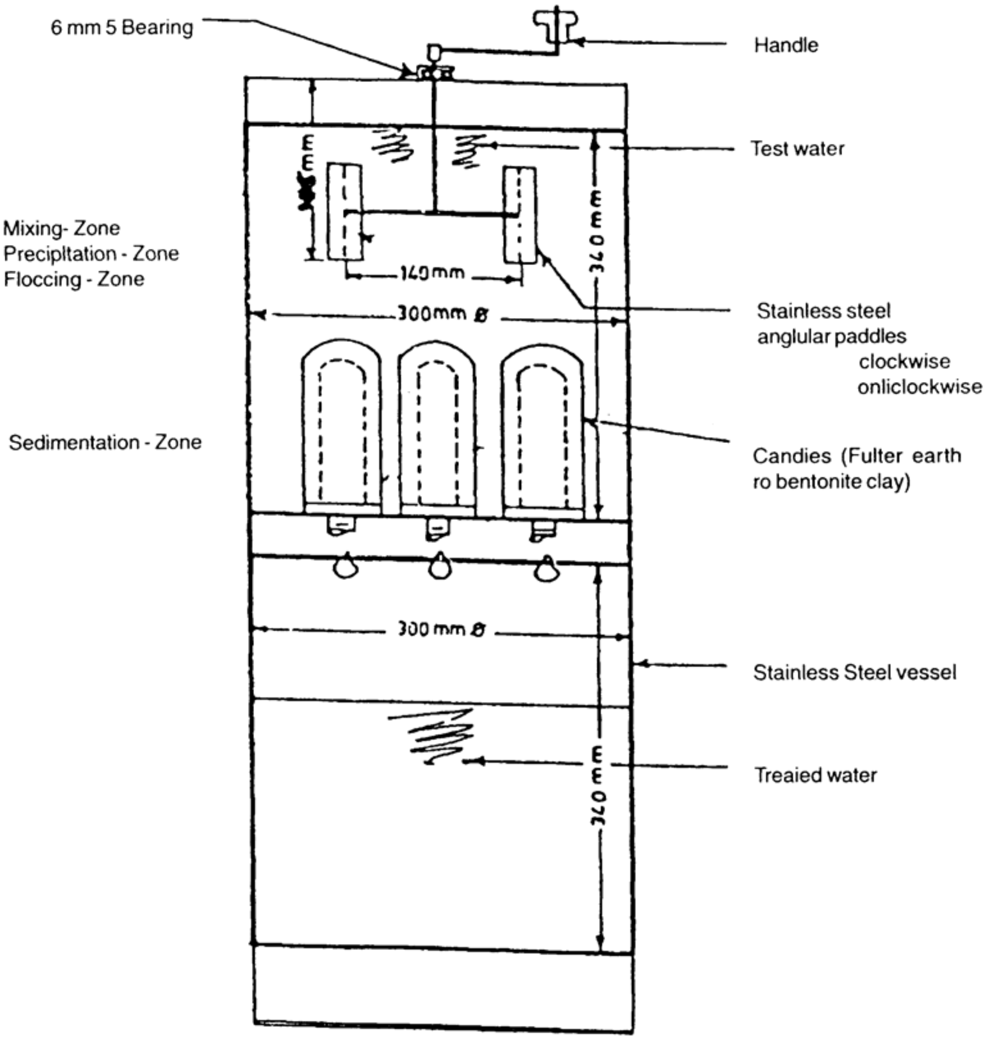


Appendix B

This section shows a few pictures taken from various organisations' documentation.

Contents:

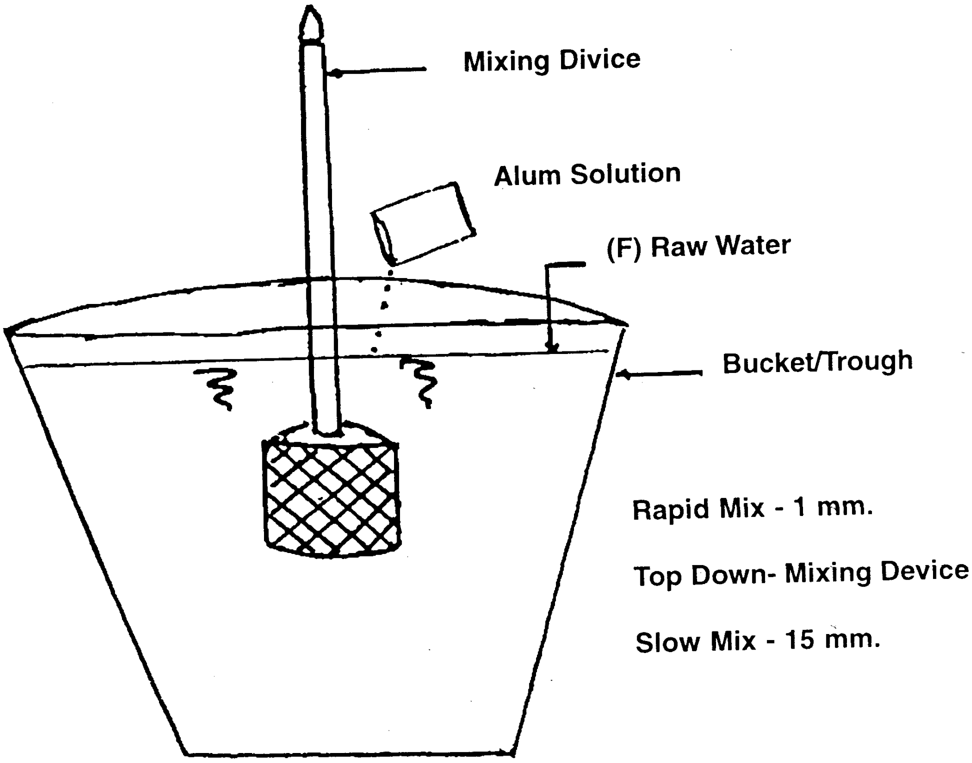
B.1 Example of Domestic Defluoridation Plant Design[49]



The mechanism causes the fluoride particles to coagulate and thus become heavier and sink to the bottom of the sedimentation zone.

[49] Designed by C.Ramanna - Superintendent Engineer, Samudaya Samhita (NGO), Bangalore

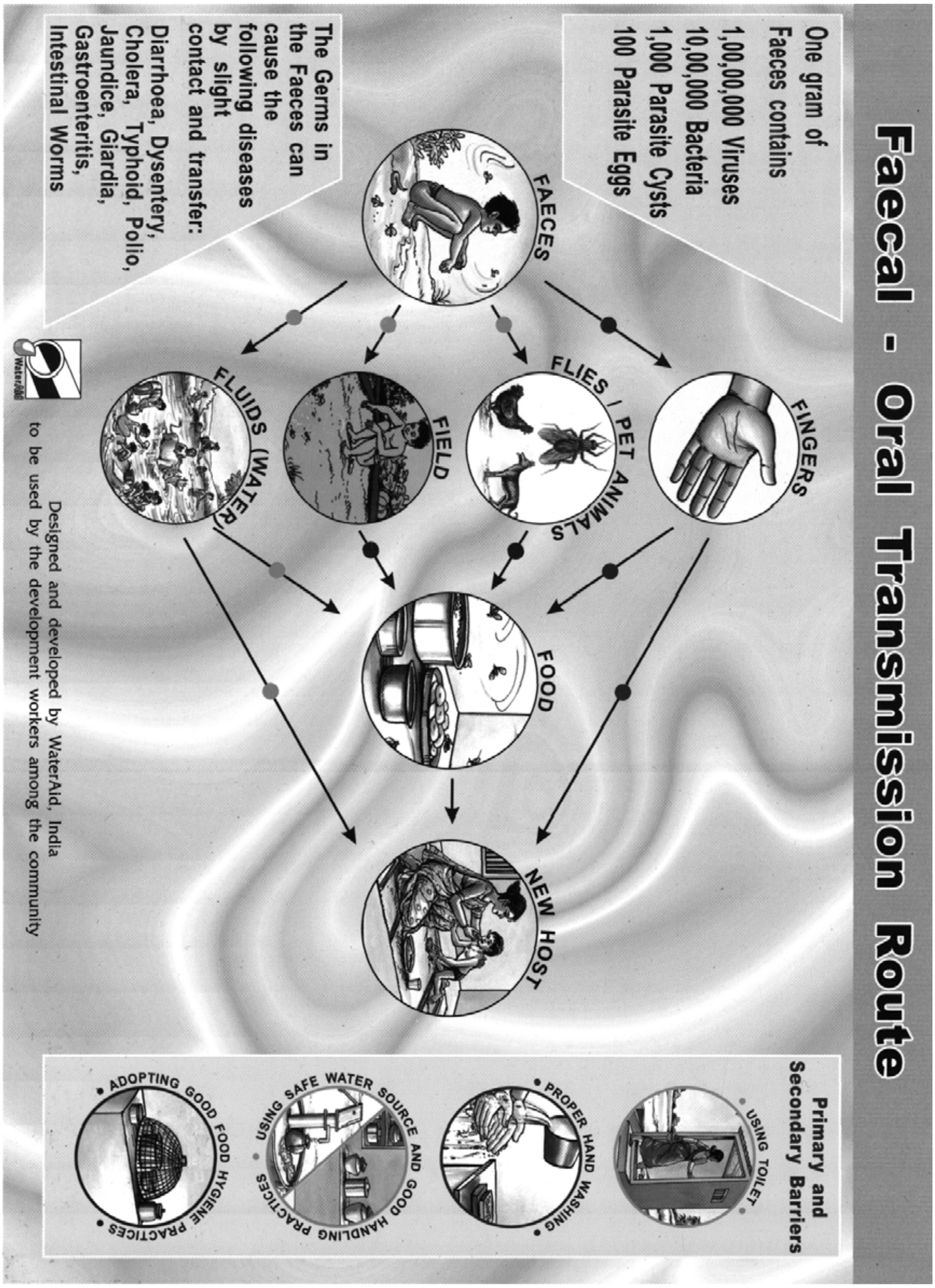
B.2 Defluoridation Technique for Bovine Drinking Water[50]



The alum particles bind to the fluoride molecules again causing them to coagulate and sink to the bottom of the trough.

[50] ibid.

B.3 Faecal-Oral Transmission Route



This is an example of the posters that WaterAid India use to educate people about the dangers of poor hygiene.

Appendix C

This section shows photos taken by the author which are relevant to the project. A description of each of the photos is at the end.

Contents:

C.1 ORSED Meeting

C.2 Surveying

C.3 Petrol Pump

C.4 Water Tower

C.5 Well

C.6 Hand-pump

C.7 Child Friendly Toilet

C.8 Paying to Use Latrines

C.9 Self-help Group

C.10 Pond

C.11 Gem Cutting

C.12 Soap Making Factory

C.13 Growing Mushrooms

C.14 Author Opening 'Cottage Industry'

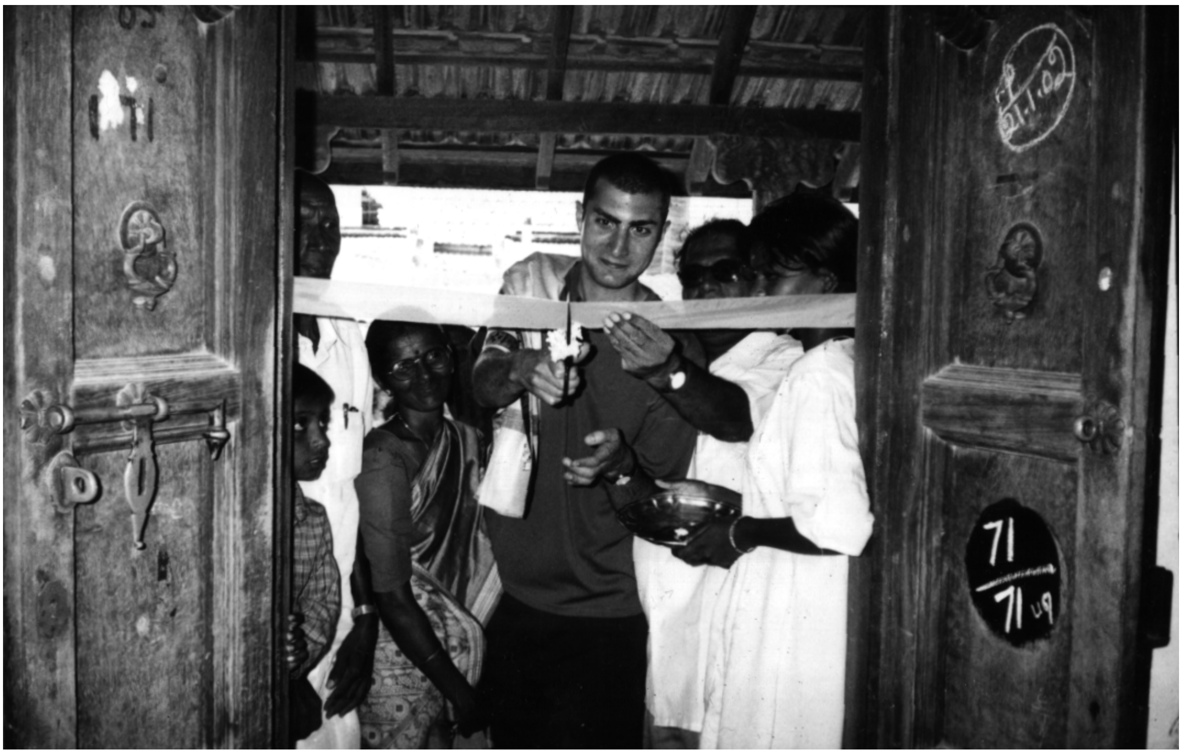


Photo Descriptions

C.1 Members of the NGO and the village committee are discussing maintenance costs of improving a large reservoirs capacity (Kilkuthapakkam village, nr Pondicherry, Tamil Nadu).

C.2 ORSED engineers survey a large empty reservoir to determine its capacity and what work needs to be done to improve it.

C.3 A pump which pumps water from the reservoir to irrigate the surrounding fields.

C.4 A 3,000 litre water tower which contains water pumped from groundwater 2 km away (Kilkuthapakkam).

C.5 A well which provides drinking water to the village, it is dry in the summer months before the monsoon (Kilkuthapakkam).

C.6 Children using a hand-pump (Kilkuthapakkam).

C.7 CFTs being used by children in an urban slum in Tiruchirappalli, Tamil Nadu.

C.8 Prospective customers paying half a rupee to use latrines (Tiruchirappalli).

C.9 A woman's self help group (Tiruchirappalli).

C.10 Children playing in a dirty pond which is used for their drinking water supply (Kilkuthapakkam).

C.11 Small gem-cutting industry in a rural village near Tiruchirappalli.

C.12 A factory making soap using locally available materials in a rural village.

C.13 Mushrooms being grown for sale on compost made from human and animal manure.

C.14 A new sewing-room to start small 'cottage' tailoring industry being officially opened by the author as 'chief executive guest'.