WHAT IS SAFE WATER AND HOW MUCH SHOULD WE DISINFECT? QUALITY VERSUS QUANTITY

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ABSTRACT

The Latin American cholera epidemic highlighted problems with the region’s water and sanitary infrastructure, and demonstrated that the risk of waterborne disease was not uniform. Although the provision of adequate water supplies is the first priority in situations of scarcity, safety of the water must be guaranteed. Water can become contaminated at the time of acquisition, transport, storage, and use. Disinfection helps guarantee water safety, but water quality monitoring is required to assure the effectiveness of treatment systems. New, low-cost, appropriate technology has expanded water treatment options for short and medium term responses to urgent water quality problems. Success of water projects depend on a number of other factors, such as the cost of technologies, community participation, recruitment of implementation partners, and the selection of potentially sustainable interventions. A project’s potential success can be enhanced by formative research to determine the appropriateness of a given project for a community. Project evaluation is important to measure a project’s impact and to make improvements.

1. Introduction

In the Americas, great disparities in access to potable water exist between countries, and between regions within countries. Priorities of any population will be determined by access to water supplies, quality of water sources, available resources and technology, the array of local health problems, and a host of population-specific factors such as educational level, socioeconomic status, and cultural beliefs. Water policies will therefore be as diverse as the regions for which they are determined.

The failure of the International Drinking Water Supply and Sanitation Decade (1981-90) to meet its goal of providing universal safe drinking water and proper sanitation provides a useful perspective that can be applied to current efforts to meet the need for safe water in Latin America and the Caribbean. The reasons that
the Water Decade fell short of its goal included high population growth rates, lack of available appropriate technology, a preference for smaller urban areas over rural populations spread over vast areas, poor organization of efforts, and inadequate education of target populations (Diamant, 1992). More recent experience has made it clear that to succeed, water improvement projects will need to take into account the knowledge, perceptions, practices, and desires of the populations being served.

The purpose of this paper is to address a set of considerations that should be taken into account when making decisions about water projects and planning for their implementation. Before presenting these considerations, various aspects of the recent cholera epidemic in the Americas will be highlighted to provide perspectives on the problems of water supply and quality and their relation to human health.

2. Lessons of the Latin American Cholera Epidemic

The Latin American cholera epidemic, which began in Northern Peru in January, 1991 and quickly spread through Latin America, highlighted growing problems with the water and sanitation infrastructure. Ten epidemiologic investigations of cholera outbreaks in Latin America elucidated risk factors for infection, which in all cases implicated water, beverages, or ice (Table 1).

Municipal water systems were implicated in five urban outbreaks (Ries, 1992; Swerdlow, 1992; Cardenas, 1993; Weber, 1994; Quick, 1997 [unpublished data]). Although piped water systems with chlorination facilities were present in all of these municipal systems, contamination was believed to have entered through cracks in the pipes, clandestine connections, and crossed connections with sewer lines. In some cases, negative pressure in water pipes caused by planned or unexpected electric power outages contributed to the problem. Further exacerbating the problem were the failures of water treatment systems and of water quality monitoring systems. The implication of these findings was that the presence of a piped, ostensibly potable water system did not guarantee safe water.

In one urban and three rural cholera outbreaks, consumption of untreated surface water was implicated as the route of transmission (Gonzales, 1992; Mujica, 1994; Quick, 1995; CDC, 1993 [unpublished data]). These populations had adequate supplies of surface water; the problem was the quality of the water. For many rural and periurban populations, surface water is the only available source, which places them at high risk for waterborne diseases. PAHO has estimated that 59% of rural populations lack safe water supplies (PAHO, 1997).

In two urban cholera outbreaks, touching water in wide-mouthed water containers was found to be a risk factor for illness (Ries, 1992; Swerdlow, 1992). The implication of these findings is that, even if water sources are safe, water stored in the home can become contaminated if stored incorrectly. In a number of urban
areas, domestic water storage is required because piped water is provided intermittently, which places those populations at risk of waterborne disease.

Finally, consumption of street-vended beverages, street-vendors’ ice, or both, were associated with cholera in three urban outbreaks (Ries, 1992; Weber, 1994; Koo, 1995). These products were made with water, presumably obtained from public water sources, and provide another example of the risks faced by Latin American populations from water in both urban and rural areas.

The principal lesson of these investigations was that, during the cholera epidemic, all water sources had to be regarded as potentially contaminated. Because cholera is an explosively epidemic disease that is easily detectable when present, it serves as an indicator of chronic problems in water and sanitary systems. The annual recurrence of cholera outbreaks in many locations despite the increasing immunity of the population is a reminder that the water quality problem continues. The water sources that permitted outbreaks of cholera are certainly able to permit the transmission of other pathogens. In considering approaches to making water supplies safe, this lesson must not be forgotten. Water systems that are assumed to be potable may not be so. The results of a 1994 study that suggested that 59% of the population of Latin America and the Caribbean had access to disinfected water may in fact be an overestimate (PAHO, 1997).

Another lesson of the cholera epidemic was that the risk of outbreaks was not uniform throughout the region. The countries most at risk for sustained transmission of cholera had higher infant mortality rates and ranked lower on the Human Development Index (HDI), which is an indicator developed by the United Nations that ranks countries by three variables: life expectancy at birth, educational attainment, and per capita gross domestic product (Ackers, 1998). The countries with the highest infant mortality rates and lowest HDI values were also the countries with the lowest water supply and water disinfection coverage (PAHO, 1997). The implication of these findings is that the countries with the greatest need for improved water supplies are those that are least able to afford them. The extent of the need requires an urgent response. Accomplishing an expeditious response will in turn require consideration of low-cost, appropriate technology alternatives that are acceptable to populations being served. Acceptance will require that participating populations be directly involved in the selection, installation, operation, and maintenance of water projects.

3. Considerations in the Planning and Implementation of Water Supply and Water Quality Projects

The debate about the relative importance of water quantity and water quality typically takes place among decision makers at a regional or national level and often do not take into account the wishes of the populations in need of services. While issues of water quantity and water quality are important, they represent only some of the factors that will determine the ultimate impact of a given intervention.
Other factors include economic considerations, available technology, the need for formative research and community organization, implementation issues, and evaluation of impact. Each of these factors will be considered in this section.

3.1 Water supply

Populations that suffer from a scarcity of water must prioritize the uses for that water and in such cases hygiene is often a low priority, which increases the risk of water-washed, as well as waterborne, diarrheal diseases. A number of studies have demonstrated that increasing water usage per capita results in a decrease in diarrheal diseases (Esrey, 1986). There is evidence that water supplies piped into or near the home have a greater impact than protected wells, tube wells, and standpipes.

In situations of water scarcity, developing adequate water supplies is a top priority, but there is a concurrent need to heed the lessons of the cholera epidemic and guarantee the safety of water supplies. Measures to guarantee water safety include selection of uncontaminated water sources, replacement of contaminated water sources by safer supplies that are convenient and reliable, protection of water sources, surveillance of water quality, and excreta control activities. However, even if a water supply project develops a source that can be guaranteed microbiologically, it cannot be assumed that this water will be safe at the time of consumption because water can become contaminated at the time of acquisition, transport, storage, or use, presumably when someone stores the water in a dirty container or touches the water with fecally-contaminated hands (van Zijl, 1966; Han, 1989; VanDerslice, 1993). Even in piped water systems, water treatment may be necessary if the integrity of the pipes cannot be ensured, or if water pressure is not continuous and water must be stored in the home. The decision as to whether a water supply intervention is sufficient will depend on a multitude of factors, including the microbiologic quality of the water through all its seasonal variations, the manner in which the water is delivered to the home, and the ability of the local population to monitor and maintain the quality of the water. Water storage practices will also determine whether an intervention will have a positive impact.

3.1.1 Water Storage

Because of the problems of intermittent water delivery in piped systems in urban areas and the lack of piped systems in rural and periurban areas, the problem of water storage deserves consideration as a water supply question. Whether a family must transport water from a distant source to their home for storage, or must store water from a piped system that only intermittently provides service, the potential for contamination and adverse health impacts is considerable. Several innovations have been devised to prevent the problem of water contamination during storage. Narrowing the opening of water vessels to hinder the introduction of hands was shown to lower fecal coliform counts in stored water (Roberts, 1994) and reduce the spread of cholera (Deb, 1986). Placing a tightly fitting lid and spigot on water vessels was shown to lower fecal contamination of stored water (Hammad, 1982).
In another study, persons provided hygiene education and plastic vessels with spigots were found to have significantly lower levels of contamination of hands and vessel water than persons who received only education or who served as controls (Pinfold, 1990). Water storage innovations such as the ones mentioned above are inexpensive and simple and should be incorporated into any water supply project that will require storage of drinking water in the home. Any new intervention will also require education as to its appropriate use. Direct community participation in the implementation of the intervention will encourage ownership of the project and increase prospects for success.

3.2 Water quality

While provision of water of high microbiologic quality at the source is a desirable objective, other considerations are equally important. Delivery of the water in an uncontaminated state is a challenge faced not only by developing countries, but also by developed countries, which are increasingly facing waterborne disease outbreak problems caused by aging delivery systems, inadequate treatment facilities, or microorganisms resistant to treatment (Moore, 1993; McKenzie, 1994). To guarantee microbiologically safe water, one must consider whether treatment is also necessary.

For populations not on continuous flow, positive-pressure, piped water systems, several low-cost water treatment and storage interventions are in use and have been evaluated. A variety of studies have demonstrated that water treatment in the home can prevent illness. Boiling drinking water has been shown to prevent illness (Blake, 1993), but this approach is relatively expensive and potentially damaging to the environment. Acidifying drinking water with citrus fruit juice protected against cholera in one study (Mujica, 1994), but its effectiveness in protecting against other pathogens has not been evaluated. Two studies in Asia evaluated the use of alum potash in stored household drinking water, which successfully reduced cholera transmission (Khan, 1984) and lowered fecal coliform counts in stored water (Oo, 1993). A Brazilian study found significantly lower fecal coliform counts in stored water of families using sodium hypochlorite as compared to families using placebo (Kirchhoff, 1985). Two studies in Bolivia demonstrated a statistically significant reduction in water contamination by *E. coli* and a decrease in diarrheal diseases by 44% using 20-liter plastic containers with a narrow mouth, lid, and spigot, and water treatment with locally-produced hypochlorite disinfectant (Quick, 1994, Quick, 1998). Solar disinfection of stored water has also been shown to decrease diarrheal disease incidence (Conroy, 1996). Appropriate filtration technology, including slow sand filtration and microfiltration, has been developed and shows promise, but documentation of health impact in the medical literature is lacking.

The growth in the number of inexpensive, simple water treatment interventions improve the prospects for incorporating water treatment into water supply projects. The added margin of safety provided by water treatment could help correct the disparate water safety standards that now exist between developing and more developed countries.
3.2.1 Monitoring water quality

An important lesson of the Latin American cholera epidemic was that water quality monitoring systems were deficient. Whether the focus of a water project is on improving supply or quality, there is a need in both cases for the development of simple, inexpensive, reliable water quality monitoring systems. This is particularly true for many rural areas, where water quality control infrastructures do not exist. For chlorinated systems, monitoring could include testing for chlorine residuals and also for indicators of microbiologic quality. For non-chlorinated water supplies, testing for microbiologic quality is necessary. Such testing adds an expense to a water project that should be incorporated into the project budget and ideally would be recovered by getting the population to share in paying for the service.

Monitoring water quality requires threshold levels of contamination above which action should be taken. The World Health Organization recommends a level of no detectable colonies of fecal coliforms or *Escherichia coli* per 100 ml of drinking water. Some have felt that WHO recommendations have been too stringent (Feachem, 1977). For small untreated water supplies, reaching a level of no detectable fecal coliforms (or *E. coli*) may be unrealistic without chlorination, and less stringent guidelines may be more feasible (Feachem, 1980). Such an approach could set flexible water quality goals that could be altered as progress is made. Regular monitoring would be necessary to assure that quality goals were being met and would have to take into account seasonal variation in the levels of water contamination.

3.3 Economic considerations vs. available technology

An important problem encountered in most water and sanitation interventions that have been studied, such as tube wells, piped-water systems, water storage tanks, pit latrines or flush toilets, is that they are relatively capital-, time-, and labor-intensive (Briscoe, 1978; Esrey, 1985; Esrey, 1986; VanDerslice, 1985). Developing countries are limited in their ability to employ such interventions by cost and logistical barriers, and progress can be slow (de Macedo, 1991; World Health Organization, 1992). Because of this problem, in the last few decades a number of alternative, lower-cost technologies have been developed to help circumvent this problem. These technologies offer the possibility of planning interventions for the short, medium, and long term. Interventions that require large investments of money and time to implement, such as piped water systems with water treatment facilities, often require long-term planning with multiple implementation steps. Appropriate technologies that cost less and are simpler to implement can provide medium or short term options for needy populations that are unlikely to be able to mobilize the resources for a major project.

The appropriateness of alternative technologies for a given situation depends upon a number of factors which should be considered before an investment is made. First, what does the technology cost? Second, what does it cost to train personnel, and to operate, maintain, and repair the technology? Third, is the technology
locally available? Local availability increases access, decreases shipping costs, and increases the likelihood of being able to maintain the technology, make repairs, or replace parts. Fourth, if the technology is not locally available, what are the shipping and import duty costs? Can parts be replaced easily? Is technical assistance available to be able to maintain or repair the equipment? Fifth, what is the technical complexity of the technology? Can local personnel realistically be trained to set up, operate, maintain, and repair it? Sixth, is the technology sustainable? That is, is the technology income generating or does it require a subsidy to operate? Are start up, operating, maintenance, and repair/replacement costs affordable to the population being served and is the population willing to pay for it? If not, the intervention will not be sustainable without permanent subsidy.

Before any project is undertaken, the above factors should be considered. Then, a menu of promising technologies can be developed and details of their acquisition and implementation determined. With this information, potential donor organizations and recipient communities may be approached.

3.4 Formative research

The developing world is littered with broken water pumps and unused latrines, testimony to well-intentioned but poorly planned intervention projects. Many of these failures are preventable. Formative research techniques have been developed which can be used to determine the optimal match of population with technology (Curtis, 1997). Extra time spent laying the groundwork could mean the difference between success and failure.

Formative research consists of the following elements: 1) systematic investigation of risk factors for illness in a given community, 2) consideration of hygienic interventions which could potentially reduce that risk, 3) determination of local perceptions of hygiene and diarrhea causation, 4) identification of decision leaders in the community, 5) determination of the most effective means and channels of communication in the community, and 6) investigation of local perceptions of which diseases most need to be addressed and which services are most important for the community. At the same time, information about available technological options must be presented to the community so that residents can make an informed decision about what technologies fit with their desires. Information about community characteristics, opinions, needs and desires can be obtained through meetings with local authorities and community groups, focus groups, structured surveys and observational studies, review of disease surveillance data (if available), case control studies, and trials of behavior change interventions. Formative research need not be excessively expensive or time consuming, but sufficient time and money should be allotted to do it well. It should be viewed as laying the foundation for the project, an investment that can help ensure its success.

Formative research should help determine whether the community considers diarrhea, water quantity, or water quality to be problems worth addressing. If the
community does not prioritize these issues, then it is likely that a water project designed to reduce diarrhea in this community may fail. Rather than force an unwanted project on the community, the project could be taken elsewhere or an attempt could be made to educate the population about the need for the project before starting.

If a population believes that a water project is a high priority for them, the prospects for success improve. Information obtained through formative research will then help guide the project by directing the selection of the most appropriate technology for the community’s needs and resources (based on their preferences), the recruitment of local leaders and community groups best suited to promote the intervention, and the determination of the best technical approach for educating the community about the project. All of these activities are oriented toward moving the population toward changing their behavior and helping them to take ownership of a project.

3.5 Community organization

Many development projects are vertically oriented, that is, decisions about project implementation are made in government bureaucracies or development agencies, and not by the communities themselves. Projects are often managed using a “top down” approach (Mpahla, 1997). Although decisions to implement water interventions are usually made with good intentions and are often based on scientific data supporting use of the interventions, the project may fail without community participation.

A number of investigations have been conducted to test the effectiveness of water and sanitation interventions in preventing diarrheal diseases (Briscoe, 1978; Esrey, 1985; Esrey, 1986; VanDerslice, 1985). Recent critical reviews of water and sanitation literature contend that excreta disposal interventions have greater impact on diarrhea rates than water availability enhancement projects, which in turn have a greater impact than water quality improvements (Esrey, 1986; VanDerslice, 1985). There is evidence, however, from contingent valuation studies that many communities, when given a choice of water quality or excreta control interventions, would choose water quality first (Serageldin, 1994); the desire for improved human fecal waste disposal often follows. The success and sustainability of any intervention will therefore depend on collaboration with the participating community. A community is more likely to take ownership of a project if it desires the project and if it participates in the decision to implement it.

Similarly, when communities participate in, or better yet, take control of the implementation and management of the intervention projects, the consequent empowerment of the communities often leads to a more successful outcome (Makhetha, 1997; Mpahla, 1997). Accomplishing this transfer of control requires time and effort. Community leaders and organizations must be recruited, educated, and take on meaningful participatory roles. Informed decisions must be made about how to allocate the budget to different activities, how to implement the...
project, how to ensure equitable employment opportunities, how much to pay labor, and how to run the project. Training is necessary on how to budget, manage a bank account (for projects that include user’s fees or that earn income), make collections, supervise personnel, allocate tasks, write reports, and order, receive, store, and distribute materials. Community members must be trained to operate, maintain, and monitor the quality of a water system. Perhaps most important, the community, and the individuals within the community, must accept responsibility for paying for the intervention. True ownership of a project includes paying for it.

3.6 Issues in implementation

One of the more daunting aspects of efforts to provide safe water to the millions of persons without access is the sheer magnitude of the need. To accomplish the goal of safe water for all will require tens of billions of dollars and many years (de Macedo, 1991). One mistake made by some development agencies has been to focus much of their resources on the definitive solution: piped, treated water delivered to every household. While it is important to plan for and work toward this ultimate goal, some thought should be given to alternative approaches that can help alleviate the problem for many at-risk households in the short to medium term. There are several approaches that can be taken to achieve this objective.

First, develop a menu of available appropriate technologies with their costs and implementation, operation, and maintenance requirements and share this with the communities. Particular attention should be paid to technologies that have already been used in neighboring communities and the utility and sustainability of each intervention.

Second, seek partnerships with other organizations working in the same region. Collaboration with other agencies can multiply the skills brought to a given project. For example, one agency might be particularly strong in engineering expertise, but weak in community organization, communication, or evaluation skills. Partnerships also offer the potential of increasing financial resources available for a project and increase the likelihood that monitoring of the project will continue once it has been launched. Partnership with private companies, though not traditionally employed in public health projects, can prove beneficial in terms of financial resources, marketing expertise, distribution efficiency, and money management.

Three, prioritize project sites based on the readiness of the population to participate. Results of formative research should inform this decision. Populations that have an active desire to participate and that can organize themselves to implement the project should be considered first for such projects. Conversely, communities that do not prioritize water or diarrhea as a problem for them are not ready for an intervention project and are in greater need of education and consciousness raising. In some cases, however, the exigencies of the current situation in a community might determine the priority. For example, an emergency situation such as El Niño-related flooding or an earthquake that destroys a community’s water infrastructure requires assistance in the short term. A
community that experiences high endemic levels of a waterborne disease problem, such as typhoid fever or diarrheal diseases, might not require emergent attention, but would be a candidate for a medium term project. Long term projects, which would likely include large-scale, piped-water systems requiring big financial investments and major coordination, are often decided politically, although need and ability of the community to absorb such a project should be considered.

Four, don’t reinvent the wheel. Try to imitate successful projects. Whenever possible, an attempt should be made to use of local “experts” who have learned from experience and can work with other communities to accomplish similar projects.

Finally, pay attention to issues of sustainability. If a community is unable to operate, maintain, and repair a locally-implemented technology, to cover costs of the project, or to exhibit the motivation to use the intervention, then success will be unlikely. A project that permits full or partial cost recovery will have a greater likelihood of success, because it will not prove as great a drain on scarce resources. In addition, populations that make a financial commitment to a project will value it more. Social marketing can help make projects sustainable by applying marketing techniques that can help in cost recovery or even income generation.

3.7 Evaluation

Evaluation is often neglected in many development projects, but responsibility for a project does not end with its implementation. There is much to be learned from any given project, such as how to approach communities effectively, how to determine a community’s needs, which implementation methods are most effective, and whether a project needs midcourse corrections so that it functions better. It is equally important to evaluate projects that are failures as it is to evaluate successes. Each project provides lessons that are useful for future projects.

Evaluation may take several forms. For novel interventions that have not been field tested for efficacy, testing for health outcomes would be important. For interventions that have been repeatedly proven to improve health, such as chlorinating water systems, studying health outcomes would not be as useful. Far more important would be an evaluation of service coverage in a community, the quality of services, or community compliance with the intervention.

Selection of indicators is a very important process because appropriate indicators will focus the evaluation on specific objectives. Potential indicators can grouped in several categories, which include water quality, morbidity/mortality, population coverage, acceptability of intervention, compliance with intervention, willingness to pay, cost-effectiveness, sustainability, and cultural attitudes.
4. **Conclusions**

The lessons of the Latin American cholera epidemic must not be forgotten as efforts are made to correct inequities in the distribution of water services in the hemisphere. Although improvement of water availability is a top priority for communities with scarce supplies, source water quality must also be monitored on a regular basis. To guarantee water safety, it is important that treatment options are made generally available because water can become contaminated at the source or in the process of acquisition, transport, storage, or use. New, low cost technologies have made widespread water treatment more feasible. The prospects for success can be improved if formative research identifies communities that are ready to take on water projects, if the communities participate directly in the implementation of the projects, if appropriate implementation partners are recruited, and if potentially sustainable projects are selected. Evaluation of the impact of water projects is important to ensure progress in efforts to provide safe water for all.

5. **References**


Table 1. Mechanisms of transmission of epidemic cholera in Latin America, as determined in 10 epidemiologic investigations, 1991-1997 (adapted from Tauxe, 1995)

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<th>Trujillo, Peru</th>
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<th>Guayaquil, Ecuador</th>
<th>El Salvador, Rural</th>
<th>Saipina, Bolivia</th>
<th>Riohacha, Colombia</th>
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