Delivery of Subterranean Arsenic Removal in West Bengal

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Institute of Environmental Sciences

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TiPOT

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Preface

The present report is the result of the TIPOT project that was funded in the Asia Pro Eco Programme of the EU (Contract reference no.: ASI/B7-301/2598/24-2004/79013). The objectives of the project were the development of a low-cost technology for in-situ treatment of groundwater for potable and irrigation purposes and to formulate practice-based guidelines for this a rural water treatment technology for eastern India. Roughly more than 70 million people in the Bengal region are affected due to arsenic exposure especially through consumption of drinking water. The aims of the project were therefore the assurance of arsenic free water for general consumption and irrigation at low cost and to enhance food safety in the affected areas through sustainable irrigation and farming practices.

A consortium of universities and institutes worked together on the project. The lead partner was Queens University Belfast (QUB). Other participating partners were: National Metallurgical Laboratory, Jamshedpur, India (NML); Institute for Sanitary Engineering, Water Quality and Solid Waste Management, Stuttgart, Germany (ISWA); Universidad Miguel Hernandez, Alicante, Spain (UMH); Institute of Environmental Management and Studies, India (IEMS), and the Institute of Environmental Sciences, Leiden University, the Netherlands (CML).

Having a successful history in countries as Germany and Switzerland, ISWA (with help of especially NML and RKVM-IAS), applied the in-situ technology in a case study site near Kolkata. In anticipation of the positive results, other partners worked on issues as arsenic in food (UMH), arsenic and irrigation (QUB) and the way to bring the technology to the people in India (CML and IEMS).

This report describes the results of the study that was carried out by the Department of Environment and Development of the Institute of Environmental Sciences (CML), working together with the Ramakrishna Vivekananda Mission - Institute of Advanced Studies, Kolkata (RKVM-IAS). The authors worked together on the project. Prof. Wouter T. de Groot of CML was the senior researcher who designed and developed the system for analysis and supervised the research team. He participated in all TIPOT meetings and visited the research site twice. Sukanya Sarkhel, based at RKVM-IAS, conducted all fieldwork and was a key-informant concerning information about the research site and India in general. She visited the Netherlands twice in the scope of the project and she assisted the foreigners logistically on their visit to her country. Marieke Hobbes, research fellow at CML, spent much time on literature search and writing of this report. She guided the research and visited the research site.

The authors would like to thank all people who made this research possible. In the consortium, the authors worked together with Mr. N.K. Nag of IEMS of whom we received lots of information and fruitful reactions on our propositions of the delivery of various kinds of in-situ treatment plants. The people working at RKVM-IAS, especially Prof. H.S. Ray and Prof Mukherjee are thanked for their substantial and practical guidance and Mrs Angana Dutta at RKVM-IAS for the organisational support. In Kasimpur village, about 60 households participated in the study, the people that are in need of clean water and who should use the technology. Their opinions and ideas were indispensable for the study. Besides, various key-informants helped to start up the study in the village and provided information about the village,

about the households, tube wells, irrigation systems, self-help groups, political parties, history, cropping practices, etc. Thanks to you all!

Leiden, July 2007

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a report of the TIPOT project, sponsored by the EU

by Wouter de Groot, Sukanya Sarkhel and Marieke Hobbes
working for CML (Leiden University), RKVM (Kolkota) and supported by IEMS (Jamshedpur)

Summary

The present report focuses on *how the arsenic removal system investigated by the TIPOT project may find its way into West Bengal society* (under the assumption that the system purifies well water to arsenic levels below the health standards). The institutional structure to perform this function is called the ‘delivery system’.

A delivery system is made up of manufacturers and end users and all actors between them, such as retailers, state government and NGO agencies, panchayats, marketers, contractors, banks and laboratories. Moreover, the delivery system contains the formal and informal rules that regulate the relationships between these actors. These may be legal rules of public procurement, for instance, or rules for water quality assurance, or the

The technology investigated by TIPOT consists of subterranean arsenic removal (SAR), so that the water is clean already when it comes out of the well. This is achieved by aeration and re-infiltration of a part of the pumped-up water, which builds up arsenic absorption capacity in a zone around the well. The absorbed arsenic precipitates in the pores between the soil particles but these volumes are so small that it takes a very long time before a new well has to be taken into use.

All elements of the systems can be locally made with well-known sanitation techniques (pipes, valves, plastic reservoirs etc.), and existing local contractors will find no difficulty to construct them. It is quite likely that the systems can be built as add-ons to existing wells. For public systems serving some 100 to 1000 households, cost may be as low as 10 INR per household per month. Willingness-to-pay research indicated that willingness to pay might be higher than that, if the panchayat would take the responsibility as central actor in the delivery system. Virtually all local people and elite persons that we interviewed found the panchayat the most natural actor to take this lead role; trust is the key issue here.

The technological simplicity of the SAR technology is a great asset for the delivery system. We may assume that if a small number of key actors is present, the market will organize itself based on already existing entrepreneurship. Below, we focus on these key actors and their roles.

Key actors and roles in brief

The delivery system for subterranean arsenic removal (SAR) in West Bengal society, envisioned by us on the basis of our research and discussions, contains the following key elements:

- A state-level government or NGO as driving and enabling agent for approved arsenic technologies (including SAR if that technology works indeed), e.g. modelled like the one already existing in West Bengal for renewable energy .
- The panchayats as central actors/owners, or other institutions that may command the same levels of trust in the communities.
- Certified and controlled quality assurance agents (possibly to be replaced by self-control in situations of justifiably high trust between users and central actor).
- These actors should focus on relatively large public systems serving some 100 to 1000 households. With our design of T2000 as one example, these systems are likely to be designed as add-ons to existing wells, fully with local technologies and knowledge. They may be run and maintained by a dedicated operator, which is a guarantee against overdraft and neglect.

Other functions and actors will most likely follow spontaneously enough, especially if the driving and enabling agent supplies the knowledge, standard contracts etc. that help actors such as panchayats and contractors to find each other smoothly and with low transaction cost.

Key actors and roles in some more detail

Our concluding chapter 7 presents the delivery system as we envisage it after our conceptual and empirical explorations in some more detail. We do so under the assumption that the SAR system really delivers water of good quality (including arsenic quality) throughout. This assumption has also underlain our empirical work such as the willingness-to-pay interviews.

Central actor and scale of technology

The interviews reported in Chapter 6 have clearly pointed at the panchayat as the preferred central actor. Both the local and the elite respondents trust that the panchayat has the financial and management capacity to establish and run the system, and trust that if the panchayat asserts that something like arsenic is a problem and something like SAR is a solution, this is sufficiently likely to be true. This in turn implies that institutions that might command the same type and level of trust could be central agents as well. Examples could be a large social or religious NGO or a university. Other organizations may play a role in the establishment of SAR systems as well, of course, but these then should work under the panchayat or the large NGO as ‘central trust holder’.

With an agency such as the panchayat as central actor, the scale of the SAR system would logically be relatively large, e.g. in the order of the T20000 we discussed in the interviews (see Chapter 4). Such a system could serve some 400 households. This scale allows for a dedicated operator, which will guarantee smooth running and curb the risk of overdraft without expensive devices being necessary. Strong economies of scale exist as well, and as we have seen, the cost of the large-scale system might well turn out to be lower than the willingness to pay (if the panchayat would be central actor), so that it could run without subsidies if necessary.

T20000 as we designed it is of course not necessarily the optimum lay-out. It may well be, for instance, that the recharge tank and the storage tank be better placed in sequence than parallel, with the recharge tank overflowing into the storage tank when full. This does not make essential differences, however, since the effect on the arsenic and the cost of the system will remain virtually the same.

Apart from the panchayat for large-scale systems, organisations such as schools or clinics may also become central actors running a medium-scale system, primarily for the people they are directly responsible for but possibly also for the surrounding community. These would be relatively rare cases in the long run if SAR would be massively adopted but may play an important role especially in the take-off phase of the technology, because the organisations may move relatively fast and be relatively free of budgetary constraints. Because we are interested here primarily in a delivery for state-wide SAR for everybody who may be threatened by arsenic, we concentrate on the ‘panchayat option’.

The delivery system will then be composed of the panchayats and the water users, plus the contractors and maintenance suppliers, possibly banks for specific credits, plus water quality assurors and possibly more. We feel that contractors, banks and others do not pose a design problem for the delivery system because everything in SAR can be composed of very common local technology (as in TIPOT’s field experiment) and because financial thresholds do not appear to be very high at present. The water quality assurors deserve some more attention, however.

Water quality assurance

Water quality assurance is essential for health and willingness-to-pay. Quality assurance actors may be of many types (private, government laboratories, NGOs etc.) but all will have to meet the following conditions:

- They will have to be contracted by the central actor that is also the ‘central trust holder’, *i.e.* the panchayats or other organisations as discussed
- They will have to be certified by the ‘driving and enabling agency’ (see below).
- They will have to be checked by an independent scientific institution (say, university or national laboratory).

West Bengal society has enough potential quality assurance actors to enable competitive procurement, facilitated by standard procedures designed by the ‘driving and enabling agency’ (see below).

This system is fool-proof in the sense that it safeguards against the tendency to sell water even when not arsenic-free. The simpler alternative of *self-control* may be feasible too, however, in situations of justifiably high trust between users and central actors. Technically, the current state of the art allows for field checks of water quality that may already be of sufficient accuracy.

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The ‘driving and enabling agent’

A second institution that deserves attention has not been conceptualized yet because we have focused on how the delivery system would look like once in full swing. Often, however, delivery systems fail to come about even though potential actors would all be interested to work together. As said in Section 4.6, markets work because actors know each other and have established trust and routines. Trust takes care of that actors do not need enormous amounts of time and energy to get all details of deals on paper and check upon each other's behaviour. Routines, examples of which are standard contracts and the unwritten expectations that new transactions will essentially be carried out as were the previous ones, serve the same purpose of low transaction cost. New delivery systems on new markets are therefore sometimes hard to establish. Actors that have not worked together yet will start out with low levels of trust in their relationship. It is even possible that for some actors, the whole job of building trust is just too energy-consuming and risky to make it seem worthwhile to start the relationship at all.

It is therefore quite likely that even if the SAR technology works and the panchayats are the obvious central actors, a market establishment facilitator is essential to get the system off the ground. This 'driving and enabling agent' may be designed to fulfil the following roles:

- Awareness-raising on arsenic
- Knowledge repository and teaching on arsenic
- Approval of arsenic technologies, e.g. conditional (what works best under what circumstances)
- 'Public marketing' of approved arsenic technologies (not only SAR, obviously)
- Certification of contractors (incl. water quality assurors) and possibly technologies
- Drafting and distribution of standard contracts, e.g. for between panchayats and contractors
- Thinking out roles of actors to support the panchayats
- Support other organizations that might be interested in establishing their own SAR system (schools, clinics etc.)
- Select locations with enough iron in groundwater for SAR to be applicable
- Organize demonstration and learning projects for SAR and other approved technologies.

The scale at which such an organization should work is logically the state level, because the arsenic is an all-Bengal but not an all-India problem. It is interesting to note that West Bengal already has a 'driving and enabling agent' for renewable energy, called WBREDA (www.wbreda.org). Experiences and formats for the agency for arsenic technologies are therefore available already.

The study's empirical basis

The selection of the village concerned mainly that the in-situ SAR experiment of the project could be established in a safe environment of the mission post of RKVM. Kasimpur village used to be an agrarian village, but at the time of the study a remaining 100 of the 350 households were identified as mainly agrarian of which we took a random sample of 33 households for data on agrarian topics. All but one participated in the lengthy research consisting of time use diaries and extensive interviews on all cash and material flows covering a full year. Of the remaining 250 households, an additional random sample was taken of 30 households for topics specifically focusing on awareness of arsenic contamination and on the willingness to pay study.

The field study took place from December 2004 till April 2006. We have collected most of the data through personal interviews with the household members. Adult household members (aged between 12 and 60) were interrogated regarding various issues, such as household composition, demography, land use, time use, food and water intake, awareness about arsenic contamination in ground water, willingness to act, willingness to pay for arsenic free water, etc. More specifically, for the various topics the methods were as follows.

For insight in the **perception on arsenic contamination** and its impact on health, 61 respondents from different age, sex and occupation were first asked whether they know that arsenic contamination in ground water is a problem for this district as a whole. If the answer was "yes" they were asked to explain their views on this arsenic contamination. If the answer was "no" the researcher explained the impact of arsenic by showing pictures of affected people, among others. She also described the current scenario including the health related problem in the district and in the Barasat Block I and II (where the village is located) were also described to them. Their reactions were noted.

To get the respondent's **perception on the provision of the SAR technology** CML developed a couple of user-friendly draft variants of the technology. The model plant in Kasimpur looks very complex, while the user friendly technologies CML drafted were easily understandable. We showed and explained these drawings to academic, administrative and local people. We discussed how it could function technically, how much such a thing could cost and how it could function in the household or the village. The respondents were asked about their views on the most suitable technology model and the manner the technology should be offered (e.g. leasing, buying, provision by the local government etc.).

To elicit households **willingness to pay** for arsenic free ground water the Contingent Valuation Method (CVM) was be used. CVM is a widely used, non-market valuation technique that estimates the demand for a proposed commodity in a hypothetical market. In the context of provision of the In-situ technology the question concerning the costs of technology was not clear. CVM study provided information about the contribution that households said they would be willing to pay. After discussing the impact of arsenic contamination, the respondents were informed about the hypothetical situation that "if we would have three different technologies of the in-situ technology for the removal of arsenic from the ground water, would you be willing to contribute money or time to obtain arsenic free water?" If the answer was "no" (the respondents' willingness to pay was thus zero), they were asked for the reason. If the answer were "yes", the three technologies were explained to them and they were asked to express their own opinion about the suitability and viability of each of the technology in the respondents' social and economic situation. Then we proposed a payment ladder, containing payment ranges starting from INR 10 – 100 per a specified amount of water per cycle per day, and payment vehicle options (how they will pay). Finally, the respondents were asked about the amount he would be willing to pay for this arsenic free water supply.

In order to estimate the **demand for drinking water and the calorific intake** per individual per household we used 24 hours recall interviews on the amount of each of the food items and the water intake per household member for potable and cooking purposes. Since women take decision in cooking and housekeeping, all the information related to food and total water consumption was gathered from the women. The water consumption of household members was measured by the number of glasses or bottles of water consumed per day.

For the **time allocation studies**, the respondents' primary activities, i.e. the activity corresponding with the major aim of the activity, were reported with a preciseness of 15 minutes for one day followed by a four to five days' gap, from March 2005 up to April 2006. Some respondents recorded their own diary, but most co-operated by 24-hour recall interviews. The times use records for the sample household members were gathered throughout the day, the housewives and the young members were interviewed in the morning and in the afternoon the male farmer members. The reported activities were translated to the categories of an empirical form, which was based on the analytical time/cash categories. Assistants helped entering these data in the empirical form/table in the database.

Further, a questionnaire was developed covering all **material and cash flows**. To make the interviews feasible, appointments were made per topic with the knowledgeable person of the household, for instance, the women about all details of livestock and food and water consumption, the male head on the fields and crops. Thus, interviews covered topics on field type, land use in different seasons, area, ownership, production details and marketing of different crops in different seasons, inputs detail per crop i.e., material input (e.g. seed, fertilizer, pesticides), labour (e.g. lab hour per activities like harrowing, fertilizing, harvesting), and also the capital inputs (like tractor, plough etc) and capital per crop and storage. If a household produced more than two crops annually, the interviewer visited the respondent several times on appointment to complete the information about the production activities per crop. By repeatedly visiting households, the researcher gained trust and could enhance the validity of the data. Actually, at the initial stage of field survey household members seemed uncertain and the data they supplied about the landholding and other demographic characteristics at the initial period differ much with the interviews after 4-5 days interactions.

Because the researcher spent so much time in the village during the periods of the field survey, she could **observe** specific feature of the village and the villagers. The researcher got the idea about, among others, the location, village routs, house types, division of labour, female work force participation, culture, religion, various social aspects, water-use and about different group and types of settlements on the basis of which a map of the village has been drawn by the researcher.

Further, some specific key-respondents in the village provided **general information** about land, labour, politics, culture, etc. Secondary data were used such as market prices and conversion factors. A database was developed in "Microsoft Access" to enter and store all the data.

1.
Concepts and methods for exploring the delivery system of SAR

This section is devoted to the key concepts of the exploration of the delivery system of the technology and the methods used to arrive at the report's recommendations.

1.1 The SAR and delivery system concepts

SAR means 'subterranean arsenic removal'. This is a technology that works to keep the arsenic in the ground before it might move into the drinking water or irrigation water supply wells and pipes. An other term denoting the same idea is 'in-situ groundwater treatment'. In all parts in the report when we speak about SAR in specific terms, e.g. on cost or performance, we specifically refer to SAR of the type developed by ISWA, Germany, because that technology is the core of the TIPOT project. What this SAR does is to build up adsorption capacity for capacity in the soil, so that the arsenic gets stuck there before reaching the well.

The term 'delivery system' denotes the whole structure of a technology's manufacturer and the technology's consumers ('end users') and everything in-between. These in-between parties may be, for instance, banks, NGOs, government agencies, marketing companies, leasing agents, maintenance suppliers, help desks and so on, each of them performing specific functions in the supply chain. The term delivery system emphasizes that for a technology such as SAR, manufacture is often less difficult than its sustainable application by end-users. Operation and maintenance, rather than just making the thing itself, are what counts in final success or failure. The delivery system concept helps to overcome the bias in technology sciences that design and manufacture of hardware is considered the most interesting part and carries most prestige (Morrison, 2003). Besides, as is described by for instance Galway (2003) and Valente (1996), a prerequisite for adaptation of new technologies is effective co-ordination, communication and involvement among beneficiaries and stakeholders.

It may be noted that the delivery system concept does not comprise the most 'upstream' part of the supply chain, where technologies are designed and tested. In other words, for this report we do not pay attention to the adaptation and testing of the SAR technology between the EU and India. The reason is that we think this international inter-trade, though obviously essential, is not complicated enough to warrant explicit scientific attention. This choice also implies that for the present report, we assume that ISWA's SAR technology is locally effective and stable to a degree that small-scale application can do no harm. (Note that this is not a claim that this technology would be the best of all or warrant large-scale application.)

1.2 Economic concepts

Economic aspects are important for the adoption of a technology. A technology such as SAR requires special conceptual care in this respect because many of its benefits are long term, difficult to assess financially and accruing at the collective system level.

A first distinction is between economic and financial accounting. Economic accounting aims to account for all cost and all benefits connected to adoption of a technology, irrespective of to whom they matter. This implies, for instance, that subsidies (i.e. cost to the government) are included as a cost. Financial accounting takes in only those effects into account that translate into cash for the actor involved and to the extent that they do so. In this accounting, for instance, subsidies lead to lower cost for the subsidized actor.

Next, we need to be aware of the distinction between justification, capacity and willingness to pay.
Justification to pay is what an actor should be willing to pay or forego, maximally, for the acquisition of a technology if the actor would be willing to maximize his economic net benefit and if all benefits and all cost accruing to the actor would be perfectly identified and monetarized.
Willingness to pay is what an actor is actually willing to pay or forego for the acquisition of the technology.
Capacity to pay is what the actor is able pay from his own financial or social capital. These three values may turn out to be quite different, in practice. Willingness to pay may be higher than justification to pay, for instance, if the actor sees non-economic benefits, e.g. for political reasons or reasons of morality. Willingness to pay may also be lower than justification to pay, e.g. if the actor regards it as somebody else's responsibility to bear the cost or if the actor is unaware of the benefits.

Finally, Costs and benefits accrue on various system levels. One is the individual level, where households make their decisions. Another is the collective level, where actors such as states decide on the common good. The difference between the two defines what may be justifiable permanent levies or subsidies. If a technology is highly desired at the individual level, but undesirable at the collective level due to negative effects on that level (e.g. due to pollution or unsustainability), a levy to rectify the difference is justifiable. And the other way around, if justification, willingness or capacity to pay is lower at the collective level than the justification to pay at the collective level (e.g. because the cost of diseases at left at that collective level), is subsidy is justified. But note that the reasons for that gap, and with that the reasons for the subsidy, are different for the three cases.

1.3 Research history and report structure

There is an enormous amount of publications on the arsenic contamination problem in West Bengal, India and Bangladesh. The site http://www.eng-consult.com/arsenic/refs.htm, for instance, gives a reference list of 139 papers related to arsenic. There is the arsenic info crisis centre on line (http://bicn.com/acic/) that includes an info-bank of news articles, scientific papers, comprehensive links to other relevant sites, online forum, email newsletter, and local site search. There is also the www.sos-arsenic.net where several links can be found to topics related to arsenic pollution and project combating the problem in West Bengal and Bangladesh. There is a very good report from the World Bank (2005) that deals not only with the arsenic problem but that also extensively describes proposed and applied technologies and alternatives.

In spite of all this, the arsenic problem is not nearing solution. One difficulty lies in the lack adoption of arsenic purification technologies – in our terms, failing delivery systems. This phenomenon urged a quite cautious and foundational approach in the first period of CML's research. After all, why would the SAR technology fare any better than the others? CML therefore started out with a fundamental review of concepts and the structuring of an applicable model of thought about delivery. The preceding section gives an indication of the types of questions that were addressed, focusing as it does on the economic justification of permanent state involvement, by way of subsidies, in a delivery system. Parallel to this fundamental research line, an empirical field study was started in the model village, focusing especially on people's capacity to pay, hence on the empirical assessment of freely available cash and time. These two lines were heading for a meeting point at which the principled basics of a delivery system were envisaged to arise.

In the informal background of this research design, however, several assumptions were slowly shifting. One, for instance, was the degree to which the state was trusted at the village level and deemed capable and willing to play a major role in the delivery system. In many developing countries, all these levels tend to be very low, which would imply that the major burdens to deliver the SAR system would have to be borne by actors such as households, self-help groups and market parties such as banks and contractors. Not so in West Bengal, however. All respondents of our interviews, be they private, NGO or GO, found it totally natural that the state should be and could be the central actor in the arsenic-free delivery system. Another example is that in many countries with a emancipating low-income population, drinking water supply is supposed to be basic right and therefore unpriced. Willingness to pay would then be zero as a matter of principle, even if people would acknowledge the high value of arsenic-free water. Contrary to some predictions, however, this condition did not appear to exist in our fieldwork village. And finally, when ISWA, NML and RKVM had successfully established the SAR technology in the model village fully with local materials and local craftsmanship, the cost and maintenance problem of the SAR technology turned out to be at such unproblematic levels that formal studies on the local capacities to bear these burdens were (happily) dropped.

With that, the research shifted towards a more informal and focused approach (without dropping the empirical work that required a long-term involvement). A number of concrete designs of how the SAR technology could look like in practice were made and put at central stage in interviews with local people and government informants. This, together with the insights gathered in the conceptual explorations, converged rapidly into an outspoken result.

This history of the research is found back in the report structure. Chapter 2 explores the arsenic problem in West Bengal, because that problem constitutes the demand side of the SAR delivery system. Chapter 3 introduces the village where the SAR field experiment and the empirical studies took place. It also informs on the methods of these empirical studies and some of their results, on arsenic awareness in particular. Chapter 4 reports on some key notions from the conceptual explorations. Making use of these insights, Chapter 5 is focused on the technical and institutional aspects of the concrete designs. Chapter 6 then reports on the results of the interviews based on these designs, in terms of general opinions on the technology, willingness to pay for the various mixtures of technology and institutions, and ideas on the delivery system. The concluding Chapter 7 summarizes these results and adds some elements to form a proposal for a complete delivery system of SAR in Bengal society.

2.
Exploring the demand side of SAR

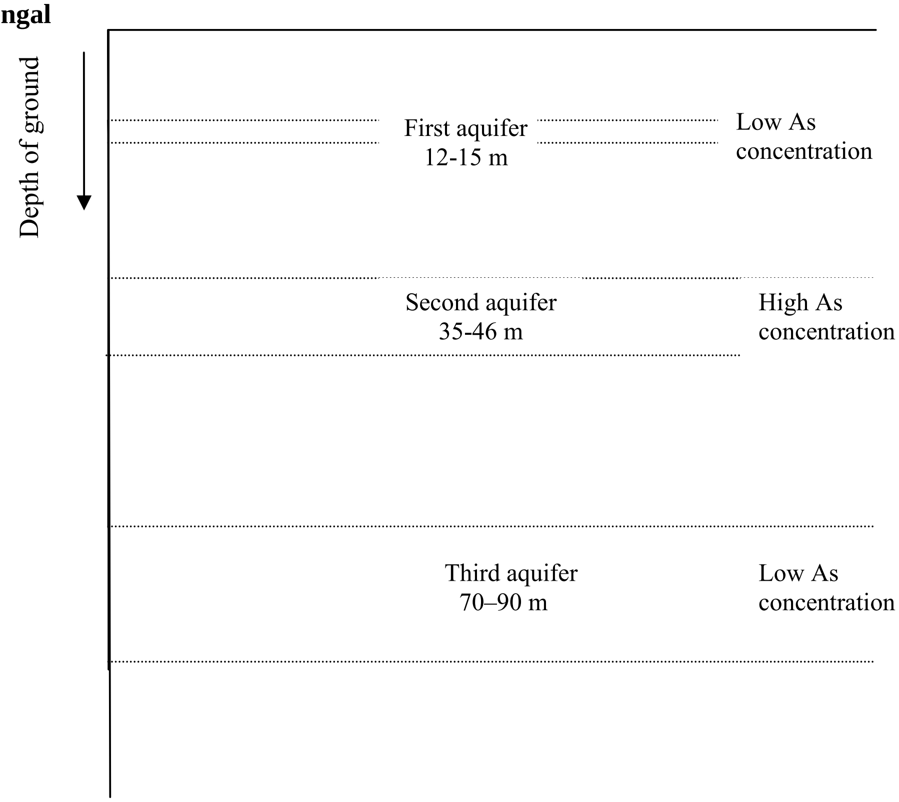
This chapter explores the demand side of the SAR technology. We will first discuss the existence of arsenic in groundwater in West Bengal. Then, in sections 2.2 and 2.3, we continue with the arsenic problem in drinking water followed by the arsenic problem in irrigation water. We continue with the local perceptions of the arsenic problem, followed by the arsenic problem in GO perceptions in sections 2.4 and 2.5 respectively. An overview of all solutions for drinking water is given according to source, in situ treatment and post treatment of arsenic rich water in section 2.6. We continue the chapter with the solutions for drinking water that have been applied (and failed) in West Bengal (section 2.7). The chapter is rounded off by a discussion on irrigation water.

2.1 Arsenic in groundwater in West Bengal

In West Bengal most drinking water used to be collected from open dug wells and ponds without an arsenic problem. However, due to pollution, this water became contaminated with diseases such as diarrhoea, dysentery, typhoid, cholera and hepatitis. Since the 1970s and 1980s shallow hand-pump wells (at depths less than 70 metres) were established to provide clean drinking water that helped to control these diseases. Arsenic was found in the waters of West Bengal in the 1980s. An estimated 30 million people in the Ganges delta are drinking well water contaminated with arsenic (New Scientist, 2004). Of these people, more than 6 million live in West Bengal, India (Chakraborti, 2002).

In West Bengal, the contaminated aquifers in the region are mainly Holocene alluvial and deltaic sediments, which form the western margins of the Bengal basin (World Bank, 2005). The five worst affected districts of West Bengal are Malda, Murshidabad, Nadia, 24 North Parganas, and 24 South Parganas (ibid.). These cover an area of about 23,000 km^2 where arsenic concentrations found range between 1 and 3,200 µg per litre. The Quaternary sedimentation patterns vary significantly laterally, but sands generally predominate to a depth of 150–200 m in Nadia and Murshidabad, while the proportion of clay increases southwards into 24 North and South Parganas, as does the thickness of surface clay (World Bank, 2005). A shallow "first aquifer" has been described at 12–15 m depth, with an intermediate "second aquifer" at 35–46 m, and a deep "third aquifer" at around 70–90 m depth (World Bank, 2005). High levels of As in groundwater are especially found in the second aquifer. CGWB (1999, as cited in World Bank, 2005) noted that the depths of arsenic-rich groundwater vary in the different districts but where high-arsenic groundwater exists, they are generally in the depth range of 10–80 m. Low levels of As are found in the groundwater from the first aquifer and the third aquifer, usually. For shallow water from the first aquifer one reason for the low As amount when actually drunk is that the water is harvested through open dug wells that are likely to contain groundwater that is oxidized. Groundwater from the deep aquifer also have low arsenic concentrations, except where only a thin clay layer separates it from the overlying aquifer, allowing some hydraulic connection between them (World Bank, 2005). Figure 1 gives a visual representation.

Figure 1. Schematic overview of the three aquifers depths and their As concentration in West Bengal



2.2 The arsenic problem of drinking water

Arsenic pollution is a severe problem leading to a wide variety of diseases, such as skin lesions, blackfoot disease, diabetes, hypertension, skin cancers, and internal cancers (lung, bladder and kidney) (World Bank, 2005). Chakraborti et al. (2002) describe in detail the epidemiological diseases that they encountered in the As affected villages that they studied in West Bengal and Bangladesh. A total of about 30 million people in the Ganges delta, of which more than 6 million live in West Bengal, drink water with arsenic concentrations higher than 50 µg per litre and are thus at risk, and more than 300 000 people may have visible arsenical skin lesions (Chakraborti, 2002). (Worldwide, arsenic contamination from groundwater is found in China, Taiwan, Cambodia, Lao People Democratic Republic, Pakistan, Myanmar, Vietnam, and Nepal).

In 1995, the WHO lowered the guideline value from 50 to 10 µg per litre. The Indian standard value is still 50 µg per litre.

2.3 The arsenic problem of irrigation water

Regarding arsenic concentration in irrigation water, neither international agencies nor individual countries propose any recommended maximum permissible values (World Bank, 2005).

The arsenic problem of irrigation water concerns two issues. The first is that withdrawal of irrigation water spoils the deep wells used for drinking water. The second concerns arsenic ingestion through the food chain. There is not that much literature on the issue of arsenic poisoning via crops through irrigation. In this section we first give a small overview of the history of irrigation water in West Bengal and its sustainability. Then, we deal with some topics that are of importance to figure out to what extent it is desirable to go into more detail on possible solutions of contaminated irrigation water. These topics concern: (1) standards for As concentration in the food and the extent to which As rich irrigation water contributes to the problem, (2) the tolerable amount of arsenic in irrigation water for which crops, and other water quality requirements (related to the option of surface water as a solution), and (3) preconditions for solutions.

Irrigation on drinking water wells and its possible impact

In the 1960s and 1970s, agriculture in West Bengal was still rain-dependent and each year there was only one crop following the monsoon (Roychowdhury et al., 2002). There was thus no arsenic problem at all. To meet the food demand of the increasing population, four to five crops in one year are common at present. To reach this end ground water is used for irrigation (ibid.). The status of aquifer exploitation is as high as 79.40% from a single district North 24-Parganas (taken from Roychowdhury et al., 2002, that cite Directorate of Agricultural Engineering). This heavy withdrawal of groundwater may be the reason why iron pyrites decomposes and releases arsenic in water. Also Johnston et al. (2001) describe the risk of unsustainability of the supply of arsenic free water (especially relevant when large amounts of water are used). Within the same localities, there can be a big difference between the arsenic concentrations in the ground. In some cases, the arsenic-rich and arsenic-free zones may be separated by low-permeability materials such as clays. In other cases however, the arsenic-rich zones may be in hydraulic connection with arsenic-free zones. By pumping water from arsenic-free zones, arsenic-rich water may be induced to flow into previously uncontaminated strata, and eventually may reach the well. In the same vein, Chakraborti et al. (2002) state that:

> *"Rapid depletion of deep aquifers results in a deleterious influx from the As-contaminated aquifer above. Intensive efforts to provide deeper tube-wells for supplying drinking water may be counterproductive if the aquifer is simultaneously depleted by irrigation demands. The thoughtless exploitation of groundwater for irrigation without effective watershed management, which would have involved, for example, harnessing huge surface water and rainwater resources is now seen in retrospect as a terrible mistake."*

Standards for As in food

Concerning the issue of the possible arsenic impacts through the food chain, we first look at As standards in food. There is no standard maximum level of arsenic in food in

South and East Asian countries (World Bank, 2005), but there are some other standards. For instance, the provisional tolerable daily intake value of inorganic arsenic according to FAO/WHO (1989) is 2.1 μg/kg body weight. The WHO (1981) states that intake of inorganic arsenic of 1.0 mg per day may give rise to skin diseases within a few years (for a person of 50 kg this amounts to 20 μg/kg of body weight). The UK declared a statutory limit of 1 μg/kg fresh weight in foods for sale in the UK (Arsenic in Food Regulations, 1959, cited in Warren et al., 2003). This leaves a safety factor of 50 compared to the FAO/WHO norm if we assume a body weight of 50 kg and a food intake of 2.1 kg per person per day.

Addressing the As contaminated irrigation water, the question is raised to what extent the food contributes to the arsenic contamination. Several studies showed that most of the arsenic enters the food chain by cooking vegetables and rice with arsenic polluted water. Bae et al. (2002) for instance proposes that the content of arsenic in cooked rice is higher than that in raw rice and absorbed water combined, suggesting a chelating effect by rice grains, or concentration of arsenic because of water evaporation during cooking, or both. Studies by Carbonell-Barrachina within the framework of the TIPOT project (see other project reports) reach the same conclusion. There are several other studies on arsenic contamination on vegetables and fish (e.g. Das et al, 2004; Burlo et al., 1999; Carbonell-Barrachina et al., 1999; Carbonell-Barrachina et al., 1997). It would appear that in the rice-dominated diets of West Bengal, the intake of arsenic from food depends more on the concentration of arsenic in the cooking water than food itself. This would imply that for the health problem of West Bengal, the arsenic contamination of drinking water is of much greater urgency than of the irrigation water.

Standards for irrigation water

If we want to address the issue of contaminated irrigation water despite the fact that drinking water should prevail, it would be good to assess the tolerable amount of arsenic in irrigation water. Next to arsenic levels, it would be good to know other standards for water quality used for irrigation in order to study the option of surface water (perhaps in addition to groundwater). In order to say more about possible alternatives, it would be good to know the amount of water needed, quality of the water needed (in terms of As but also to which extent it needs to be purified) for which crop, for which surface, for which season. No standards are known for arsenic in irrigation water. Theoretically, one could derive a standard for irrigation water from a standard pertaining to an element further in the causal chain. The standard of 1.0 mg per person per day might be a starting point for instance. We could then set aside 75% of this standard to the pathway through drinking water, which would leave 0.25 mg per person per day as acceptable burden through the food pathway. If we would then know how much food a person digests per day, we may derive a standard of acceptable arsenic in food. If we then would know how much the food crops take up from the irrigation water, depending on the arsenic content of the irrigation water, we arrive at a standard for irrigation water. Knowledge gathered in the TIPOT project could be helpful in these calculations.

Economic preconditions for application of solutions

As long as the government or, more likely, the international market to which the products are exported, does not prohibit arsenic rich vegetables and cereals on the market, it is not to be expected that any farmer would be economically inclined to invest in clean irrigation water.

One alternative that we can think about is an (inter)national certification. This could go along with the certification of organically grown products. Sustainable farming has been promoted by the Indian government and standards have been developed under the National Programme for Organic Production (NPOP, see http://www.apeda.com/organic/) that sets a system of certification for products. (NPOP's system of certification does not mention arsenic). The organic market mainly concerns the export and is underdeveloped in India. This has been worded by Carroll (2005) as follows:

> *"It takes 20 minutes of hunting and asking around to get to the two shelves at Food Bazaar assigned to organic foods. The section is unidentified and the selection little more than cereals and pulses. There are only two brands on offer, both uncertified.……..This one instance is as representative of the domestic market for organic produce as it gets -- inadequate retail presence, little to no certified branded produce, an incomplete range, uncompetitive price points, and government policies that are skewed towards exports."*

Thus, domestically, there is little chance for market development of certified products. However, there might be on the international market. A more radical effect would be ensured if importing countries would set arsenic standards on imported food, e.g. the UK norm of 1 µg/kg fresh weight in foods. A well-known anecdote illustrating the power of international relations for environmental clean-up is that the issue of cholera in Bombay was only addressed after the government of Egypt had declared a boycott of all products from Bombay into Cairo.

In 2002 it was estimated that West Bengal, the largest producer of rice in the country, produced 15.3 million tones of rice, of which 2.3 million tones was marketed (Ghosh and Harriss-White, 2002). Since 1998-99, there is free trade of grains between the Indian states, but subsidies are state dependent.

2.4 The arsenic problem in local perceptions

According to current literature, awareness in the rural remote areas is still very low. Chakabroti et al. (2002) mention that among 11,000 villagers afflicted with arsenical skin lesion(s), when asked the reason for their disease, that 40% responded that it was a 'curse or wrath of God' and 50% did not know the reason. Paul (2004) conducted a study on the level of knowledge among rural residents regarding arsenic poisoning in medium and high risk regions in Bangladesh. Table 1 shows the average knowledge scores. This table shows that the average composite knowledge score for the study area is only 19 out of a maximum score of 40. Of the 356 respondents, 35 (10%) had never heard of the groundwater arsenic contamination problem (all these respondents came from the low risk region). The table also indicates that 92% of all respondents in the medium risk region and 76% from the low risk region knew that the manifestation of arsenic-related symptoms in the villages studied was due to arsenic contaminated tube well water, but a considerable number of respondents were unaware of the cause of the contamination. Nearly 50% of the respondents in both study sites who were aware of the arsenic contamination were not entirely familiar with the signs, symptoms, and diseases caused by the ingestion of arsenic contaminated water. Additionally, nearly two-thirds of all respondents were not able to correctly specify the incubation period for visible symptoms associated with the consumption of arsenic through contaminated drinking water. A similar percentage of respondents were unaware of the various arsenic mitigation techniques available and potential solutions to the arsenic problem.

Table 1. Respondents arsenic knowledge by arsenic risk regions. Source: Paul (2004)

Knowledge component	Risk region		
	medium	low	total
Arsenic poisoning (8)[a]	5.33	3.94	4.63
Sources of arsenic poisoning (4)	3.66	3.04	3.35
Symptoms of arsenic poisoning (8)	5.74	2.00	3.86
Arsenic-related diseases (12)	5.09	0.73	2.90
Preventive measures (4)	2.85	1.12	1.98
Solution to arsenic poisoning (4)	3.28	1.95	2.61
Overall (40)	26.04	12.81	19.39

[a] Figures within parentheses indicate total possible scores.

Thus, the study showed that arsenic awareness is not widespread in the study villages, and that there are gaps in arsenic knowledge regarding the diseases caused by arsenic poisoning and mitigating measures available to prevent contamination. This study identified arsenic risk region, level of education, gender, and age as important determinants of arsenic knowledge.

2.5 The arsenic problem in GO perceptions

The paper of Chakabroti et al. (2002) heralds what has happened in India since the arsenic calamity came to light in 1983, the year that the first As contaminations among 63 patients were reported.

A group of organizations worked together from 1983 to 1989 on the problem, reporting on the scope of affected areas and As related patient cases, leading to a prediction of “a grim and dangerous future” (Chakabroti et al., 2002). In 1987 a paper was published that caught attention by the media by which the government could no longer ignore the issue (ibid.). In the same year Calcutta High Court ordered to seal contaminated wells, but in practice only a few were sealed, and some were opened again, because people were not given an alternative source of drinking water, as was highlighted by the media (ibid.).

From 1989 to 2001, the information on the scope of the As problem increased and the problem also received lots of media attention (Chakabroti et al., 2002). In 1995 an international conference on arsenic pollution was held after which the government admitted part of the problem (not in full scope and denied some of the findings), but also stated that undue panic was created by the conference (ibid.). Chakabroti et al.

(2002) state that it took the government 8 years to accept that Calcutta has an As problem.

Despite the fact that the government of West Bengal initiated several As committees and task forces, awareness if often said to be still weak. Our own results in the research village are in Chapter 3.

2.6 Solutions for drinking water proposed and applied

There are broadly three ways to access clean water in places where arsenic is found in the ground. The first is to tap from a clean source, the second is to clean the source (in-situ treatment) and the third is to clean the polluted water (post-treatment of polluted water). There is a wide range of solutions that fit in one of the three. There is an enormous amount of literature that deals with various technologies to access clean water (e.g. WHO, 1997; World Bank, 2005; Galvis et al., 1998, Hussain et al., 2001, Parga et al., 2005; Howard, 2003; Ming-Cheng Shih, 2005). Johnston et al. (2001) and World Bank (2005) give the most extensive and detailed overview of the methods. In this section, we will give a brief description of the main solutions that are proposed and applied, mainly based on the overview of Johnston et al. (2001), and we will briefly discuss their strengths and weaknesses. We do not aim to be exhaustive; there are more solutions than we describe here.

Tapping clean source

Rainwater harvesting

The harvesting of rainwater seems to be the most sustainable way to access clean water. The source may not last the whole dry season, however, and therefore promotion of rainwater harvesting will need to be combined with other solutions. Good designs of rainwater tanks are available and at relatively low cost (Howard, 2003). The main risks concern the feaces that gets in the tank, especially from birds, but this is relatively easy to deal with (ibid.). Besides, close to urban areas, and when metal roofs are used, collected rainwater can contain unsafe levels of lead and zinc, and possibly other metals (Johnston et al., 2001).

The World Bank (2005) reports some social issues regarding rainwater harvesting, namely that (1) some users don’t like the taste of the water, (2) that it has been reported from Bangladesh that the return to rainwater harvesting may be viewed as a step backwards to several decades ago when it was quite widely used.

Surface water

The per capita available surface water in arsenic affected areas of West Bengal is about 7000 cubic meters (Hossain et al., 2005). During the monsoons, the average annual rainfall in this region is about 1600 mm (ibid.). In addition, West Bengal is richly endowed with other available surface water resources such as wetlands, flooded river basins, lagoons, ponds, and ox-bow lakes (ibid.). This available surface water can be tapped as an important source of drinking water. However, surface water is often heavily polluted with faeces as a result of poor sanitation and hygiene and it may also be contaminated with chemicals from industrial or agricultural runoff, such as heavy metals, pesticides, phosphate or nitrate. Surface water is usually free from arsenic contamination. However, there are cases where surface water was contaminated because the source of the water originates from arsenic rich rocks (Johnston et al., 2001) or waters affected by mining activities (World Bank, 2005). Surface water always needs to be purified. Usually, it is best to include multiple barriers to purify surface water (Johnston et al., 2003). They often start with sedimentation to remove coarse suspended solids that could clog filters or reduce disinfection efficiency and can remove at least 50%, and up to 90% of turbidity and suspended solids (Johnston et al., 2001). This is followed by coagulation and filtration (see Johnston et al., 2001) or alternatively the inexpensive alternative to coagulation, slow sand filtration (see e.g. Galvis et al., 1998; Graham and Collins, 1996) or bank filtration, where water, originating mainly from the river , is pumped up at a short distance from the river (see e.g. Johnston et al., 2001). Johnston et al. (2001) mention that slow sand filtration will not efficiently remove arsenic or agricultural chemicals such as pesticides. Further, the water might still be needed to be disinfected to kill pathogens by boiling, ultraviolet (solar or artificial) radiation (e.g. Acra et al., 1989; EAWAG, 1999), or chlorination (see Singer, 2000; WRC, 1989; WHO, 1997b).

Dug wells or ring wells

Dug wells are traditionally the most wellknown method of groundwater use. The water from dug wells has been found to be relatively free from dissolved arsenic and iron, also in locations where neighbouring tube wells are severely contaminated (World Bank, 2005). The World Bank provides an example of a case in western Bangladesh where a 30 m deep tube well with a groundwater arsenic concentration of around 2,300 µg per litre is located just a few meters from an 8 m deep dug well with an arsenic concentration of less than 4 µg per litre.

The reasons for the relatively low concentrations of arsenic in dug wells are not fully known, but possible explanations include (ibid.):

- The water in the dug well slowly oxidizes due to its exposure to open air, large diameter and agitation during water withdrawal which can cause precipitation of dissolved arsenic and iron (ibid.).
- Dug wells accumulate groundwater from the top layer of a water table, which is replenished each year by arsenic-safe rain and percolation of surface waters through the aerated zone of the soil (ibid.).

Construction of such wells with cement ring walls provide bacteria free water, if the place is sunny and without trees. Caution should be taken however; the water should be well prevented from bacterial contamination etc. Recommended is to completely seal the well and withdraw the water by a hand pump. However, the lack of oxygen then might put the oxidation process at risk.

The water can be treated further with simple sand filters, or chlorination for disinfection.

A report of SOS arsenic.net describes a project that promotes the development of dug wells in Bangladesh. "…..with a very limited budget has a big impact…..Dug wells and rainwater harvestings have shown that arsenic free water can be obtained at low cost (i.e. 50 USD)." (sos-arsenic.net/english/project2003/project-report-august03.html#sec6). A list of advantages according to this webpage is as follows:

- Dug wells are indigenous technology in Bangladesh.
- The wells are cheaper and easier to construct and less susceptible to bacteriological contamination (BRAC, August 2000).
- Natural biological filtration occur, when water percolates through sand bodies (develop microbial flora whose metabolism contributes to the effectiveness of removing effluents).
- In dug wells within the standing water simple sedimentation take place and has been found frequently a substantial reduction in BOD (Biological Oxygen Demand).
- Natural iron coagulation and settlement occur within standing water (decrease in arsenic, suspended solids, ammonia, nitrate and phosphate content

Care has to be taken however, despite the tendency for low arsenic concentrations in dug well waters, not all are found to be below acceptable limits (World Bank, 2005). Water testing is thus necessary. Besides, they may run out of water supply during the dry season.

Deep tube wells

Deep tube wells are an attractive option. The middle-level aquifer contaminated with arsenic is passed over and the risks on microbial hazards are low because of the natural filtering of aquifer materials, and long underground retention times (Johnston et al., 2001). Questions arise though on the sustainability in terms of arsenic leaching into the deep layer and in terms of the sinking of water table. There is still the risk on arsenic, but this is most likely because of the uncertainty of the depths of the deep tube wells that have been tested positive on arsenic contamination (Howard, 2003). Besides, there is still uncertainty on the arsenic movement in the sub-surface and the scale and degree of arsenic contamination in the deep aquifer (ibid.). The initial capital costs of deep wells are around 700 and 800 USD (World Bank, 2005). Chakraborti et al (2002) report that some newly constructed deep tube wells where initially no As was found, were found As positive after some time. They also report that the analysis of 2146 deep tube-wells (100–450 m) from six districts showed 22.3% of the samples to contain more than 10 µg per litre As and 9.9% to contain more than 50 µg per litre As. Chakraborti et al. (2002) further state that water in deep aquifers takes decades, even centuries, to accumulate and is inadequately replenished by rainfall.

Rapid depletion of deep aquifers results in a deleterious influx from the As-contaminated aquifer above. Intensive efforts to provide deeper tube-wells for supplying drinking water may be counterproductive if the aquifer is simultaneously depleted by irrigation demands. The New Scientist (December, 2005; p5) reports that in Bangladesh the deep aquifers from which allegedly arsenic-free water is extracted receive an arsenic top-up every rainy season. Fendorf (Stanford University) speculates that arsenic gets into the aquifers when seasonal flood water trigger its release from sediments close to the surface, transporting it down into the aquifers.

Pre-treatment (in situ treatment): clean the source

The technology that is tested in the TIPOT project is an in-situ treatment. Quoting World Bank (2005) on this technology:

> *"In situ oxidation of arsenic and iron in the aquifer has been tried in Bangladesh under the Arsenic Mitigation Pilot Project of the Department of Public Health Engineering (DPHE) and the Danish Agency for International Development (Danida). The aerated tube well water is stored in feed water tanks and released back into the aquifers through the tube well by opening a valve in a pipe connecting the water tank to the tube well pipe under the pump head. The dissolved oxygen in water oxidizes arsenite to less-mobile arsenate and the ferrous iron in the aquifer to ferric iron, resulting in a reduction of the arsenic content in tube well water. Experimental results show that arsenic in the tube well water following in situ oxidation is reduced to about half due to underground precipitation and adsorption on ferric iron. The method is chemical free and simple and is likely to be accepted by the people but the method is unable to reduce arsenic content to an acceptable level when arsenic content in groundwater is high."*

Johnston et al. (2001) state that the technique should be considered with caution. First they state that oxidants are by definition reactive compounds, and may have unforeseen effects on subsurface ecological systems, as well as on the water chemistry. Secondly, they mention that care must be taken to avoid contaminating the subsurface by introducing microbes from the surface. Finally, at some point pore spaces can become clogged with precipitates, particularly if dissolved iron and manganese levels are high in the untreated water. For more information on the technology of the TIPOT project and many of the points raised by the World Bank and Johnston et al., see the project publications (co-) authored by ISWA.

Post-treatment of arsenic rich water

Many solutions are found to remove arsenic from the water. There are many sources that describe and compare the various technologies, for instance Parga et al. (2005), Johnston et al. (2001). Parga et al. (2005) describe that the removal efficiency for arsenic is often much lower for As(III) than for As(V) by using anyone of the conventional technologies for elimination of arsenic from water, so either elevation of pH or oxidation of arsenite to arsenate is considered a prerequisite for any treatment method to be efficient. Table 2 gives an overview of technologies that remove arsenic from the groundwater, taken from Parga et al. (2005) with data from Johnston et al. (2001) and some other sources added. The most common arsenic removal technologies are grouped into the following four categories:

- Oxidation
- Coagulation
- Sorptive filtration
- Membrane filtration

Table 2. Overview of technologies that remove arsenic from the groundwater. Sources: Parga et al. (2005) with data from Johnston et al. (2001) and some other sources.

Technologies	**Advantages**	**Disadvantages**	**Removal (%) and cost**
Oxidation/precipitation; reactions that reduce (add electrons to) or oxidize (remove electrons from) chemicals, altering their chemical form (Johnston et al., 2001). Oxidation is often done as pretreatment to convert arsenite (As(III)) to arsenate (As (IV)).			

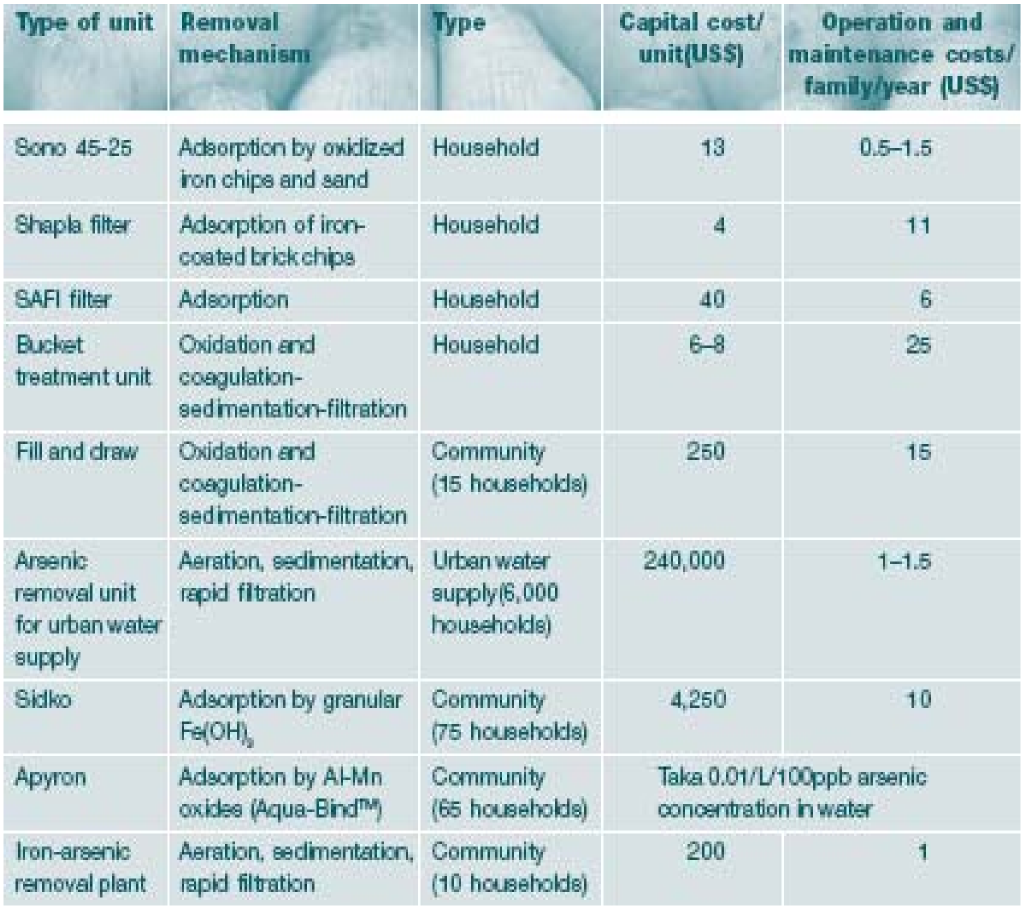
Air oxidation	• Relatively simple, low-cost • Also oxidizes other inorganic and organic constituents in water	• Mainly used as pre-treatment • Oxidation process is very slow taking weeks.	80
Chemical oxidation (e.g. chlorine, ozone, permanganate, Hydrogen peroxide, Solid manganese)	• Oxidizes other impurities and kills microbes • Relatively simple and rapid processes • Minimum residual mass • Common chemicals that are available	• Efficient control of the pH and oxidation step is needed	90
Coagulation/co-precipitation: Coagulation with metal salts and lime followed by filtration is a well-documented method of arsenic removal from water (World Bank). A coagulant is added to contaminated water. After adding the coagulant, the water should be stirred, allowed to settle, and filtered for best results. Coagulation improves parameters such as turbidity and color, and can reduce levels of organic matter, bacteria, iron, manganese, and fluoride, depending on operating conditions (Johnston et al., 2001). If arsenic is present as arsenite, the water should be oxidized first.			
Alum coagulation	• Durable powder chemicals are available • Relatively low capital cost and simple in operation	• Generates arsenic rich sludge • Low removal of arsenic • Pre-oxidation required (low removal of As (III)) • Optimal over a relatively narrow pH range	90 Relatively inexpensive
Iron coagulation	• Common chemicals are available • More efficient than alum coagulation on weigh basis	• Generates arsenic rich sludge • Medium removal of As(III) • Sedimentation and filtration needed	94.5 Relatively inexpensive
Electrocoagulation with air injection (Parga et al., 2005)	• The EC process operates on the principle that the cations produced electrolytically from iron and/or aluminum anodes enhance the coagulation of contaminants from an aqueous medium. • Removes both As(III) and As(V) • It does not require the addition of chemicals or regeneration and has a high efficiency rate.	• ?	?
Lime softening	• Lime (Ca(OH)2) hydrolyzes and combines with carbonic acid to form calcium carbonate, which acts as the sorbing agent for arsenic removal. • Most common chemicals are available commercially	• Readjustment of pH is required • Large coagulant doses are required and thus generates large volume of waste	91 Relatively inexpensive (more expensive than iron/alum coagulation)
Sorption techniques; The efficiency of sorption techniques depends on the use of an oxidizing agent as an aid to sorption of arsenic. Saturation of media (i.e. when the sorptive sites of the material have been exhausted and the			

medium is no longer able to remove the impurities of the water) takes place at different stages of the operation, depending on the specific sorption affinity of the medium to the given component (World Bank,….) and the total run lengths (Johnston et al., 2001).			
Activated alumina	• Relatively well known and commercially available	• Needs replacement after four to five regeneration (less than iron exchange resin) • Generates arsenic rich waste • Works best in slightly acidic waters (pH 5.5 to 6) • Water containing arsenite should be oxidized before treatment.	88 Moderately expensive
Iron coated sand (UNESCOPRESS, 2005)	• Cheap sand coated with iron oxide is a by product of water cleaning stations (that use sand to remove Fe from water) • Remove both As(III) and As(V) • It is easy to use, requires no power and can be produced locally. • A family filter (now produced for less than 30 euros per piece) can produce 100 litres of arsenic-free water per day	• Replacement of sand necessary each year • Produces toxic solid waste	93 Cheap
Ion exchange resin	• Well-defined medium and capacity • The process is less dependent on pH of water • Exclusive ion specific resin to remove arsenic	• If arsenic is present as arsenite, the water should be oxidized first because it only removes arsenate (Johnston et al., 2001). • Requires high-tech operation and maintenance • Regeneration creates a sludge disposal problem • Run lengths determined by sulphate, thus resins are only appropriate in waters with under 120, preferably under 25 mg/L sulphate (Johnston, . • Limited life of resins	87 Moderately expensive
Dolomite	• Remove better arsenate than arsenite both As(III) and As(V)	• ?	?
Biosorbent (Murugesan et al, 2006)	• arsenic removal with the waste produced during black tea fermentation (the tea fungus) • an effective biosorbent for As(III) and As(V); • The metals in the waste can be desorbed from the mat and the mat can be easily degraded which is not possible in chemical adsorbents.	• ?	?

Membrane techniques These make use of synthetic membranes, which allow water through but remove many contaminants from water including bacteria, viruses, salts, and various metal ions (World Bank…). They are of two main types: low-pressure membranes, used in microfiltration and ultrafiltration; and high-pressure membranes, used in nanofiltration and reverse osmosis (ibid.). See Ming-Cheng Shih (2005) for an overview of membrane technologies.			
Nanofiltration	Well-defined and high-removal efficiency	• Very high-capital cost • Pre-conditioning • High water rejection	95 relatively expensive
Reverse osmosis	No toxic solid waste is produced	High tech operation and maintenance	96 relatively expensive
Electrodialysis	Capable of removal of other contaminants	Toxic wastewater produced	95 ?

The costs of the technologies are of great importance. To have some idea of the costs that are involved, Table 3 and Table 4 give an outline of the costs of various technologies applied in Bangladesh and in India.

Table 3. Comparison of Arsenic Removal Mechanisms and Costs in Bangladesh (copied from World Bank, 2005)



Type of unit	Removal mechanism	Type	Capital cost/ unit(US$)	Operation and maintenance costs/ family/year (US$)
Sono 45-25	Adsorption by oxidized iron chips and sand	Household	13	0.5–1.5
Shapla filter	Adsorption of iron-coated brick chips	Household	4	11
SAFI filter	Adsorption	Household	40	6
Bucket treatment unit	Oxidation and coagulation-sedimentation-filtration	Household	6–8	25
Fill and draw	Oxidation and coagulation-sedimentation-filtration	Community (15 households)	250	15
Arsenic removal unit for urban water supply	Aeration, sedimentation, rapid filtration	Urban water supply(6,000 households)	240,000	1–1.5
Sidko	Adsorption by granular $Fe(OH)_3$	Community (75 households)	4,250	10
Apyron	Adsorption by Al-Mn oxides (Aqua-Bind™)	Community (65 households)	Taka 0.01/L/100ppb arsenic concentration in water	
Iron-arsenic removal plant	Aeration, sedimentation, rapid filtration	Community (10 households)	200	1

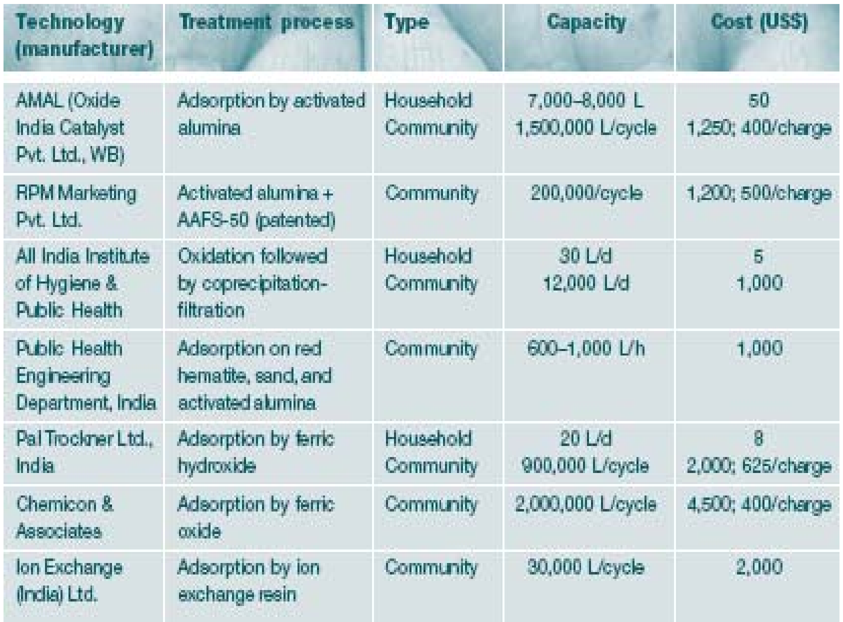
Conclusion

The overview shows that there is no simply best option, and solutions will have to be worked out depending on the circumstances. Progress appears to be possible along two parallel tracks:

(1) Technological improvement within the separate groups of options (rainwater, surface water, very shallow wells, in situ treatment of shallow wells, add-on technologies of shallow wells, deep wells).
(2) The development of measurement- and assessment systems that may efficiently indicate which (combination of) technologies is most appropriate in a given situation (water sources, aquifers, economic capacities, population density, etc.).

In all this, rainwater and surface water appear to deserve much attention as a source for both potable and irrigation water. A restructuring of irrigation towards surface water may help safeguard the low arsenic levels in deep wells.

Table 4. Comparison of Costs of Different Arsenic Treatment Technologies in India (copied from World Bank, 2005).



Technology (manufacturer)	Treatment process	Type	Capacity	Cost (US$)
AMAL (Oxide India Catalyst Pvt. Ltd., WB)	Adsorption by activated alumina	Household Community	7,000–8,000 L 1,500,000 L/cycle	50 1,250; 400/charge
RPM Marketing Pvt. Ltd.	Activated alumina + AAFS-50 (patented)	Community	200,000/cycle	1,200; 500/charge
All India Institute of Hygiene & Public Health	Oxidation followed by coprecipitation-filtration	Household Community	30 L/d 12,000 L/d	5 1,000
Public Health Engineering Department, India	Adsorption on red hematite, sand, and activated alumina	Community	600–1,000 L/h	1,000
Pal Trockner Ltd., India	Adsorption by ferric hydroxide	Household Community	20 L/d 900,000 L/cycle	8 2,000; 625/charge
Chemicon & Associates	Adsorption by ferric oxide	Community	2,000,000 L/cycle	4,500; 400/charge
Ion Exchange (India) Ltd.	Adsorption by ion exchange resin	Community	30,000 L/cycle	2,000

2.7 Solutions for drinking water applied in West Bengal

Since 1997, the government West Bengal, the World Bank, UNICEF, WHO, and other international aid agencies and with NGOs have initiated a two-phase program to combat the arsenic crisis (Hossain et al., 2005). The first phase was to identify contaminated tube wells and the second to provide clean drinking water. Tube wells were painted green or red corresponding to arsenic concentrations below and above 50 µg per litre (the national standard), respectively, utilizing field kits for arsenic testing. But, the tests kits turned out not to be reliable; false negatives were as high as 68% and false positives up to 35% (Rahman et al., 2002).

Of the 2000 arsenic removal plants (that capture the dissolved arsenic using ferric salts) installed in villages in West Bengal, four out of five are either abandoned or deliver smelly and discoloured water (New Scientist, 2004). Based on an interview with Chakraborti the article also states that India has so far spent 3 million US dollars on plants to capture the dissolved arsenic using ferric salts and that of the 20 percent of removal plants still apparently functioning well, many are not removing arsenic to the required standard, mainly because villagers do not know how to maintain the plants. More details are provided by Hossain et al. (2005). The paper evaluates the efficiency of 18 ARP (Arsenic Removal Plants) projects from 11 manufacturers. None of the plants could achieve the WHO standards of 10 µg arsenic per litre and only two achieved the Indian standard of 50 µg per litre. The urine samples of the villagers in the project's area were found that 82% contained arsenic above the normal limit.

Hossain et al. (2005) summarise the causes of the poor performance as follows:

- *Maintenance.* The manufacturers did not give the correct directions regarding "forward washing".
- *Clogging.* The problem of sand gushing was not taken into account.
- *Lack of user friendliness* The system provided both arsenic free water (for drinking) and arsenic polluted water (for other purposes) and there was no prevention of tapping "wrong" water.
- *Poor management of sludge from the plant.*

2.8 Solutions for irrigation water proposed and applied

As far as we know, literature on arsenic contamination of irrigation water concerns mainly the effects of arsenic polluted water on the amount of arsenic in the crops and the resulting health impacts. However, no specific solutions are put forward for the use of poisoned irrigation water. As we have seen in the previous section, there are three ways of having access to clean water. We will discuss what these solutions would have to offer for irrigation water. It is important to keep in mind that (1) irrigation water concerns large quantities, that (2) that the options to access clean water are often costly and (3) that clean water is scarce and that groundwater is affecting the deep aquifer (see section 2.4.1).

Broadly stated by Chakraborti et al. (2002), up to now, no efforts have been made to adopt effective watershed management to harness the extensive surface water and rainwater resources in West Bengal. Proper watershed management and participation by villagers are needed for the proper utilization of water resources and to combat the As calamity; there are huge surface resources of sweet water in the rivers, wetlands, flooded river basins, and oxbow lakes.

More specifically, tapping water from clean sources may offer access to clean water, but only at a certain period of the year. Harvesting of rainwater may form some buffer before the dry season starts, but it will not last. Surface water offers a good source when being close to a river. Or, a big pond may offer enough water for a certain period. The need for irrigation water however, is the highest during the dry season when water is scarce.

Concerning TIPOT's technology of in-situ treatment of shallow wells, it may be noted that if the technology would work well indeed for drinking water purposes it might be up-scaled to also supply arsenic-free irrigation water.

3.
The study area and research

The present chapter introduces the village where the field trial with the SAR technology was carried out and the empirical studies were undertaken. We also discuss the methods of these empirical studies as well as one result, namely concerning the awareness on the arsenic problem. Other results, especially n willingness to pay and delivery system, are in chapter 6.

The village of Kasimpur is one of the nine moujas of Kasimpur Panchayat located in Barasat I (see Figure 2) in the district of north 24 parganas in West Bengal. The village is about 40 kilometres from Calcutta. The village is well connected to the city, because the train station *Datta Pukur* is about 2 km from the boundary of the village which takes about 10 minutes by van rickshaw. The nearest market, *Duttapukur Haat*, is near the train station. Products are also transported by train to Calcutta.

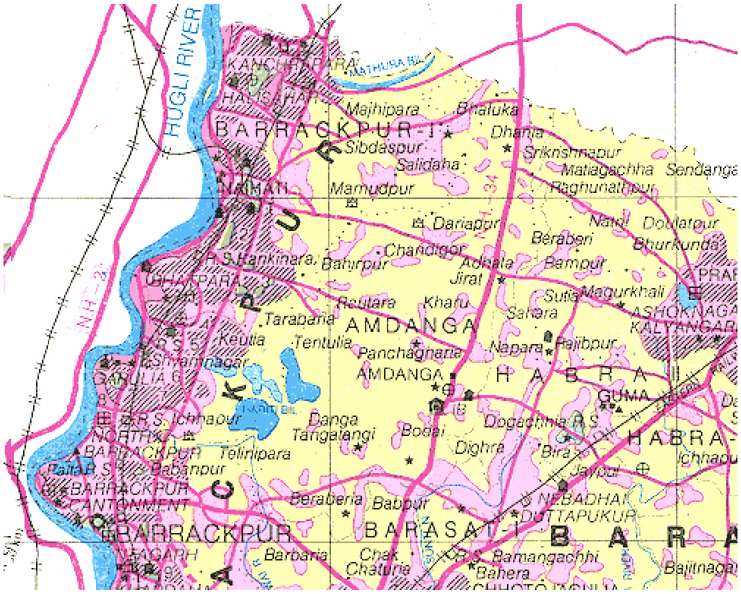


Figure 2. Research area

3.1 Methods

Site selection and sampling

The selection of the village concerned mainly that the in-situ SAR experiment of the project could be established in a safe environment of the mission post of RKVM. Kasimpur village used to be an agrarian village, but at the time of the study a remaining 100 of the 350 households were identified as mainly agrarian of which we took a random sample of 33 households for data on agrarian topics. All but one participated in the lengthy research consisting of time use diaries and extensive interviews on all cash and material flows covering a full year. Of the remaining 250 households, an additional random sample was taken of 30 households for topics specifically focusing on awareness of arsenic contamination and on the willingness to pay study.

Interviews and observations

The field study took place from December 2004 till April 2006. We have collected most of the data through personal interviews with the household members. Adult household members (aged between 12 and 60) were interrogated regarding various issues, such as household composition, demography, land use, time use, food and water intake, awareness about arsenic contamination in ground water, willingness to act, willingness to pay for arsenic free water, etc. More specifically, for the various topics the methods were as follows.

For insight in the **perception on arsenic contamination** and its impact on health, 61 respondents from different age, sex and occupation were first asked whether they know that arsenic contamination in ground water is a problem for this district as a whole. If the answer was "yes" they were asked to explain their views on this arsenic contamination. If the answer was "no" the researcher explained the impact of arsenic by showing pictures of affected people, among others. She also described the current scenario including the health related problem in the district and in the Barasat Block I and II (where the village is located) were also described to them. Their reactions were noted.

To get the respondent's **perception on the provision of the SAR technology** CML developed a couple of user-friendly draft variants of the technology. The model plant in Kasimpur looks very complex, while the user friendly technologies CML drafted were easily understandable. We showed and explained these drawings to academic, administrative and local people. We discussed how it could function technically, how much such a thing could cost and how it could function in the household or the village. The respondents were asked about their views on the most suitable technology model and the manner the technology should be offered (e.g. leasing, buying, provision by the local government etc.).

To elicit households **willingness to pay** for arsenic free ground water the Contingent Valuation Method (CVM) was be used. CVM is a widely used, non-market valuation technique that estimates the demand for a proposed commodity in a hypothetical market. In the context of provision of the In-situ technology the question concerning the costs of technology was not clear. CVM study provided information about the contribution that households said they would be willing to pay. After discussing the impact of arsenic contamination, the respondents were informed about the hypothetical situation that "if we would have three different technologies of the in-situ technology for the removal of arsenic from the ground water, would you be willing to contribute money or time to obtain arsenic free water?" If the answer was "no" (the respondents' willingness to pay was thus zero), they were asked for the reason. If the answer were "yes", the three technologies were explained to them and they were asked to express their own opinion about the suitability and viability of each of the technology in the respondents' social and economic situation. Then we proposed a payment ladder, containing payment ranges starting from Rs 10 – 100 per a specified amount of water per cycle per day, and payment vehicle options (how they will pay). Finally, the respondents were asked about the amount he would be willing to pay for this arsenic free water supply.

In order to estimate the **demand for drinking water and the calorific intake** per individual per household we used 24 hours recall interviews on the amount of each of the food items and the water intake per household member for potable and cooking purposes. Since women take decision in cooking and housekeeping, all the information related to food and total water consumption was gathered from the women. The water consumption of household members was measured by the number of glasses or bottles of water consumed per day.

For the **time allocation studies**, the respondents' primary activities, i.e. the activity corresponding with the major aim of the activity, were reported with a preciseness of 15 minutes for one day followed by a four to five days' gap, from March 2005 up to April 2006. Some respondents recorded their own diary, but most co-operated by 24-hour recall interviews. The times use records for the sample household members were gathered throughout the day, the housewives and the young members were interviewed in the morning and in the afternoon the male farmer members. The reported activities were translated to the categories of an empirical form, which was based on the analytical time/cash categories. Assistants helped entering these data in the empirical form/table in the database.

Further, a questionnaire was developed covering all **material and cash flows**. To make the interviews feasible, appointments were made per topic with the knowledgeable person of the household, for instance, the women about all details of livestock and food and water consumption, the male head on the fields and crops. Thus, interviews covered topics on field type, land use in different seasons, area, ownership, production details and marketing of different crops in different seasons, inputs detail per crop i.e., material input (e.g. seed, fertilizer, pesticides), labour (e.g. lab hour per activities like harrowing, fertilizing, harvesting), and also the capital inputs (like tractor, plough etc) and capital per crop and storage. If a household produced more than two crops annually, the interviewer visited the respondent several times on appointment to complete the information about the production activities per crop. By repeatedly visiting households, the researcher gained trust and could enhance the validity of the data. Actually, at the initial stage of field survey household members seemed uncertain and the data they supplied about the landholding and other demographic characteristics at the initial period differ much with the interviews after 4-5 days interactions.

Because the researcher spent so much time in the village during the periods of the field survey, she could **observe** specific feature of the village and the villagers. The researcher got the idea about, among others, the location, village routs, house types, division of labour, female work force participation, culture, religion, various social aspects, water-use and about different group and types of settlements on the basis of which a map of the village has been drawn by the researcher.

Further, some specific key-respondents in the village provided **general information** about land, labour, politics, culture, etc. The panchayat pradhan (local government official) gave us the initial information about the Kasimpur panchayat and the village.

He provided the voters list from which we got the final list of agricultural households. He also supplied some other information on numbers of tube wells in the village, depth of tube wells and about the irrigation system. He gave us the information about the self help groups, political parties and the performance of the panchayat. One key-respondent was head of our sample households, gave information on history of the village, previous cropping practice, irrigation system of the village, etc. An elected local panchayat member of the village, helped us in selecting the agricultural household from the list of household. Secondary data were used such as market prices and conversion factors. A database was developed in "Microsoft Access" to enter and store all the data.

3.2 People, livelihoods, social and political organisation

Table 5 gives information about some features of the panchayat as a whole, such as local infrastructure and area. Panchayat village is one of the more agrarian villages of this panchayat.

Table 5. Some special features of Kasimpur Panchayat (the case study village Kasimpur is one of the mouja's of Kasimpur Panchayat).

Some special features	**Description**
Total area	3,167 hectares
Amount of moujas (villages)	9
Amount of elected panchayat members	22
Population	35,324
Number of households	10,448
Backward class population (SC/ST)	5-6%
Primary schools (up to class 4)	11
Secondary schools (up to class 10)	2
Junior school	1
Private kindergarten schools	5
Post office	2
Bank	1
Litreacy centre (sponsored by government)	9
Health centre (sponsored by government)	4

Source: Panchayat Office, Kasimpur (1999-2000)

Livelihoods

Total population of Kasimpur village consisted of about 1500 people divided over 350 households. The main occupation of almost 30 percent of the households is farming, but most households are involved with at least some of the many other occupations in the village, most of which are related to agro-based work, such as daily labour, business in vegetables, promoters, traders (jute and milk), teacher, private tutor, carpenter, bee cultivator, money lenders, doctors (quack) etc. Table 6 shows the amount of agrarian households that are also involved in other livelihoods than farming.

Table 6. Livelihood activities of the agrarian households in Kasimpur village. Source: field survey.

	Description of Activities	Amount of households (N=33)	Percentage Total
Farming Activities		33	100
Off farm Activities			
	Labour in service sector (in shop, bank, post office, van driver etc.)	11	33
	Other business (e.g. construction materials, raw materials, vegetables)	10	30
	Business and distribution of cow milk	10	30
	Sewing	5	15
	Factory	4	12
	Tuition	3	9
	Mason	3	9
	Panchayat member	2	6
	Carpenter	1	3
	Cultural activities (like singing, dancing, etc.)	1	3

Division of labour

In all the households, the male is the head of the household, makes the monetary decisions and is the main wage earner. The female is responsible for the housekeeping, rearing children, looking after livestock and helping in agricultural work. Usually women take decisions concerning rearing their children. If the household has a home garden, the woman looks after it most of the time, but the man also helps.

Household size

Table 7 Household sizes among the agrarian households of Kasimpur village. Source: field survey

Household size classification	Number of households (N=33)	Percentage of households
Small Household (family size of less than 4 members)	8	24
Medium Household (family size of 4 to 6 members)	22	67
Large Household (family size of 7 members and above)	3	9

As in the rest of the world, the household sizes in India have been shrinking over the decades. These days, the institute of the joint family is making place for the creation of nuclear families. As Table 7 will show, this is also apparent among the farming households in Kasimpur. The household sizes vary between a maximum of 7 to a minimum of 1. In this wide range the average household size was 4.3. The table shows three classes of household sizes, namely, large households with 7 or more household members, medium households with 4 to 6 household members and small households with 1 to 3 members.

Household composition and literacy

Table 8 provides some main characteristics of the agrarian households of Kasimpur village, namely the percentage males and females, the age groups and the educational status.

Table 8 Main characteristics of the agrarian households in Kasimpur village. Source: field survey.

Main characteristics	**Total number in sample**	**Percentage**
Sex (N =142)		
Male	77	54
Female	65	46
Age Group (N =142)		
Child (less than 12 Years old)	15	11
Adult (12 years <age < 60 years)	116	82
Old (60 years and above)	11	8
Educational Status (N=139)		
Illitreate	34	25
Primary Schooling (up to class five)	42	30
Secondary Schooling (up to 10 Class)	54	39
Educated (above 12 class)	9	6

The table shows among the sampled population 54 percent are male and that of 46 percent are female. The age group composition of the sampled households shows that the majority consisted of the economically active groups of adults, 82 per cent. The economically dependent group was about 20 percent of the population, i.e. children 11 percent and elderly 8 percent. The low percentage of children is not representative for India.

Houses and property

The village has three types of houses. (1) pacca, which are constructed, (2) kachcha, those made up of mud and straw, and (3) semi-pacca, those are mixed. Among the agrarian households, 67 per cent have constructed house, 27 percent owned semi-constructed and 6 percent live in mud houses.

There are quite some newly built pacca houses and houses being built in the village. These mainly belong to people from Calcutta and would like to stay in the village for the weekend. These houses are severely protected. Also land is protected, especially by fences of bricks. According to a key respondent, only people who bought land in Kasimpur but do not live there do that to show that that piece of land is theirs. If they would not protect it, there is a chance that other people will eat some pieces of your land. There are many mango tree gardens (some mixed with banana) and all these fruit tree gardens have fences too. A key respondent said that otherwise people will steel the fruits.

Social events

Almost all the households have electricity and they spend lots of leisure time by watching television programme. Some farmers watch programmes on farming news and training. The children go to play ground or for swimming after returning home from school. They usually play cricket or football while the male adults spend time in local clubs, where the members also celebrate some social occasion like Independence Day, Republic Day, and "pujas", where they celebrate and pray with different idols of god. People also organize themselves to conduct blood donation camp once a year and play cricket and football tournaments during winter, etc. As far as we have noticed (and we never got complaints of the women in the village) there is no problem in the village related to alcoholism.

Political situation

There are 3 major political groups in the panchayat area as well as in the research village, namely the Communist Party of India Marxist (CPIM), the Congress and the Trina Mul Congress (TMC). Among these parties the CPI (M) is the ruling party in the Kasimpur Panchayat as well as in West Bengal.

Self help groups

There are 4 self-help help groups (SHGs) in the Kasimpur panchayat area, consisting of at least 8 members of different families. They can open an account in the bank with their own gathered money. The funding is based on a grading mechanism in which we find a grading system. At the initial period of six months the 1st grading of the performance of SHG takes place. This implies among others that they have to conducted periodical meetings with members, they gathered funding and started small projects like agribusiness, poultry, dairy etc. If they have proved to be viable, the bank will give 4 times a loan of their deposited fund in the bank. After 1 year there will be another grading, and after that they can run any independent project with the help of the bank. In the study area they have 4 SHGs (e.g. "Dristi", "Sristi" "Bijiya"). The members of "Dristi" are from BPL families.

3.3 Land use and agriculture

Agricultural land holding

Table 9 shows the land holding pattern of the sampled agrarian households. It shows that 91 percent of the farmers in the sample are marginal farmers, cultivating less than one hectare land, and that 9 percent are small farmers, cultivating between 1 and 2 hectare. The cultivable land holding of the agrarian households ranges between a maximum 15 bigha to a minimum of 1 bigha in the sample, with an average of 3.58 bigha i.e., 0.58 hectares. Of this land, 82 percent is cultivated and 18 percent fallow. The land distribution pattern in the above table shows that 60 percent of the land used by the marginal farmers is possessed by the tillers and that 40 percent of the land used by the small farmers is possessed by the tillers. The remaining land is rented as tenancy.

Table 9. Landholding pattern and possession of the agrarian households in Kasimpur village. Source: field survey

Land holding pattern	Number of households (N=33)	Percentage of land under possession (100)
Marginal farmer (cultivated land is < 1 hectare)	30 (91 percent)	60
Small farmer (cultivated land is between 1 and 2 hectare)	3 (9 percent)	40
Medium farmer (cultivated land is between 2 and 4 hectares) Large Farmer (more than 4 hectares)	-	-

The type of the soils in the village varies from sandy to clayey loam and sandy loam.

Cropping

According to key-respondents, the quick urbanization resulted in a shift in land use pattern since the past few years from cultivation to alternative use. West Bengal is ranked first in paddy production in India. Rice is the major crop in West Bengal and also in Kasimpur. There are three varieties of paddy in India, namely Aus, Amon and Boro. They are planted during the various seasons. There are three main agricultural seasons in the village as in West Bengal. The first season of the year the farmers called summer *Chaitra-Baisakh-jaisthya* (February to May), followed by Monsoon *Asarh-Srabon-Bhadra* (June to September), to end with the winter *Pous-Magh-Phalgun* (October to February). The Aus variety is cultivated during winter, Amon during monsoon and Boro during summer. The latter variety is a high yielding variety and needs much water for good production. The farmers in the sample cultivated only two varieties, Amon and Boro. Farmers mentioned that the weather changes affect the production of paddy. The monsoon season has changed. Instead of continuous rainfall, there have been huge rainfalls for three days, followed by three days of sun.

Other crops grown in Kasimpur village are oil seed, potato, tomato, onion, banana, mango, winter vegetables like, cauliflower, cabbage, Indian flat bean (sem), carrot, green pea, spinach, summer vegetables like bottle gourd (Lagenaria siceraria), bitter gourd (Momordica charantia), gourd , pumpkin, pointed gourd, ladies finger, egg plant, luffa (different varieties), green chilly and major cash crop like jute. For marketing products farmers have to be lucky, they told. One farmer told that he was lucky, when he sold the potato harvest. He stored the potatoes for 2 weeks in his house and then the prices went up already. The farmers using a cold storage were unlucky, because after 6 months the prices were low again, and then they had to sell.

Agricultural inputs

Seeds

The farmers mentioned that they access to quality seeds is a major problem. Most farmers said that they are too poor to afford certified seeds. Farmers usually use seeds from previous harvest added with some seeds from the market. The Panchayat also distributes paddy seed to the poor farmers for free. The seeds available in the market are imported come from other states such as Punjab, Haryana, Uttar Pradesh, Maharastra and Orissa, and some of the hybrid seeds imported from abroad. To keep the prices lows, the government subsidizes the quality seeds.

Fertilisers and pesticides

Like seeds, fertilizers are also imported from other states. Farmers pay a high price for fertilizers and availability is major problem in remote areas in India. The government provides a transport subsidy for carrying chemical fertilizers to inaccessible areas and provision is also made for subsidy on its price, so that small and marginal farmers of inaccessible areas can avail of this costliest input. In the case study, the farmers applied chemical fertilizer for cultivation of paddy, jute and other vegetables. The composition of the fertilizer is N-P-K, a combination of nitrogen, phosphate and potash. The quantity in the combination varies for different varieties and crops. Pesticides are widely used. The farmers of Kasimpur usually used Metacid, Thiodan, or Thimet for protecting paddy, jute tomato. Especially the production of eggplant required lots of poison (Folidol) said the farmer. One of the farmers said "we don't eat our own egg plants. We just produce for sale. I suffered a long sickness due to stomach infection from folidol". Two of the respondents told us about the problems of the production related to excessive use of fertilisers. According to them, the yields were going down due to the chemical fertilisers. They said that because so many investments had to be made in one cropping, it was difficult to gain in one cropping. There is a downward spiral.

3.4 Current water supply systems in Kasimpur

Irrigation water

Water is a main input for the agricultural production. There are three sources of irrigation water in the village; surface water, water from one deep tube well and water from shallow tube wells. The arsenic level of the deep tube well was 100 µg per litre, which was only used for agricultural purposes. The water was distributed through pipes to the agricultural fields. The farmers that were beneficiaries cultivated seasonal crops throughout the year and paid a tax to the Panchayat according to their land holding and water demand. Other farmers did not have access to this water and were dependent on rainwater and water from shallow tube wells. One of these tube wells was tested and results showed arsenic content of 500 µg per litre. The development of the shallow tube wells used to be subsidized by the government with 3000 INR, while the total costs of establishing a shallow tube well were about 6000-7000 INR. Shallow tube well owners also sold their water for 60 INR per hour flow. The costs of fuel were about 25 IRN per litre.

However, farmers encountered problems with the water availability. During the dry season the shallow tube wells fell dry and did not provide enough water to satisfy the irrigation demand. Farmers said that in the dry season of 2005, the lack of water, combined with unlucky weather circumstances led to early harvesting and marketing of the paddy, which resulted in low prices. Farmers even lost on the whole production process.

Water for household purposes

There are several public taps in the village, with the water originating from the deep tube well with an electric public pump. The As concentration of this water is negligible. People go to the taps to collect water for household purposes and wash themselves and their clothes near the taps. Taps lead to spilling of water; often people do not close the tap, or, when the tap is broken, the water just flows on the ground without any purpose. Some of the public wells have hand pumps as well. Some households use shallow tube wells with a private pump. This is usually a hand pump, but sometimes an electric on. We took a sample of one of the households' shallow tube wells during summer 2006 and the As concentration was 10 times higher that WHO norms.

3.5 Views on arsenic and arsenic problem

Local government

The local government is well aware of the arsenic problem in the region. We conducted an interview with the Panchayat Pradhan of Kasimpur on August 31, 2005. He mentioned that the problem was becoming more and more severe now a day and that in other parts of the district of north 24 Parganas many cases of affected patients were reported. In this panchayat had only been a few cases of arsenic pollution reported. However, people are becoming aware of the problem, he said. He said that he gave it a high priority on the agenda. Together with the Public Health Engineering Department (PHED) he worked on providing As free water in the village. He said that they did the following:

He had been here since July 2003 and had initiated working against As problem. Since 2 months he had been working on testing and awareness among the people about As poisoning. They had tested pumps and marked them in green/red. The panchayat subsidised the testing of the water: 50% of the costs were paid by the panchayat and the other 50% by the individuals. The cost of testing one sample was 120 INR. They also spoke with the villagers to make them aware about the problem and suggested them to use the water from the other deep tube wells. He said that according to the policy of West Bengal Government (i.e. the construction tube wells of 500 feet (about 150 meters) and more), in the whole of Kasimpur, they constructed 10 deep tube wells. The construction costs per pump were 50,000 INR, of which Panchayat paid 95% and villagers paid 5% by way of a fund generated by the major beneficiaries.

Local people

The main problems that people faced concerning drinking water were normal water borne diseases, such as diarrhoea etc. Some people thought that those illnesses were caused by the arsenic pollution. One respondent told that there was one woman in Kasimpur village that was affected with As. She was suffering from a sickness and the doctors told that it was due to As. Generally, the As awareness among the local population is low and people do not exactly know the effects of arsenic contamination. Table 10 shows the amount of people that were aware, unaware and partly aware about the arsenic problem.

Table 10. Awareness on arsenic contamination in Kasimpur village (N = 61 adults)

Fully aware	Partly aware	Unaware
21 percent	18 percent	61 percent

Following are some remarks of the respondents that we categorised as partly aware:
“Panchayat marked some tube wells in the village as arsenic polluted and it is unsafe.”
“Aware about the problem but I don't think water of my tube well is contaminated”
“It causes (short term health impact like) skin lesions and blisters”.
“It is a substance in contaminated water that will lead to health problems. It is not visible”.
“If the situation is so bad why govt. is silent? Govt. should supply pure water to the people”.

The majority of the people were unaware or only slightly aware of the arsenic contamination. Following are some remarks of some of these respondents.
“It is the responsibility of the government”
“If the situation is so severe the government should do something about it”
“I did not know about arsenic and its impact. But from the pictures and the information that you gave I see that it is very dangerous.”
“This is serious problem but not more serious than poverty, malnutrition, illitreacy"
“I am not interested in this. We are poor and cannot arrange our food.”
“I don’t know about arsenic. I know that surface water is polluted, and cause severe health problem, not the ground water”.
“Are the tube wells of this village are contaminated? Our water is good. We don’t have any problem. It seems severe in the district. But not in this village”

4.

Potential elements of the delivery system of SAR

4.1 Introduction

Everybody is involved daily in delivery systems. The supermarket, the computer help desk, the car repair garage, the insurance agent, they are all parts of delivery systems of food, transport, security and so on. Yet, delivery systems are very poorly conceptualised scientifically. What, for instance, is 'the product'? In environmental science, the answer is that if we aim to compare the environmental impacts of products, we should move away from the concrete manufactured thing and compare 'functional units', for example the packaging of 1 litre of milk or the provision of 1 hour of comfortable sitting (Van den Berg et al., 1995) The poor scientific basis on delivery systems is also visible in the arsenic problem. In the chapter on safe water technology of the WHO report on arsenic in drinking water, for instance, we find 52 references to literature on the natural science and health aspects of the arsenic, 99 references on the technologies for solving the problem, but 11 references to how this technology is supposed the reach the population. None of these is a scientific publication, but reports of organisations such as the International Water and Sanitation Centre (IRC), WB or UNICEF. There is one chapter in the report focussing on social sciences, but it only gives attention to awareness and communication with the local population and does not deal with provision systems.

Many provision systems work perfectly well in practice, but the design of new ones is an abstract business, simply because all design is abstract business, if we want to avoid that we just choose something because we are used to it or because it vaguely looks good. One way or another, design implies that potential components of a not-yet-existing system are selected and assembled to form that new system, guided by criteria such as efficiency, environment or equity. Here again, design is something we do everyday (we make a holiday plan, we design a social tactic etc.) and yet it is poorly conceptualised scientifically, possibly because design is a synthetic activity that is difficult to reach with the overwhelmingly analytical devices of normal science (De Groot, 1992).

In this chapter, therefore, we necessarily start out with a relatively fundamental look on the principles for the not-yet-existing provision system of SAR for West Bengal. We then move to an exploration of the potential elements of this PS. These are the potential actors and the potential relationships between, out of which the PS may be constructed.

4.2 What is supplied? Conceptualising from technology to utility

What has been designed by ISWA and can be built and installed by manufacturers is a technology. On the other side of the supply chain, what the envisaged users of the technology need is not this hardware but health, or at least a trustworthy supply of arsenic-free water. In this section, we will explore what lies along this line between 'technology' and 'utility', in abstract terms but in such a way that they can later be translated into concrete actors with concrete functions, obligations and remunerations in the SAR provision system.

The concepts will be arranged concentrically around the technology.

The first concept then is, logically, **the technology**. With this we refer to the 'naked' hardware, installed and tested *in situ*, plus a guarantee that the supplier is liable for major, structural breakdowns. The abstract actor attached to the technology then is the 'technology supplier'. Note that for the sake of simplicity, we do not distinguish between different types of actors here, such as actors specializing in manufacture of subcomponents or actors specializing in assembly or installation. Our story starts with the technology supplier as the actor who has installed and tested the machinery in the village and we assume that he is the one receiving the remuneration in return.

Usually when we buy something of some complexity, it comes with 'directions of use'. For SAR, this will certainly of great importance. Irrespective of who will in fact carry out the operation and maintenance, transferring the knowledge of how to do so will require more than just a piece of paper. This brings us to the concept of 'extended technology'. **The extended technology** is here defined as the technology plus the provision of the necessary knowledge and tools for operation and non-structural maintenance and repair. The **certification** and **quality check** will be delivered separately by a specialised provider.

The concentric arrangement of the two concepts now defined requires that we distinguish between *inclusive* and *specialized* providers. This is because actors can either supply the extended technology (*i.e.* the technology plus the knowledge) or specialize in supply of only the additional element, in this case, the knowledge. In other words, there may either be one 'extended technology supplier', or a 'technology supplier' plus a 'knowledge extension supplier'. Both structures may be effective, and both can be conceptualized this way. The certifier and the quality check provider will always specialised, never inclusive. Thus, when anybody buys the technology, it has to be certified: the buyer needs to be sure that the technology is working. Besides, the certification and quality check need to be carried out on a regular basis because the technology may break down, and this risk is especially high in the rural localities in developing countries. Decisions have to be made on the period covered by the certification. How often needs the water to be checked on the arsenic content? This is dependent on the scale of the technology (whether it supplies water for a whole village or only for one household). It is also dependent on the local characteristics of the soils. During monsoon, for instance, the water table fluctuates which might influence the arsenic content in the water provided by the technology, because the absorption zone might change. Research is conducted to answer this question. Thus, depending on the circumstances, scientific experts should decide in co-operation with the local experts on the term necessary for certification. Local experts, such as in our case panchayat pradhan or panchayat members, have to be involved in this issue, because they have knowledge on the local situation and what the local people think would be trustworthy enough.

Certification cannot be done by the same agency as the one providing the operational technology. Blending different interest in one agency is not trustworthy. What are then the qualities a certifying agency should have? First of all, the agency should be an independent institute, independent of any funding from firms that might be involved in the production of the operational technology. Preferably, the organisation should be non-profit, so that there the chances for bribing are the smallest. The second prerequisite is that the organisation is scientific trustworthy. In practice, it would be best if the organisation has a good name in society.

After this little detour, we return again at the technology and its forms that can be envisioned. We keep up the distinction between inclusive and specialized suppliers in the rest of the exploration.

Next on the ladder is **the operational technology**. This is defined as the technology working, and kept on working, in the way it is meant to. This may be achieved by an inclusive actor (then to be called ‘operational technology supplier’), or by adding a specialized actor (‘operation supplier’) to the preceding rung. The operational technology also includes the **certification** and **quality check**.

All three provision stages defined up till now work on what may be called the input side of the production of arsenic-free water. The thing-to-be-supplied can also be defined on the output side, however, which in our case is the arsenic-free water itself. This is not necessarily the same as supplying utility, because utility could also be defined further along the causal chain, e.g. as health. This would not be practical in our case, because health depends on so many more factors and actors. Therefore, we define arsenic-free water as the end of the supply chain. **Arsenic-free water is the utility**. Inclusive actors supplying arsenic-free water are the ‘utility suppliers’ in our nomenclature. Theoretically, it is easy to imagine such an actor, who operates the technology, tests the water for arsenic and then supplies it to the users, remunerated by any form of compensation method (see below). In practice, it is likely that users will not trust this all-inclusive actor enough, since the actor is financially dependent on the water being arsenic-free. Probably, therefore, also one or more specialized actors may enter the scene here. We may call them ‘utility guarantors’.

Recent trends in society and the literature point at the many advantages of extending the definition of ‘what is supplied’ in the direction of utility in stead of only the technology. One example is the shift towards supplying the continuous presence of an up-and-running vehicle, usually though some form of leasing out, instead of the purchasing of a car. In more general terms, this is a form called the sale of a performance in a service economy (EC, 2001). Section 5.5 provides more details.

4.3 Users, suppliers and ‘Central Actor’

The notion that risks and maintenance may be brought to bear on producers rather than consumers is of great importance for the arsenic problem. It is of course not forbidden or impossible that rural households supply maintenance of the technology or organise water quality control. In our nomenclature, the household is then both user and a supply actor. They ‘co-produce’. The nomenclature implies, however, that the abstract ‘user’ is defined as the entity using the utility, not the technology. No burdens of risk, maintenance or any other is implicitly shifted to or expected to any entity called ‘user’. This, we hope, may help avoid the well-known problem that households are implicitly expected to co-produce supply elements that they are not motivated or capable to supply, with failure of the supply as a result.

We now have a first notion, however abstract, of types of possible actors in the supply chain. Theoretically, there need to be only two types at minimum: one all-inclusive utility supplier and one category of users. On the other extreme, there may be quite many actors, all specializing in one function, within the supply chain (see above) or outside it, e.g. as banks or government authorities. How will all these actors relate to each other? In order to keep this question within reasonable bounds, we have found it useful to define the ‘central actor’. **The central actor is the actor with the right to distribute the utility (i.e. the arsenic-free water) directly after its production**. The central actor is set as the pivot between suppliers on the one side, and the users on the other. With that, the central actor will usually also be the financial link between users and suppliers. If the central actor remunerates one or more actors on the supply side for the right to distribute the arsenic-free water, it is justified (though not necessary) that users remunerate the central actor (see Chapter 1).

In concrete reality, the position of central actor in subsequent sections and chapters, may be taken by a household, a commercial firm, a government agency, and NGO or others. But before going to that concrete level, we pay attention to the abstract options of types of relationship between the central actor and the utility users and suppliers.

4.4 Concepts of relationship between Central Actor and users

This section deals with the theoretical dimensions of the relationship between the central actor and the users. These dimensions are essential and exhaustive. Here, we first describe the dimensions and its various options per dimension. Then, all the dimensions may be combined and put in concrete examples.

We distinguish four essential dimensions in the relationship between the central actor and the users. These concern:
(1) the manner in which the utility (= arsenic free water) is provided,
(2) the manner in which the rights are distributed
(3) the manner in which the obligations are distributed, and
(4) the basis of the remunerations.

Availability of utility

There are basically two ways in which water is available for the users. The first way may be called batched water. The user has to go to the pump to fetch water before she can use the water. This implies that the user has to put effort in getting the water. The other way is that the user has directly access to a continuous water supply system with running piped water. For this system, the user does not need to put effort in getting the water. This distinction is essential: people will never batch much more water than they actually use, while a continuous water flow makes it possible to spill water easily. This could be resolved by using tap that closes off automatically after, say, 10 seconds.

Distribution of rights

Who has the right to use the utility? There are several options we can think of.

(1) The first one is that the rights are distributed to **predefined users**. Thus, a certain group of people are allowed to use the utility.

(2) The second option is that **everyone** has the right to use the utility.

(3) The third option is also that everyone has the right to use the utility, but arranged through **transferable water rights**. Thus, everyone gets rights for a certain amount of water and is allowed to sell these rights. Transferable generalised water rights may serve efficiency but equity only to a certain degree, as is explicated in the following example. If the system's capacity would be 10.000 buckets per year, and if there would be 100 households, each household may receive 100 bucket vouchers (this serves equity). Vouchers may be used or sold at will. Vouchers then will tend to end up with households most motivated and closest to the well, because people far from the well are not very interested. There will be no wastage. This will lead to efficiency. At the other side of the coin, however, we will see that the poor will be inclined to sell, so that health is traded off for food etc. There are many existing examples concerning transferable rights and quotas, for instance in irrigation systems where people get a water right per hectare that they can sell, tradable quota in fisheries, tradable milk quota in the Netherlands, and on a larger scale the Kyoto protocol.

Distribution of obligations (=payment)

Next to the rights, we have the obligations. The question is: "Who is paying for the utility?" Again, three options come into being.

(1) Obligations are distributed to users. Thus, the user himself is paying for the use of the utility.

(2) Obligations are distributed to everyone. This implies that everyone pays for the utility, independent of whether people use the utility or not. This implies that the utility is paid for from taxes.

(3) Obligations distributed to specific others. It is possible that others are willing to pay for the utility, such as NGO's. Thus, others are subsidising (part of) the utility. A subsidy from the government does not fall into this category, since it will be at the expense of other public goods, unless the government received a specific subsidy to spend on clean water from the World Bank or some other organisation

In practice, it is not necessary that 1, 2, or 3 is taking up the full payment. The payments may be shared between everyone and the specific other (for instance in the situation where a development organisation is subsiding and the government fills up the rest).

Basis of remuneration

There are several ways in which the payment can occur.

1. **One-off**. One purchases the eternal right of utility. The remuneration is then irrespective of use.
2. **By unit of time**. The payment is made on a time basis (thus not on the basis of the amount of utility). Thus, per month for instance, a fixed price is being paid. This case may be illustrated in the Netherlands, for instance, where some employees that use a lease car from their boss, may use the car for private purposes (unlimited within the national border) when paying a friendly fixed percentage of the lease amount per month.
3. **By unit of utility**. The third manner to remunerate is by unit of utility, i.e., in our case, the payment for the amount of the arsenic free water that is provided. This kind of remuneration takes place in the option ‘transferable water rights’ as described in the dimension on ‘distribution of rights’. The question remains on how to measure the amount of water. In line with the first dimension on availability of utility (batched or piped) it can be measured by
    a. Batch. In this way, the payment occurs by bucket taken from the pump or tap.
    b. Hours of flow. This resembles the batch payment, but for lack of exact measurement of litres, people count the time of water flow. In the case of irrigation water this system is sometimes applied when people pay per hour of water flow.
    c. Utility meter. By far the most obvious way to measure the amount of utility is to use a utility meter, such as a water meter or a park meter.

Examples

The dimensions generate alternative systems for clean water supply. In theory, 90 systems could be generated by combining the various dimensions one by one (taking the ‘unit of remuneration’ as having five dimensions. When taking the ‘unit of remuneration’ it is reduced to 54). Here, we describe four examples from reality.

Example 1:
Availability of utility: continuous
Distribution of rights: not important
Distribution of obligations: not important
Unit of remuneration: by unit of time

This is the well known hate object of the World Bank, because people may use a continuous flow of water without limitation (whether the obligations are paid by the users themselves or by someone else) which leads to inefficiency and wastage of water.

Example 2:
Availability of utility: continuous
Distribution of rights: users
Distribution of obligations: users
Unit of remuneration: by unit of utility, meter

This is a typical western urban system, where people pay for the water they use and pay their water bill on a monthly or yearly basis.

Example 3:
Availability of utility: batched
Distribution of rights: everyone
Distribution of obligations: specific other
Unit of remuneration: not important

This may be an example of arsenic free water from a village pump that is being paid by a development organisation.

Example 4:
Availability of utility: batched
Distribution of rights: not important
Distribution of obligations: users
Unit of remuneration: utility by batch

In this situation people would pay by bucket. This would be an efficient way for water use.

4.5 The relationship between CA and suppliers

The relationship between the central actor and the suppliers is essentially a normal commercial market where actors negotiate over rights and obligations, with government actors bound by the rules of public procurement.

These normal market relations do not require special attention here. The only point worthy to note is that the central actor may also lease/hire the operational technology in stead of buying the extended technology. Leasing and hiring implies that the provider retains the ownership and the liability. The difference between leasing and hiring is the term of use; i.e. hiring is on a short-term basis, while leasing is on a long-term basis. As described by EC (2001), leasing is attractive for users, especially because:

- the users do not carry any risk (the risk is with the provider of the operational technology)
- minimum own knowledge is necessary
- there is a high motivation from the leasing agent to deliver because the agent gets paid per unit or performance.

Leasing a car is a well known practice. However, leasing takes place in many other areas as well. In the case of arsenic free water provision, leasing of the utility would imply that the central actors only pays (e.g. per litre) when the arsenic-free water is actually supplied and certified.

4.6 Facilitators

In the previous sections, we discussed the role of the suppliers, central actors and users and their relations. There are important actors outside the supply chain, too. These we call the facilitators. According to function, we may define:

- financial facilitators
- collective action facilitators
- information facilitators
- market establishment facilitators.

Financial facilitators

Implementations of the SAR technology will cost money, so there is a need for financial facilitators (e.g. banks). If we follow the same way of reasoning as we did in the previous part of the chapter, we will look at the central actor and its relations with the suppliers and the users. As said, the central actor is set as the pivot between suppliers on the one side, and the users on the other and will usually be the financial link between users and suppliers. Since we do not pay much attention here to the suppliers, we do not need to go into deeper detail in the money business on firm level here.

For calculating the cost of the SAR technology systems, a distinction may be made between capital costs (initial investment) and maintenance costs (yearly returning costs). In all cases, the costs of the various SAR technology systems will be relatively low, depending on its size, kind of operation (operational technology or extended technology), and whether it is a add-on on an existing well or anew system.
All knowledgeable persons in West Bengalese government are convinced that the government is very willing to promote and to invest in cheap sustainable technologies that provide arsenic free water. We may thus assume that if the government would be the central actor, it can access sources to buy the technology (initial investment costs) without much trouble. This may be any governmental bank that is willing to assist in investments. The payment could also be partly or fully subsidised, either by the government (i.e. spreading the financial burden as a tax over all citizens) or by a specialised agent such as NGOs, or a special subsidy by the GO (received from the World Bank for instance).

Financial capacities are different at the level of users. They are the people that usually do not have much money to spend. Even if the users would be the central actor and would be able to access sources of funding for initial investments, there is no direct financial benefit generated by the arsenic free water that may be used to repay the loan or interest. We may assume that the foregone costs, thus the money that people would not spend at hospitals due to arsenic related diseases and the costs people safe by staying healthy and working, are an indirect benefits that should help convince people to invest. This cost benefit analysis is difficult to make however, in which different time horizons are weighed in the same calculation. More on the willingness to pay for arsenic free water in the model village is in Chapter 6.

If people organise in self-help groups, they have more easily access to financial assistance, because banks are hesitant to give loans to individuals without collateral but they give loans to self-help groups. If people from the “below the poverty line” (BPL) group organize in a self-help group, they receive subsidy from the government. A self-help group must organize meetings at least once a month and the minutes have to be shown to the bank. All the government banks have to accept these self-help groups. A 15 to 50 percent of the loan will be repaid by the GO if you are BPL. The longer the self help group exist (and shows good behaviour in repayment), the more money the group can borrow from the bank.

Collective action facilitators

In case self-help groups would act as user groups or central actor for arsenic free water, collective action facilitators could become important. De Groot and Tadepally (2007) analysed the relation between collective capital and collective action based on a case study on village-level irrigation systems. In the Indian state of Andra Pradesh, the majority of the 73,000 village-level irrigation systems ('tanks') are in a serious state of neglect. Restoration of the tanks is profitable at the community level but unprofitable for farmers individually. In order to overcome this problem of collective action, farmers must not only have a positive motivation towards tank restoration, but also have the capacity to bring this motivation into collective action, i.e. the mutual trust and the institutions that are often referred to as (collective) social capital. This paper analyses the effect of the approach of a local NGO that focuses on awareness-raising and advising the community with the aim to bring about tank restoration sustained by the villagers themselves. It is found that (pre-existing) collective social capital, as measured through five simple indicators, strongly correlates with successful tank restoration. Social capital does not appear to be constructed by the NGO's activities as such, however; a community with pre-existing social capital that is too low for tank restoration will fail, irrespective of the continuation of NGO efforts. Not the NGO efforts but successful collective action itself adds to collective social capital. It is concluded that development agents that aim to bring about a specific group-based action should focus on groups with sufficient collective social capital for that action. Alternatively, development agents that aim to enhance collective social capital should embrace any collective action that a community is motivated for and capable of. The facilitator may be a member of the group, or an outsider that is well respected by the group, or perhaps an NGO. For more information on specific guidelines for community work on collective action see for instance Allen et al. (2002).

Thus, for identifying possibilities for collective action, it is important to study the level of collective social capital in a village or the potential user group of the technology. An assessment of existing social capital, with a focus on self-help group potential, has been made in our research site.

Information facilitators

Many studies identify a lack of awareness of arsenic contamination among the stakeholders. The study of Paul (2004) arsenic awareness identified arsenic risk region, level of education, gender, and age as important determinants of arsenic knowledge. The findings of this study will aid in making existing health education programs more effective and in reducing the risk of developing arsenic-related illnesses. The World Bank (2005) emphasizes that awareness should also explicitly include information on what arsenic is not; arsenic pollution is not contagious and arsenic is not a germ that dies when boiled. Besides, it should be made clear that while turbid surface water is unsafe, some clear groundwater can also be contaminated (ibid.). Hossain et al. (2005) conclude their paper concerning the ineffectiveness of arsenic removal plants with a call for education "for the villagers about the existence, magnitude, danger and symptoms of the arsenic problems ….. training them on issues of water management and involving the whole community in the maintenance of their water source". The awareness on the arsenic poisoning as found in our research village is described in Chapter 3.

Furthermore, the provision of information is of the essence for any technology to work. In well-established delivery systems, information is often provided by the involved market parties (sometimes regulated to some extent by government regulations to prevent unfounded claims or force the provision of information on risks etc.). In cases in which the government takes a special interest because of the large collective level risks (e.g. smoking) or benefits (e.g. arsenic technology, solar technology), public or semi-public bodies may be assigned to information provision to the public or market parties, especially in the early phases when a delivery system is not well formed yet. Such bodies may also be helpful in organising the market (without themselves becoming market parties, see next section).

Market establishment facilitators

Markets work through trust and routines. Trust takes care of that actors do not need enormous amounts of time and energy to get all details of deals on paper and check upon each other's behaviour. Routines, examples of which are standard contracts and the unwritten expectations that new transactions will essentially be carried out as were the previous ones, serve the same purpose of low transaction cost.

New delivery systems on new markets are therefore sometimes hard to establish. Actors that have not worked together yet will start out with low levels of trust in their relationship. It is even possible that for some actors, the whole job of building trust is just too energy-consuming and risky to make it seem worthwhile to start the relationship at all. In such a case, a delivery system may fail to come into being in spite of a potential match between supply and demand. The same holds for the routines, especially for small actors such as individual households, self-help groups or small local contractors. Small actors such as those rely much on standard contracts, lacking as they do to think out and put on paper all the possible ramifications of the new technology and the new relationships. (In some cases, small actors may piggyback on a few larger ones that have established market routines as first movers.)

Sometimes, new markets may arise smoothly especially when the new technology is not too different from an existing one and actors that already trust each other through previous transactions come together and use existing routines to get the new delivery system in motion. This phenomenon is particularly helpful in mixed cases that only partly consist of really new elements. In fact, SAR may offer an example here, since much of it consists of standard drinking water supply techniques and is already built locally by existing contractors in the model village. If panchayats would be central actors for SAR and if panchyats are already used to work with this type of contractors (e.g. for basic water supply), this could become the core structure around which the other, new elements in the delivery system, e.g. the water quality assurance, could be built.

5.
Options for providing the SAR utility

Note that with 'utility' here we refer to certified arsenic free potable or irrigation water. In this chapter, therefore,, we focus on ways to provide this water, which then includes the hardware, the maintenance and water quality assurance. We do so in the form of relatively concrete designs. This level of concreteness is necessary because we needed to discuss willingness to pay and opinions of the delivery system with actors and valid answers cannot be obtained if respondents lack a concrete image of what in fact they are talking about. As stated earlier, the designs are not to be regarded as having any formal or approved status. We used them entirely as discussion triggers. The results of these discussions are in the next chapter.

5.1 Design criteria

Design principles form criteria which the selected technology should fulfil at least. Johnston et al. (2001) select technical, environmental criteria, and socioeconomic criteria for choosing the right technology.

Concerning the *technical criteria*, we distinguish the following items. The water delivered need to require the standard **quality** (both chemical and bacteriological) and required **quantity**, throughout the various seasons. According to Johnston et al. (2001) the domestic water needs for drinking, cooking, and food preparation is about 7-10 litres per capita per day. Technologies should be reliable and **robust**, with little possibilities for faults due to weakness or obvious user error. In our case, it is a prerequisite that the technology is protected against overdraft for instance. Besides, there is a need for certification or a guarantee that the water is of adequate quality. Solutions range from continuous monitoring for large systems to contracts that ensure correct functioning of the technology on a regular basis. This task may be coordinated by public health institutes.

The technology is not allowed to have any adverse effects on the *environment*. One of the big advantages of in situ treatment is that there is no waste as is the case with many of the technologies of arsenic removal.

Johnston et al. (2001) distinguish several *socioeconomic* criteria. First, for the **economic considerations** the authors that everyone should agree that safe drinking water is a basic human right[1] and that national governments and society at large should ensure that all members of society have equitable access to meet basic needs for safe drinking water. The costs of technologies are of great importance. If the there are no water cleaning stations using sand to remove iron from the water in the neighbourhood, it is the option of iron coated sand is not feasible. Chapter 2 gave an overview of the costs of the conventional techniques. Johnston et al. (2001) group under **institutional considerations** awareness raising, technology identification and

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[1] see the Convention of the Rights of the Child states in article 24.2(c) signed by all except for the US and Somalia

verification, application and monitoring of arsenic mitigation which will all require coordination and understanding by various public and private representatives. In our report, they are integral part of the provision system. Under **gender considerations** Johnston et al. (2001) mention that the technology should not put and extra burden on women, that are in most developing countries responsible for the provision of water, and the technology should at least be gender neutral in terms of ergonomic, culture and time. The **convenience and social** criteria of Johnston et al. (2001) implies a necessary level of convenience required for the users and the existing social regulations. The effort required to go to the safe communal source and wait in a queue for one's turn to collect water should to take into account and the amount of effort that the users are willing to put into it. Last but not least, the technology should be **socially** accepted, preferably blend into the existing water supply, suitable and sustainable in terms of the local topography, hydrology, socio-cultural conditions, settlement pattern and population density.

5.2 Four systems: introduction

This section will discuss the utility systems designed for the discussion purpose. We start with the general selection criteria on the basis of which the hardware of the technology has been designed.

Selection criteria

The absorption zone (also called the oxidation zone or infiltration zone) is of pivotal importance. For a robust absorption zone, the recharge should be at least 300 l per meter of filter length. We then have an absorption zone radius between 50 and 60 cm. This implies that existing wells with a filter length of 6 meter should be recharged with at least 2 m^3. Smaller-scale systems are feasible too, but these will require construction of a new well with filter length of 1 m or so.

Underneath three technology designs are described based on single wells. This is selected for reasons of costs and flexibility. Single-well systems require storage facilities such as plastic tanks or ponds; these are cheap and easy to come by, however, in small-scale systems. Multi-well systems tend to be more efficient in situations with large centralized demand (e.g. the piped water supply system of a whole town), but the prevailing situation in arsenic-affected areas is rather the reverse. Single-well systems have the advantage that they can be simple add-ons to existing wells and can be scaled down to the level of small groups of households.

Much attention has been paid to the practical and safe operation in practice, especially the prevention of overdraft. Overdraft means that more water is drafted than can be arsenic free provided by the oxidation zone (per cycle). Thus, the overdraft water contains arsenic. Therefore we also pay attention to the operation; we describe 'operational technologies' in terms of the present report. A very important issue is to make the systems as simple as possible. There need to be as less as possible parts that can break down and need to be looked after, because the systems will have to run in rural areas in developing countries such as in India. Besides, the costs should be as low as possible. For instance, with some simple, but well considered design we omitted the use of a water meter, because water meters will break down one day or another and are costly. The description of the operation of the system includes both the manual and automatic types of operation. In some cases an operator will be appointed, in other cases a knowledgeable person can do the operation.

For all designs, the obvious assumption is that the SAR works at that particular location. This may imply, for instance:
- sufficient underground iron
- soil structure at filter depth not too coarse (which would lead to no absorption surface)
- no strong groundwater flows overloading the absorption zone.

Moreover, we assume a delivery factor at the safe side, namely 1:4. For every 4 litres pumped up, 3 can be used for drinking water and 1 is needed for recharge.

The operational technologies are named by the net supply per recharge cycle. We have developed four types of SARs for various target groups. Variants on these systems can be easily developed. We distinguish the T700E, T700M, T6000 and T20000. In the next sections, we will describe the hardware of the system, the proposed central actors (CA), the operation and daily maintenance, the non-daily maintenance and the quality check and certification. First, however, we give some more attention to the cost elements of the SAR in general.

Cost elements

Assuming the SAR technology works, one of the decisive factors for its success will be the costs. All the materials needed for the designs are locally available and the costs of the materials are relatively low. To calculate the costs of the bare technology, we should theoretically only calculate the costs of the add-ons on existing wells. Thus, the development of the well and the costs of a pump etc. should not be included. However, some of the designs will in some cases not work with add-ons only.

Table 11 gives an overview is given of the costs made for the experimental plant at Kasimpur. It should be kept in mind that the designers and builders of this plant did not bother much about the costs of the materials and the amount of materials used. The designs of the user-friendly technologies are user-friendly, not engineering-friendly, meaning to say that we did not aim at controlling everything. Instead, we aimed at making the designs proof for local circumstances where water meters will break down and where many valves will only lead to confusion. Besides, once the designs will be used on large scale, the costs of the equipment may be reduced due to large scale production.

In line with Table 11, informal cost estimates presented at the final workshop of TIPOT in Kolkota were that a tube well costs between 35,000 and 200,000 INR, a pump would be about 20,000 INR and the add-ons to make a small-scale SAR system out of the well-plus-pump unit could amount to 30,000 to 40,000 INR (pipes 4,000; 1000 l tank 3000; taps and valves 5,000 and labor 20,000 INR). In other words, some 800 US$ would be involved for a smallest-scale unit. Even if this would become somewhat cheaper if more attention would be paid to the design, cost would still be substantial and probably prohibitive for most single households. Upscaling is easy, however, as we will see below with the T20000, since larger volumes do not require much larger cost. This T20000 might cost only some 3000 US$, for instance, and serve some 400 households. If the yearly cost (interest, maintenance and operations) would then cost some 600 US$/year, that would be only 1.5 US$ per household per year, or about 8 INR per household per month, which offers a quite different picture.

Table 11. Costs of the plant built at RKVM in Kasimpur.

Costs initial utility		
Pipes from well to tank: 40 m needed?	110 INR/metre	2.40 USD/metre
Tank	3000 INR/ 1000 litres	65 USD / 1000 litres
Showerheads	200 INR / piece	4,37 USD / piece
Switches	Unclear: depending on connection total costs between 5000 and 10,000 INR	Between 110 and 220 USD
Connections		
Adapt well head		
Pump	18,000 INR	About 400 USD
Building well	Between 35,000 and 200,000 INR	Between 764 and 4365 USD
Soil samples for suitability	10,000 INR	218 USD
Quality check & certification		
Building plant	50,000 INR	1090 USD
Training in operation and maintenance		
Total		
Cost quality check (incl. technology check)		
Expert visiting	2000 INR per day including conveyance	44 USD
Water sample to lab	1000 INR per sample	22 USD
Total		
Costs leasing		

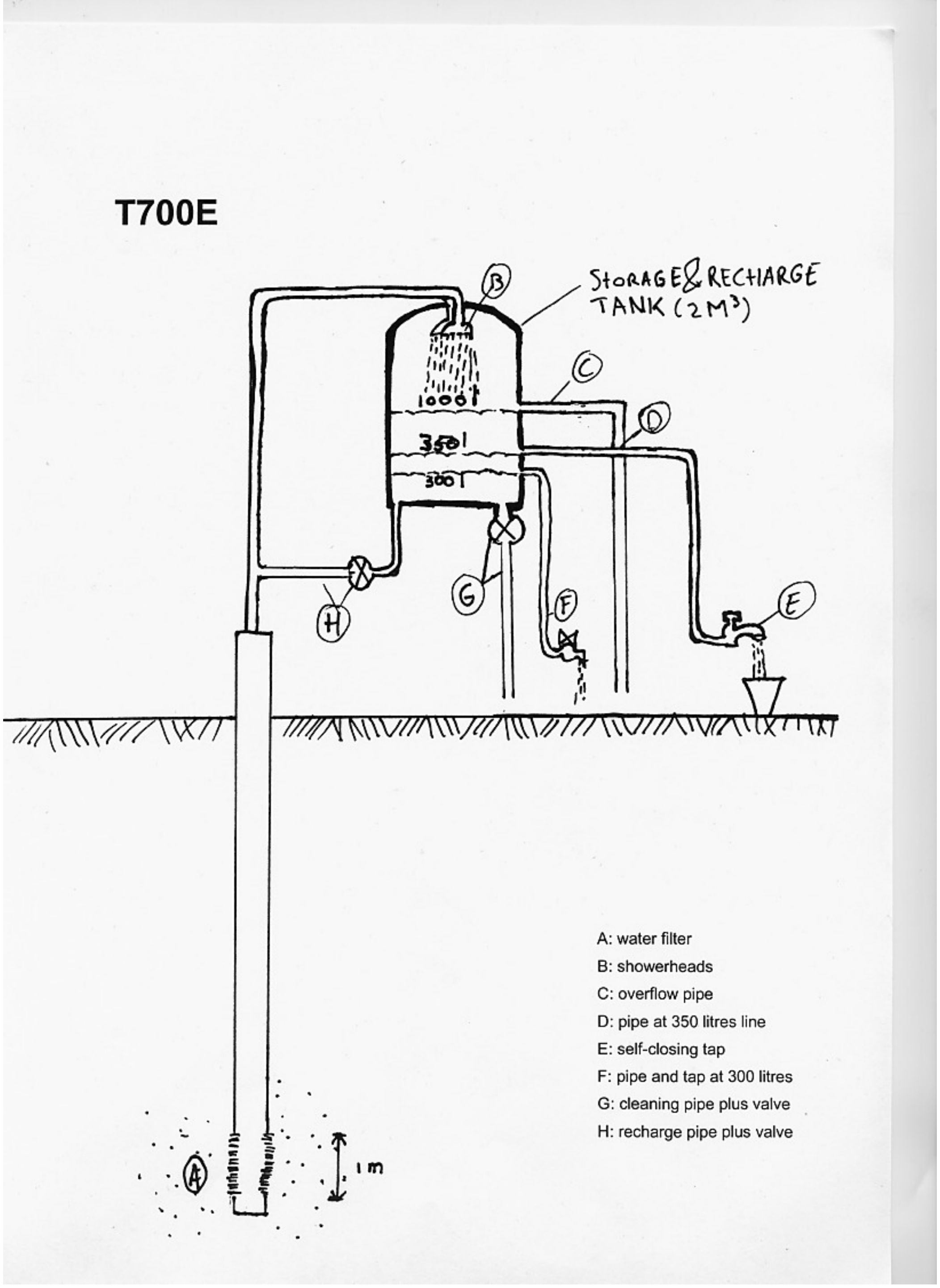
5.3 Drinking water, T 700E

The system of T700E has been discussed with local experts, local scientists and local respondents in India. The results are included this section.

Hardware of the T700E

This is an electrical unit designed to deliver 700 litres net per cycle, thus a total of 1000 litres is pumped, 700 litres is delivered for use and 300 litres is delivered for recharge. T700E is a ‘full unit’, with a new well and a new small pump (this is relatively expensive but may be good for households that do not have their own well yet but wish to have one), or the old well and pump are used as long as the filter has a length of **1 metre** only. This is the smallest unit that can be designed. The limiting factor for the minimum amount pumped per cycle is found in the length of the filter. There is another variant of the T700E, which is the T700M (manual) that uses a hand pump. This is described in the next section. Figure 3 shows the T700E. Assuming that the system has been tested and works already, we describe how this T700E works.

Figure 3. Draft design of the T700 Electrical



There is one water tank which will always contain arsenic free water. The content of the water tank should be about 2000 litres. The tank is not allowed to be filled with more than 1000 litres, because the space left on the top, 1000 litres, is necessary for the shower heads and the aeration of the water that flows from the showerheads. When water is pumped, it enters the tank through the shower heads. Thus, all the water in the tank is aerated and As free. At 1000 litres an overflow pipe is installed; at the moment the water level rises at 1000 litres, overflow starts. This is the moment that the pumping of clean water should be stopped. The overflow can be seen and heard. In order to prevent the risk of pumping too much water with an electric pump, a sensor could be installed e.g. of the same type as in water closets, for instance, that blocks the power to the pump when the water level is high.

To further protect the system against overcharge and to have enough water for recharge, the pipe with a tap from where users get their clean water is installed at the level of 300 litres. Thus, users can never draft more water than 1000 litres – 300 litres = 700 litres during one cycle. Timely recharge is thus induced by that the tap runs dry. When people have tapped 700 litres, there is no more water left to tap. Recharging has to be started with the 300 litres left in the tank. This is done by opening the valve and closing it again after the water has flown in the ground again. In order to foresee the ending of the 700 litres, it might be a good idea to install the main pipe with a tap from where people get their clean water at 350 litres. At the moment that this tap runs dry, users know that only 50 litres are left (this amount they can keep in buckets, for instance, to bridge the recharging time). This amount people can take using the pipe and tap installed at 300 litres. Another risk of overdraft is that users will start the pump when the tap runs dry, in stead of recharging first. This could be prevented by a sensor in the tank for instance, that blocks the power to the pump when there is still water in the tank. Finally, there is one cleaning pipe with valve for cleaning the tank.

Operation, maintenance and certification of the T700E

The operation of this system is simple. It can be automatic or manual with electric pump.

Automatic operation with electric pump.
Automatic operation is run by a time clock, for instance, one cycle every night. The cycle is as follows:
(1) all water left of the 700 l is emptied
(2) valve of recharge pipe opens and closes when all the 300 l of water left the tank,
(3) recharge,
(4) wait,
(5) pump starts and fills the tank (through the shower heads)
(6) when overflow starts, pump stops
(7) then back to step 1.

Manual operation with electric pump.
Manual operation can be done routinely every day. For instance,
(1) Before people go to sleep, they empty the tank and start recharge.
(2) In the early morning, people start pump and fill tank.
(3) When the overflow begins, the pump is stopped.
(4) Then back to step 1.
The whole cycle can also be done only when 700 l are used. Then it is important that some waiting time is given between recharge and pumping.

Maintenance
- The maintenance of the T700 includes the **cleaning of the tank** every now and then, because some sediment may accumulate in the tank. The job can be done by

any knowledgeable person. There are cleaning pipes, through which the waste water can be disposed of.

- The **valves** need to be checked every once in a while and replaced when necessary.
- The **showerheads** need to be cleaned regularly, since the aeration is of crucial importance.
- The **pump** need to be maintained according to its directions of use.

Certification
Certification is necessary. The water needs to meet the Indian standards for drinking water “as desirable and tolerable”. Preferably, people buy the technology with a certification of the water meeting the standards. This implies that the plant is has been working for at least a month already, which is the time needed for the absorption zone to build up. It is important that the certification will be renewed, say every half year. Households may establish a T700 system by simply copying from the neighbours and informally involving a local contractor. Quality assurance of the water is then still necessary, however. There should therefore be an easily accessible certifying agency to do the measurement at low cost.

Delivery system of the T700E

In this section we follow the theoretical lines of reasoning as described in preceding chapters. We start with the potential Central Actors for the T700E, followed by the description of the filling in of the essential dimensions in the relationship between the central actor and the users.

Central Actor of T700E
The single (richer) household or a small group of households are a typical unit to own or lease the T700E. If recharge takes place every night, there is 100 l per household member per day. Small entrepreneurs may also see business in the T700E. They may give or sell the clean water to others. Another way is that a small group of households will invest in the T700E (especially if they share a pump already, of if they agree on using one pump together).

If the central actor buys T700E

If the central actor (e.g. the household) buys T700E,

- In terms of the present report, CA buys the **extended technology** (= technology plus the knowledge and tools for operation and non-structural maintenance and repair) and **quality guarantee** from a firm and receives a **quality certification** from an independent institute.
- **Operation and daily maintenance** will be done by a knowledgeable person from the household.
- **Non-daily maintenance** will be done by the household or will be organised by the household. T700E is such a basic technology that the users can organise it by themselves. If wanted, a *technology check subscription* can come along with the quality check subscription. It might be good to have a plumber look after the hardware every year or so to have everything checked up regularly.
- **Certification** (quality check, including technology check)

  - A subscription is a good way to organise the quality check every half year for instance. This subscription may be bought when buying the initial utility for instance.
  - Or, Panchayat offers the certification (including technology check-up)

  It is to be expected that the costs of certification comes down to the CA. However, recurring costs might form a problem for the poor users. A good alternative would be that poor users are subsidised on the certification, or that the Panchayat will look after (organise and pay) the certification.
- **Who has right to use?** The CA is the owner and has the right to use the utility. The CA may also give or sell the utility to others
- **Who is paying (obligations) for the operational technology?**
- The CA is the one that buys the technology, but there are other possibilities too. The government may (partly) subsidise the technology for the households, by which the burden comes down on the shoulders of all citizens. And/or, a specific other (such as NGO) may look after (part) of the costs.
- **Remuneration**
- The CA will buy the technology at once: one-off payment. The quality check subscription will form an exception. This has to be paid every time a check up is done.

If CA leases T700E

The central actor (e.g. the household) may also lease the extended technology (= technology plus the knowledge and tools for operation and non-structural maintenance and repair) including the quality guarantee and certification from a lease agent. This option might not be that interesting for this small unit, because the maintenance is easy. Besides, there is a risk that people will use lots of water (there is no water meter, so payment should go by unit of time) by which the lease agent has no control on the amount of water used, and thus not on the use of the pump and other technology add-on's that are susceptible to break-down and need maintenance. If, one way or another, leasing will be interesting for a firm, then the situation will look like described as follows.

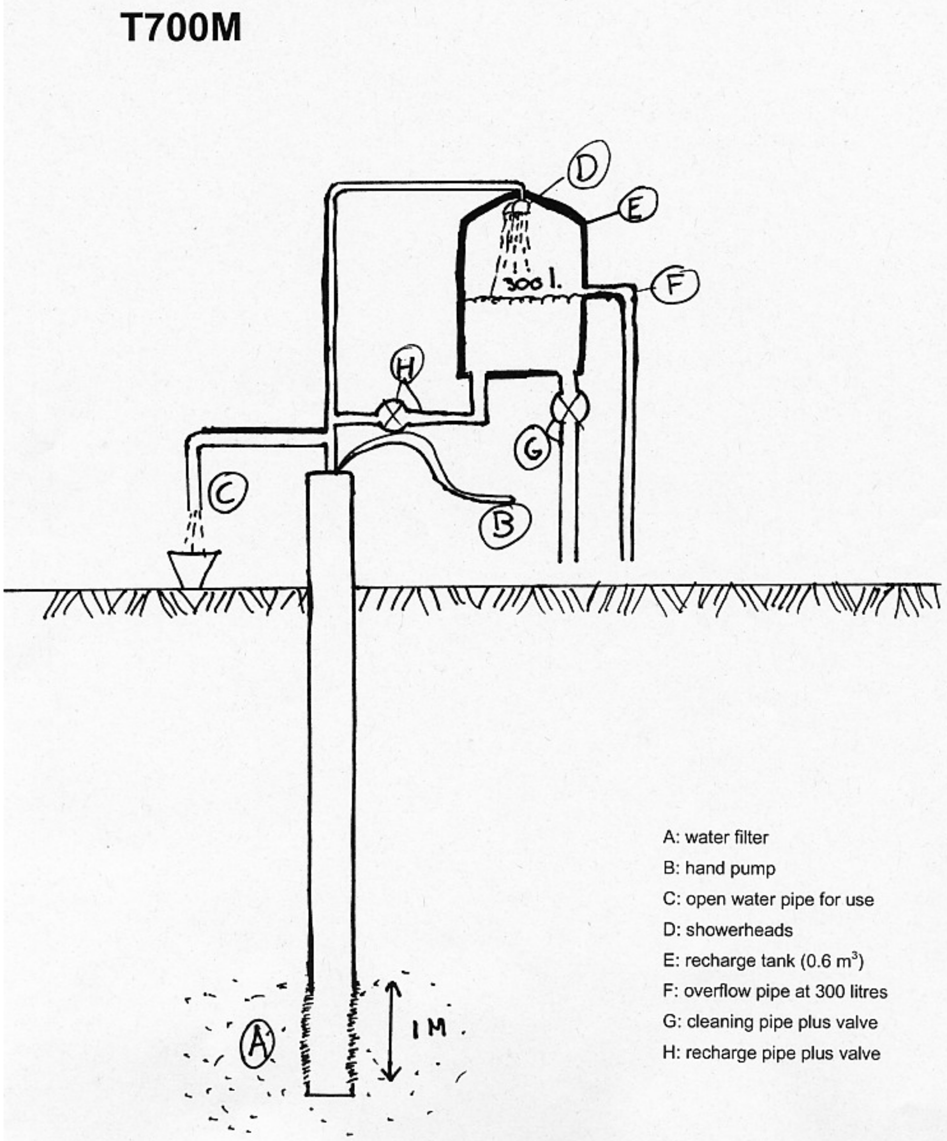
- The users (CA) will be responsible for the operation and daily maintenance.
- The lease agency is responsible for the non-daily maintenance.
- The lease agency is responsible for providing the quality check and the certification. A certificate of an independent agency is necessary.
- Who is paying (obligations) and how? CA will pay the lease agent when the lease agent delivers the service. Thus, CA pays per unit of time, for instance, per month a fixed amount of money to the lease agent. The government (from taxes) and/or a specific other (such as NGO or MPA) may take up the full costs or subsidise the expenditure, by taking up a percentage of the payments.

5.4 Drinking water, T700M

Hardware of the T700M

If the technology add-ons can easily be installed on existing hand pumped wells, this would be a good option for many users that have a hand pump already. The main problem is formed by the length of the existing filter, which is usually longer than 1 metre. One way to shorten existing filters is to put cement in the filter. Alternatively, a new filter may be installed and the existing hand pump used for the T700M system.

Figure 4. Draft design of the T700 Manual



The design of the T700M is different from the T700E, because people will not be motivated to fill a whole tank by hand in one go. We may assume that users can pump 40 litres per minute, so people would have to pump for about 30 minutes to pump

1000 litres to fill the tank in one go, which would be tiring and time-consuming, so that people will be tempted to abandon the system. We therefore designed the system such that people can just pump the amount of water they like to use at the moment. The pumped water is split in two parts, however. The major part goes directly goes to the user, and the other part goes to the recharge tank. Figure 4 shows the design.

The *hardware design* is as follows. The design needs to be such that of each amount of water pumped, a fixed part will flow in the recharge tank. This might be designed such that the water will flow through a pipe and that the pipe is split in a T. One arm goes to the recharge tank (with showerheads etc.) and the other is an open flow that can be used. The diameters of the pipes are selected such that their total resistance compares as 1: 3, so that for every 4 litres pumped up, 3 litres are for use and 1 litre to the recharge tank. The recharge tank is about 0.6 m^3 with a hole and overflow pipe at the 300 litres level. The 300 litres left is used for the shower heads and aeration. Full level of the recharge tank thus automatically implies that 700 litres have been delivered through the supply pipe. There is one cleaning pipe with valve for cleaning the recharge tank.

The disadvantage of this design is that the ratio of 1:3 as the automatic split between water for recharge and water for use can shift in the course of time without the user noticing this, e.g. because the shower heads become somewhat clogged. The design must be rethought to prevent this. One option is to install two smaller tanks in sequence. People first fill a recharge tank of 300 l and if that tank is full, it overflows into a small consumption tank of, say, 100 litres. If that tank is full, recharge can take place while people still withdraw water from the consumption tank. After the recharge tank is empty and a few hours of waiting, both tanks can again be filled in sequence. This system is safe in the sense that there is always enough water for recharge, but people have to take care to actually do the recharge after emptying the consumption tank 10 times. This could be prevented by a bigger consumption tank (1000 l) but then people would have to fill 1,300 l in one go, which is unattractive.

Operation, maintenance and certification of the T700M

The operation procedure is as follows. When the overflow starts, people should not pump any more water. The recharge tank should be emptied first and the users should wait for about hour before they pump again. Thus, the sequence is as follows:
(1) empty the recharge tank by opening the valve of the recharge pipe
(2) close valve of recharge pipe,
(3) wait one hour,
(4) use the pump as one likes
(6) when overflow starts, stop pumping.
(7) then back to step 1.

Maintenance

- This includes the **cleaning of the recharge tank** from time to time, since some sediment may accumulate in the tank. There is a cleaning pipe, through which the waste water can be disposed.
- The **valves** need to be checked every once in a while and replaced when necessary.

- The **showerheads** need to be cleaned regularly; the aeration is of crucial importance.
- The **general maintenance** as is the case of normal pumps.

Certification
See section Certification of T700E.

Provision system of the T700M

Central Actor of T700M
The single household or a group of households is a typical unit to own the T700M if they own and use a hand pump already or share a hand pump among a group of households.

If CA buys T700M

- In terms of the present report, CA buys the **extended technology** (= technology plus the knowledge and tools for operation and non-structural maintenance and repair) and **quality guarantee** from a firm and receives a **quality certification** from an independent institute.
- **Operation and daily maintenance** will be done by a knowledgeable person from the household.
- **Non-daily maintenance** will be done by the household or will be organised by the household. T700M is such a basic technology that the user can organise it by himself. If wanted, a *technology check subscription* can come along with the quality check subscription. It might be good to have a plumber looked after the hardware every year or so to have everything checked up regularly.
- **Certification** (quality check, including technology check)
    - A subscription is a good way to organise the quality check every half year. This subscription may be bought when buying the initial utility for instance.
    - Or, Panchayat offers the certification (including technology check-up)
    - It is to be expected that the costs of certification comes down to the CA. However, recurring costs might form a problem for the poor users.
    - A good alternative would be that poor users are subsidised on the certification, or that the Panchayat will look after (organise and pay) the certification.
- **Who has right to use?** The CA is the owner and has the right to use the utility. The CA may also give or sell the utility to others
- **Who is paying (obligations) for the operational technology?**
- The CA is the one that buys the technology, but there are other possibilities too. The government may (partly) subsidise the technology for the households, by which the burden comes down on the shoulders of all citizens. And/or, specific others (such as NGO) may look after (part) of the costs.
- **Remuneration.** The CA will buy the technology at once: one-off payment. The quality check subscription will form an exception. This has to be paid every time a check up is done.

If CA leases T700M
This unit is typically designed as an add-on on an existing hand pump. Leasing is an option when a new pump is installed. In terms of the present report, CA leases the **extended technology** (= technology plus the knowledge and tools for operation and

non-structural maintenance and repair) including the **quality guarantee and certification** from a lease agent. The CA are the users. This option might not be that interesting for this small unit, because the maintenance is easy. Besides, there is a risk that people will use lots of water (there is no water meter, so payment should go by unit of time) by which the lease agent has no control on the amount of water used, and thus not on the use of the pump and other technology add-on's that are susceptible to break-down and need maintenance. If, one way or another, leasing will be interesting for a firm, then the situation will look like described as follows.

- The users (CA) will be responsible for the operation and daily maintenance.
- The lease agency is responsible for the non-daily maintenance.
- The lease agency is responsible for providing the quality check and the certification. A certificate of an independent agency is necessary.
- Who is paying (obligations) and how? CA will pay the lease agent when the lease agent delivers the service. Thus, CA pays per unit of time, for instance, per month a fixed amount of money to the lease agent. The government (from taxes) and/or a specific other (such as NGO or MPA) may take up the full costs or subsidise the expenditure, by taking up a percentage of the payments.

5.5 Drinking water, T6000

The system of T6000 works with an electric pump. The system has been discussed with local experts, local scientists and local respondents. The results are included this section. T6000 has been designed with larger user units in mind, such as schools, clinics or user groups.

Hardware of the T6000

Figure 5 shows the T6000. Assuming that the system has been tested and works already, we describe the hardware and how it works. This is a unit designed as a small-scale add-on to an existing well of filter length 6 m. Due to this filter (and its resulting absorption zone), the recharge volume is 2 m^3, the supply volume is 6 m^3 and the total water throughput in a cycle is thus 8 m^3. This is not stored in a single tank as in T700 but in two tanks. The recharge tank has a working volume of 2 m^3 and extra overhead of at least 1 m^3 for the shower heads for aeration.

The supply tank can be between 2 m^3 and 6 m^3 . A small supply tank requires more frequent starting of the pump. The supply tank should be big enough to have water for cooking and drinking available when recharge is taking place. A larger supply tank enables continuous water supply. With 2 m^3 storage, for instance, users in most cases will not need to change behaviours during recharge. Adjusted to the supply tank is a pipe with a self-closing tap or it may be connected to any existing supply piping system (where self-closing taps could be constructed for saving of water as well). The supply tank is present especially to prevent overdraft. Because of that tank, the water pressures in the supply piping system do not affect the water pressures at the well. This enables a 'hard-wired', automatically balanced filling of the recharge tank.

The *hardware design* is as follows. Between well and tanks, the pipes are split in a T. One arm goes to the recharge tank (with showerheads etc.) and the other to the supply tank. The diameters of the pipes are selected such that their total resistance compares as 1: 3, so that for every 4 litres pumped up, 3 litres are for use and 1 litre to the recharge tank. The recharge tank is 3 m^3 with a hole and overflow pipe at the 2 m^3 level. Full level of the recharge tank thus automatically implies that 6 m^3 has been delivered through the supply tank.

A sensor may be installed in the recharge tank that indicates that the recharge tank is full. When the operation is automatic, the sensor may disconnect the well from the supply tank and recharge starts. When the operation is manual, the sensor may block the power to the pump once the recharge tank is full. Without sensor, users might be tempted to ignore the overflow and continue pumping (= over-drafting). The sensor can prevent this. If the system is run by an institution such as a school, the risk of overdrafting is small anyway because the rechege task can be assigned to someone. Finally, there are two cleaning pipes with valves for cleaning the tanks.

As with T700M, the risk of this set-up is that the 1:3 ratio is not maintained because of clogging in the showerheads or elsewhere. To prevent this risk, the two tanks might be placed in sequence in stead of parallel, so that the recharge tank is filled first and starts to overflow into to supply tank when full. This does not carry the disadvantage as with T700M because the system has a pump.

Operation, maintenance and certification of the T6000

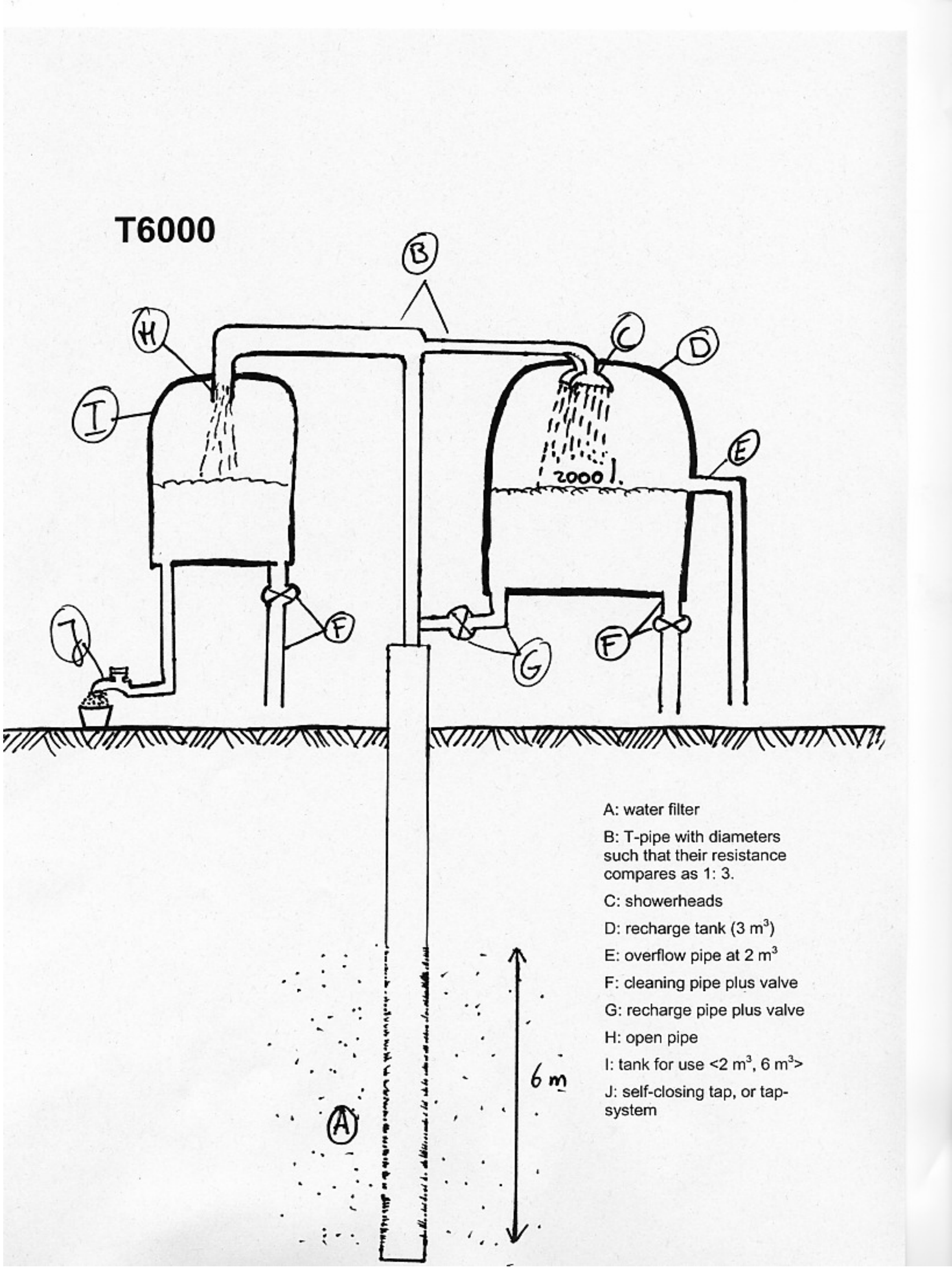
For the absorption to work in the soil, the recharge needs only be done on a volume basis. If recharge would then be necessary only once every month or so, this may entail the risk that the absorption zone could become overloaded by arsenic arriving in it due to overall groundwater flow. It might therefore be safer to recharge at least once every week, irrespective of withdrawn volumes. The operation of this system is simple. It can be automatic or manual, both with an electric pump.

Automatic operation.
Automatic operation is run by a sensor in the recharge tank, for instance, that identifies when the tank is full and when the tank is empty. The cycle is as follows:
(1) overflow of recharge tank starts or sensor turns to ‘full’,
(2) well is disconnected from the supply tank
(3) 2 m^3 of water of the recharge tank is emptied back into to well
(4) recharge tank empty (sensor)
(5) wait one hour,
(6) reconnect the well and supply tank.
Thus, when the sensor indicates that the recharge tank is full, the well is disconnected from the supply tank and recharge starts. When sensor indicates that recharge tank is empty, the system waits one hour and then reconnects the well and supply tank. During the recharge cycle, wtar can still be used from the storage tank.

Manual operation.
Manual operation can be done when the overflow starts (there is some spare water in the supply tank) or users may chose to do it every day or every other day, but at least once every week. Manual operation may be done without sensor because the overflow of the recharge tank should is easy to spot and hear. The cycle is as follows:
(1) overflow starts,
(2) pump is disconnected from power

(3) empty 2 m^3 of water of the recharge tank
(4) close valve of recharge pipe,
(5) wait one hour,
(6) reconnect pump.

Figure 5. Draft design of the T6000



Maintenance

- In T6000, the supply tank is not automatically dry every cycle; hence requires some more hygienic attention. **Cleaning of both tanks** needs to be done every now and then because some silt may accumulate in the tank. There are cleaning pipes through which the waste water can be disposed of.

- The **valves** need to be checked every once in a while and replaced when necessary.
- The **showerheads** need to be cleaned regularly; the aeration is of crucial importance.
- The **general maintenance** as is the case of normal pumps.

Certification
See section Certification of T700.

Delivery system of the T6000

In this section we follow the theoretical lines of reasoning as described in preceding chapters. We start with the potential Central Actors for the T6000, followed by the description of the filling in of the essential dimensions in the relationship between the central actor and the users.

Central Actor of T6000
If T6000 is put on a daily cycle, it can supply 60 households with 100 l day. T6000 may therefore be interesting for a group of households (10 or 20 households) or an institution that wants to be of good service to the neighbours (schools, hospitals or government), or a single household that wants to make some business in selling of clean water.

If Central Actor buys T6000

- CA buys **extended technology** (= technology plus the knowledge and tools for operation and non-structural maintenance and repair) **+ initial quality** assurance certificate from an independent institute. (**Initial utility**)
- **operation and daily maintenance** (cleaning): by household or other well knowing/trained person.
- **non-daily maintenance**: done or organised *by CA*. It is such a basic technology that he buyer can organise it by himself. If wanted, a *technology check subscription* can come along with a quality check subscription.
- **quality check (including technology check)**
    - quality check (including technology check-up) subscription when buying the initial utility or later
    - or, Panchayat offers water quality check (including technology check-up)
- **Who has right to use?** CA, may give or sell to others
- **Who is paying (obligations)?**
  CA,
  and/or (partly) everyone (by subsidy resulting in tax raise),
  and/or (partly) specific other (such as NGO or MLA)
- **Remuneration**
  One-off, except for the quality check subscription.

If CA leases T6000
Perhaps not necessary because the maintenance is easy and there is a risk on using lots of water (there is no water meter, so payment should go by unit of time). If leasing, then:

- operation and daily maintenance: CA

- non-daily maintenance: lease agency
- quality check (including technology check*)*: lease agency (certificate of independent agency necessary)
- Who is paying (obligations)?
  - CA,
  - and/or (partly) everyone (by subsidy resulting by tax raise),
  - and/or (partly) specific other (such as NGO)
- Remuneration: Per unit of time, for instance per month.

5.6 Drinking water, T20000 (100-500 households)

Hardware of the T20000

T20000 is designed to deliver 20,000 litres of water during one recharge cycle. If we assume one cycle daily (with recharge usually taking place during the night), this can supply 400 households with 50 l per day (10 l per capita per day). Walking distances to fetch the water from the system will not be prohibitive in areas with high population density. Alternatively, supply pipes may branch out from the system (ending in automatically closing taps to prevent spillage).

Being designed for public use, T20000 should generate continuous water supply, hence it needs a big supply tank to bridge the recharge period (still assuming a single-well system). Serving 400 families, a formal operator can be assigned. This enables a separation of domains: the area in front of the tank where water can be drawn is public space, but the well, other tank and piping are closed off. Thus, users can only empty the supply tank and over-drafting is impossible. Figure 6 shows the design.

Assuming that the system has been tested and works already, we describe the hardware and how it works. A good well, with capacity of at least 26 m^3 per day is necessary. We use 20 m^3 for supply and 6 m^3 for recharge. Hence, a recharge tank of, say, 10 m^3 is needed to have enough shower head height (or 5 m^3 twice). The supply tank has to be 20 m^3 (or 10 m^3 twice). (T20000 could also be equipped with somewhat smaller supply tanks if that would greatly reduce the costs.) The add-ons and operation of T20000 may be then designed as just an up-scaled T6000 with a large supply tank. Since there can be an operator now, we may also think of only a simple switch between recharge tank and supply tank, and operation as described in the next section. Overdraft might be possible if people are confronted with an empty tank and put pressure on the operator to pump into the supply tank without recharge having taken place. This risk can be prevented by a sensor that switches power to the pump only when the recharge tank has been filled and emptied. Finally, there are two cleaning pipes with valves for cleaning the tanks.

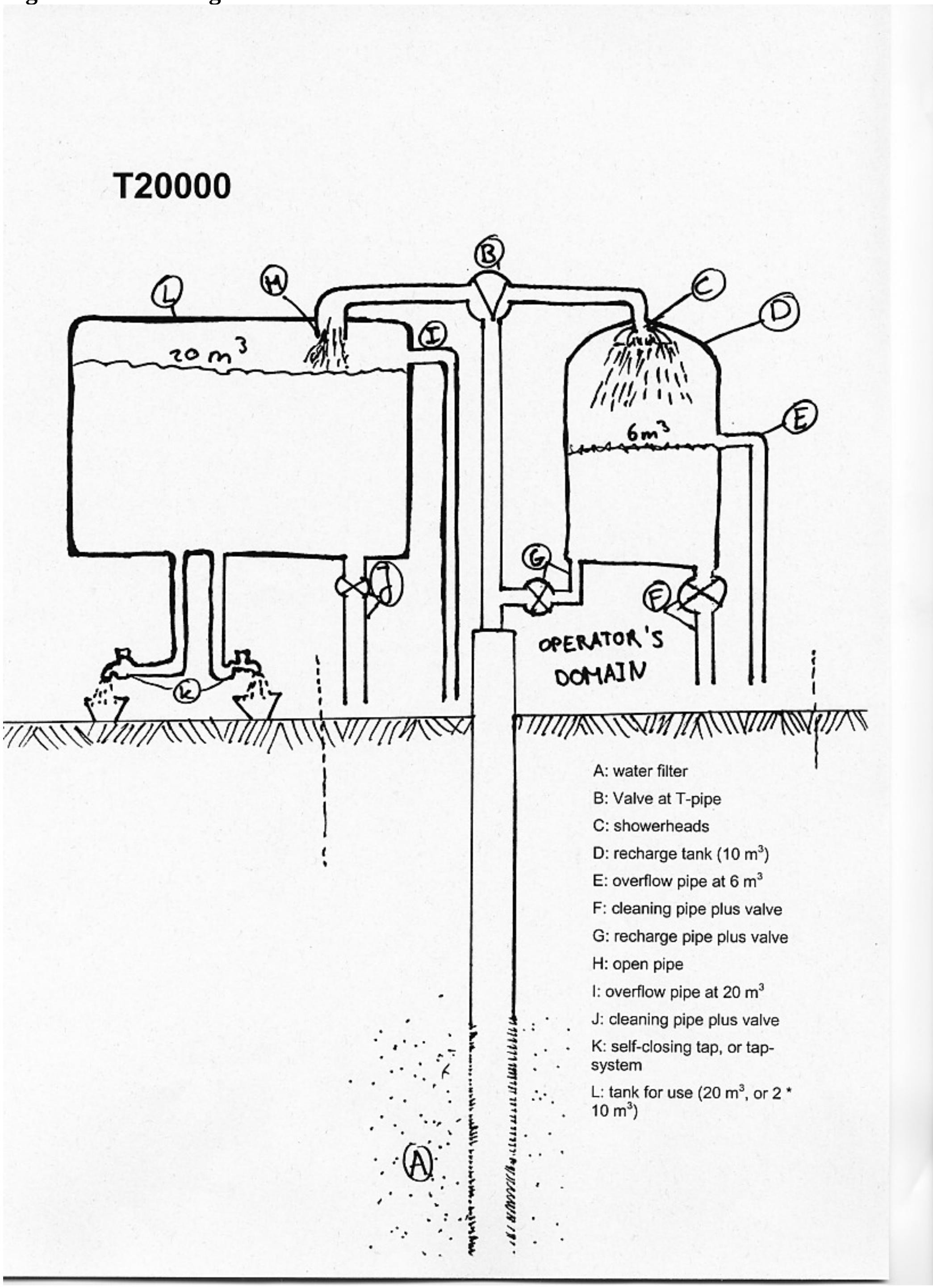
Operation, maintenance and certification of the T6000

Manual operation (by operator). The basic procedure can be:
(1) switch well to recharge tank and pump 6 m^3,
(2) recharge the well with the 6 m^3,
(4) wait till the supply tank of 16 to 20 m^3 is almost empty

(5) switch well to supply tank and fill the supply tank, which will take 16 to 20 m^3.
(6) then back to step 1.

This procedure may take place every day or any time when needed (empty supply tank), provided there is enough time for good aeration and waiting after recharge.

Figure 6. Draft design of the T20000



Maintenance

By an operator.

Certification

Certification of water quality is necessary, from an independent agency. A subscription with that agency is a good way to organize the quality check.

Elements of a delivery system of the T20000

Central Actor of T20000

A system with a capacity to provide 20.000 litres per day can be of crucial service to 400 households, provided all of these are induced to use that water only for drinking and cooking so that 50 litres is enough per household. In other words, T20.000 can be thought of as for public use, but with the water supplied such that people have to walk at least some distance to fetch it, so that they will use it only for drinking and cooking. The taps should of course be self-closing. Because of this public nature of the supply, the Panchayat is an obvious candidate as central actor to buy or lease the system and organize the remuneration either through taxes or by selling the water. Other entities may be central actor as well, however, e.g. NGOs, self-help groups or even private firms that take up arsenic free water as a regular market. Another option is that some institution such as a school or clinic organises a SAR system for itself primarily but pays some extra for some degree of overcapacity (e.g. build a T20000 in stead of the T6000 it might need for itself only), and then gives away or sells the 'excess' water to the surrounding community.

If CA buys T20000

- CA buys **extended technology** (= technology plus the knowledge and tools for operation and non-structural maintenance and repair) **+ initial quality** assurance certificate from an independent institute. (**Initial utility**)
- **operation and daily maintenance** (cleaning): operator
- **non-daily maintenance**: operator
- **quality check (including technology check)**
    - quality check (including technology check-up) subscription when buying the initial utility or later
    - or, Panchayat offers quality check (including technology check-up)
- **Who has right to use?** CA, may give away or sell to others
- **Who is paying (obligations)?**
    - The government may (partly) subsidize the technology for the households, by which the burden comes down on the shoulders of all citizens.
    - And/or, specific others (such as NGO or MLA) may look after (part) of the costs
    - If institutions or Panchayat buy the technology, they are the ones paying. They can ask for a contribution of the users.
- Remuneration

  One-off, except for the quality check subscription.

Leasing might be interesting for this big unit. The operator is then hired by the lease agent. If leasing is arranged, the users pay per month and the lease agent will look after the non-daily maintenance.

5.7 Irrigation water

The issue of the use of ground water for irrigation, also in relation to the As problem, is discussed in Chapter 2. The use of groundwater for large scale irrigation purposes in West Bengal may be viewed as a severe historical mistake. Besides, the health risk posed by As polluted irrigation water is negligible in comparison to the risk posed by potable water used for drinking and cooking (see other TIPOT reports). Finally, the economic incentive of making As free irrigation groundwater is low since there is no price differentiation between AS containing and As free agricultural products (see Chapter 2).

Technically, a SAR system for irrigation water is no problem. No storage tank is needed because the farmer can pump towards his fields directly. A source of oxygen-containing recharge water is needed, of course, but since hygienic demands of the system are low, the farmer might search for a cheaper source than a closed storage tank.

The involved quantities are large compared to drinking water supply. One cm of water per day on 0.2 ha amounts to 20,000 litres per day, hence in the same order of magnitude as the equipment needed to supply 400 households with drinking water. Such a T20000 lay-out is a high investment for 0.2 ha, even if simpler and cheaper than the T20000 for drinking water.

6.
Discussing the designs

This chapter reports on the results of the interviews with the villagers and officials that were held on the basis of the designs discussed in the preceding chapter. The concreteness of these pictures and explanations has the great advantage of avoiding one of the major pitfalls of Willingness-to-Pay research, namely that people do not really know what they are talking about. Responding to abstract notions, people may in fact give their opinions on something quite different from what the researcher thinks they do. Since our results are based on relatively concrete pictures and explanations, we think they have a good validity. The sampling of the respondents has been dealt with in Chapter 3.

6.1 The interviews

The interviews started by testing awareness of the arsenic problem. If they were not aware, they were informed briefly. Then the three designs were discussed, focusing first on perceived general feasibility and on the question who would be the most natural agent to own or bear responsibility for the technology (‘central actor’). Then, the preferred central actor was assigned to the technology and the willingness to pay was asked for that combination of technology and central actor.
Putting it more formally, the structure of the interview was:

- *Aware of arsenic problem?*

(If not, problem was stated in a few words)
T700 was explained with drawings.

- *May this be feasible?*
- *What is the most natural central actor?*

In virtually all cases, households were identified as most natural central actor. Hence next question was:

- *What would be the willingness to pay by your household?*

T6000 was explained with drawing.

- *May this be feasible?*
- *What is the most natural central actor?*

In virtually all cases, self-help groups were identified as most natural central actor. Hence next question was:

- *What would be your household’s willingness to contribute monthly to such a group for this technology?*

T20000 was explained with drawing.

- *May this be feasible?*
- *What is the most natural central actor?*

In virtually all cases, the Panchayat was identified as most natural central actor. Hence next question was:

- *What would be your household’s willingness to contribute monthly to the Panchayat for this technology?*

Here gain we note that WTP was assessed for the technology/institution combinations. As for T20000, for instance, we assessed the willingness to pay to the panchayat for this technology initiated and basically run by the panchayat. This does not imply at all that people would be willing to pay the same amount to, say, a private company for the same technology! It could even be that if people say they would contribute 10 INR per month, they would pay this amount to *anything* initiated by the panchayat, simply because people trust that the panchayat does the proper thing for good reasons and asks only for fair retribution, or simply because it is a social obligation.

6.2 Results of local people interviews

The basic response to the technology (i.e. the explanations of its working and the pictures of the various designs) was virtually unanimously positive.

On the T700 system specifically, the respondents agreed that the households were the natural central agent. Feasibility was overall perceived as low due to expected cost. Without te actual cost being disclosed to them, people said that only the very rich households, if any, could afford such a system. This caused a willingness-to-pay of zero in all but two cases (with WTP = 3000 INR).

On the T6000 system, the respondents agreed that self-help groups were the natural central agent. This did not generate any positive comments on feasibility, however; people doubted the capacity of such groups to manage a system like this. This resulted in a willingness to pay of zero in all but two cases (with WTP = 10 and 15 INR/month). Note that this does not mean that people reject T6000 as such. If a school, for instance, would run such as system, people might feel quite happy to fetch drinking water there and possibly even pay for it.

Table 12. Distribution of willingness to pay in the sample of n = 61 respondents in Kasimpur.

WTP (INR/month)	Number of respondents
0	11
5	7
10	16
15	2
20	11
25	2
30	7
40	1
50	3
90	1

On the T20000 system, 57 out of the 61 respondents stated that this is the way to do it if indeed, as the respondents agreed, the panchayat would be central agent. There were only 11 cases with WTP = 0, meaning that also most the respondents that were unaware of arsenic before the interview indicated a positive willingness to pay if the panchayat would do it. Even respondents still doubting the problem indicated a positive WTP: “If the panchayat maintains there is a problem and if they use this technology to solve it, I will contribute”. Of the 11 cases with WTP = 0, most agree with to the panchayat idea but say they are too poor to pay, or that drinking water should be free of charge as a matter of principle. The mean willingness to pay (including the zeros) was 16 INR/month per household. The full distribution is in Table 12.

Note that this average compares well to the rough cost calculation of Section 5.2, that come down to 8 INR per household per month. It must be borne in mind, however, that both figures are very tentative as yet.

We also reiterate that the willingness to pay figure relates to the combination of the panchayat as central actor of the T20000 SAR technology, not just the technology alone or connected to any other central actor. We may even go one step further and ask ourselves why the WTP figures would be so very different (with twice WTP = 0 and then WTP = 16), for what is basically the same technology applied to the same problem? The technical differences between T700, T6000 and T20000 do not appear to be able to explain this jump. Rather, it would appear that people *responded primarily to the central actor* that they envisaged connected to the technology variants and not to the variants themselves.

This implies that the conclusions of this section are better worded terms of types of central actors with technology variants connected to them then I terms of technology variants wit central actors to them. In other words:

- The **household SAR system**, designed by us as T700, is seen as un-attainable for normal households (hence WTP ≈ 0).
- The **self-help group SAR system**, designed by us as T6000, is seen as beyond the management capacity of such groups (hence WTP ≈ 0).
- The **panchayat SAR system**, designed by us as T20000, is seen as the natural solution for a problem that is credible if the panchayat says it exists, with mean WTP = 16 INR per household per month.

Trust is likely to be an important phenomenon in the background of this result. People appear to trust local government in many ways, e.g. in terms of its cognitive capacity to identify what is really a problem, its managerial capacity to manage the solution and its moral. This again implies that other organisations that may command the same status, e.g. a religious NGO or university, could achieve the same result in WTP terms.

6.3 Results of the elite people interviews

The explicit assumption throughout the interviews was that the SAR technology would work, i.e. deliver drinking water of good arsenic quality. Doubts about the technology could therefore only be voiced concerning its sustainability.

Sustainability of the technology

The local government official told us about a bad experience with another solution to combat the arsenic problem, which did not function properly after some time. Thus, he said, he was afraid that the technology would not be sustainable. It might work nice in the beginning, but then loose effectiveness.

Another respondent questioned the sustainability of the growing amount of arsenic in the ground around the well. Would that not threaten the effectiveness in the longer run? He would suspect that the arsenic would leach from the rock in the end. In that case, the plant needs to be put at another place every 5 or 10 years for instance.

Technology and water quality assurance

All respondents shared a positive feeling about the principles of the technology and the designs (T700 etc.) discussed with them.

One respondent remarked that the smaller systems are basically so simple that people can copy them. But for water quality assurance, people then would need a point to bring the water for testing. Experts would certainly also be needed to test the suitability of the site [e.g. the iron level].

An important practical aspect is that the government needs to give permission if one wants to dig a well and will give permission (against money) only if the groundwater level in the area is OK. This problem does not exist if the technology would be applied as add-on to an existing well.

It was remarked as well that the law at present prohibits the addition of any substance to groundwater. The recharge of the groundwater in the SAR technology could therefore be seen as illegal, even though only oxygen is added to the water. This was not emphasized much by the respondents, however.

Central actor

According to the bank manager respondent, the ownership of the SAR should be with the panchayat, or private, with NGOs or self-help groups. He had high hopes for the self-help groups that can receive loans from the bank for such projects.

The other respondents took the panchayat as the natural agency to take up the leading role in the use of the technology. It was mentioned that the panchayat has enough budget for such projects and it can involve its party members and other voluntary organisations for the installation and running of such plants.

The local government official said that only if there would be a guarantee and a quality check he would be willing to see if the technology would be a solution for the problems in his village. But, if there would be a quality check, guarantee and certification, he would of course be very willing to invest in it, especially if it would be a cheap solution as well. The local people would be willing to invest as well, he said, if it would be working and cheap. He said that people trusted the panchayat, and that if he would go along, people would participate.

Willingness to pay and other practical aspects

But, suppose SAR would work he exclaimed: replicate! Go to GO for a subsidy and give it to a low price to entrepreneurs. Never give it for free! If people pay for something, they will feel responsible and will protect the thing and will not destroy it, even if they pay a small amount of money. So, he imagined 1-3 people run the plant and sell the water to the villagers. They will make a business out of it. Of course, independent certification is necessary. This already happening in [nearby] Barasat where another technology is used and clean water is sold for 0.12 INR per litre. It is important that the water that is offered is totally clean according to chemical standards [such as for arsenic], but also for what people can see and taste. So, it also has to be filtered. A third respondent pointed out the willingness to pay of the consumers because of the future.

7.
Conclusion: proposed delivery system

This concluding chapter will present the delivery system as we envisage it after our conceptual and empirical explorations. We do so under the assumption that the SAR system really delivers water of good quality (including arsenic quality) throughout. This assumption has also underlain our empirical work such as the willingness-to-pay interviews.

The interviews reported in preceding chapter have clearly pointed at the panchayat as the preferred central actor. Both the local and the elite respondents trust that the panchayat has the financial and management capacity to establish and run the system, and trust that if the panchayat asserts that something like arsenic is a problem and something like SAR is a solution, this is sufficiently likely to be true. This in turn implies that institutions that might command the same type and level of trust could be central agents as well. Examples could be a large social or religious NGO or a university. Other organizations may play a role in the establishment of SAR systems as well, of course, but these then should work under the panchayat or the large NGO as ‘central trust holder’.

With an agency such as the panchayat as central actor, the scale of the SAR system would logically be relatively large, e.g. in the order of the T20000 we discussed in the interviews. Such a system could serve some 400 households. This scale allows for a dedicated operator, which will guarantee smooth running and curb the risk of overdraft without expensive devices being necessary. Strong economies of scale exist as well, and as we have seen, the cost of the large-scale system might well turn out to be lower than the willingness to pay (if the panchayat would be central actor), so that it could run without subsidies if necessary.

T20000 as we designed it is of course not necessarily the optimum lay-out. It may well be, for instance, that the recharge tank and the storage tank be better placed in sequence than parallel, with the recharge tank overflowing into the storage tank when full. This does not make essential differences, however, since the effect on the arsenic and the cost of the system will remain virtually the same.

Apart from the panchayat for large-scale systems, organisations such as schools or clinics may also become central actors running a medium-scale system, primarily for the people they are directly responsible for but possibly also for the surrounding community. These would be relatively rare cases in the long run if SAR would be massively adopted but may play an important role especially in the take-off phase of the technology, because the organisations may move relatively fast and be relatively free of budgetary constraints. Because we are interested here primarily in a delivery for state-wide SAR for everybody who may be threatened by arsenic, we concentrate on the ‘panchayat option’.

The delivery system will then be composed of the panchayats and the water users, plus the contractors and maintenance suppliers, possibly banks for specific credits, plus water quality assurors and possibly more. We feel that contractors, banks and others do not pose a design problem for the delivery system because everything in SAR can be composed of very common local technology (as in TIPOT's field experiment) and because financial thresholds do not appear to be very high at present. The water quality assurors deserve some more attention, however.

Water quality assurance

Water quality assurance is essential for health and willingness-to-pay. Quality assurance actors may be of many types (private, government laboratories, NGOs etc.) but all will have to meet the following conditions:

- They will have to be contracted by the central actor that is also the 'central trust holder', *i.e.* the panchayats or other organisations as discussed
- They will have to be certified by the 'driving and enabling agency' (see below).
- They will have to be checked by an independent scientific institution (say, university or national laboratory).

West Bengal society has enough potential quality assurance actors to enable competitive procurement, facilitated by standard procedures designed by the 'driving and enabling agency' (see below).

This system is fool-proof in the sense that it safeguards against the tendency to sell water even when not arsenic-free. The simpler alternative of *self-control* may be feasible too, however, in situations of justifiably high trust between users and central actors. Technically, the current state of the art allows for field checks of water quality that may already be of sufficient accuracy.

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The 'driving and enabling agent'

A second institution that deserves attention has not been conceptualized yet because we have focused on how the delivery system would look like once in full swing. Often, however, delivery systems fail to come about even though potential actors would all be interested to work together. As said in Section 4.6, markets work because actors know each other and have established trust and routines. Trust takes care of that actors do not need enormous amounts of time and energy to get all details of deals on paper and check upon each other's behaviour. Routines, examples of which are standard contracts and the unwritten expectations that new transactions will essentially be carried out as were the previous ones, serve the same purpose of low transaction cost. New delivery systems on new markets are therefore sometimes hard to establish. Actors that have not worked together yet will start out with low levels of trust in their relationship. It is even possible that for some actors, the whole job of building trust is just too energy-consuming and risky to make it seem worthwhile to start the relationship at all.

It is therefore quite likely that even if the SAR technology works and the panchayats are the obvious central actors, a market establishment facilitator is essential to get the system off the ground. This 'driving and enabling agent' may be designed to fulfil the following roles:

- Awareness-raising on arsenic
- Knowledge repository and teaching on arsenic
- Approval of arsenic technologies, e.g. conditional (what works best under what circumstances)

- ‘Public marketing’ of approved arsenic technologies (not only SAR, obviously)
- Certification of contractors (incl. water quality assurors) and possibly technologies
- Drafting and distribution of standard contracts, e.g. for between panchayats and contractors
- Thinking out roles of actors to support the panchayats
- Support other organizations that might be interested in establishing their own SAR system (schools, clinics etc.)
- Select locations with enough iron in groundwater for SAR to be applicable
- Organize demonstration and learning projects for SAR and other approved technologies.

The scale at which such an organization should work is logically the state level, because the arsenic is an all-Bengal but not an all-India problem. It is interesting to note that West Bengal already has a ‘driving and enabling agent’ for renewable energy, called WBREDA (www.wbreda.org). Experiences and formats for the agency for arsenic technologies are therefore available already.

Summary

Summarizing, the delivery system for subterranean arsenic removal (SAR) in West Bengal society, envisioned by us on the basis of our research and discussions, contains the following key elements:

- A state-level GO or NGO as driving and enabling agent for approved arsenic technologies (including SAR if that technology works indeed), e.g. modelled like WBREDA.
- The panchayats as central actors/owners, or other institutions that may command the same levels of trust in the communities.
- Certified and controlled quality assurance agents (possibly to be replaced by self-control in situations of justifiably high trust between users and central actor).
- These actors should focus on relatively large public systems serving some 100 to 1000 households. With our design of T2000 as one example, these systems are likely to be designed as add-ons to existing wells, fully with local technologies and knowledge. They may be run and maintained by a dedicated operator, which is a guarantee against overdraft and neglect.

Other functions and actors will most likely follow spontaneously enough, especially if the driving and enabling agent supplies the knowledge, standard contracts etc. that help actors such as panchayats and contractors to find each other smoothly and with low transaction cost.

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