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Water for a Growing Population
Water Supply and Groundwater Issues in Developing Countries

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Abstract: *The growing populations of most developing countries occur disproportionally in urban areas. This places considerable pressure on already overburdened budgets to increase the water supply and wastewater infrastructure. Moreover, little or no resources are left to supply, let alone, improve rural water supplies. To add to the problems, money has been spent on studies that have never been implemented. Projects have been constructed that have not fulfilled their purpose. This paper examines some of these problems, emphasizing groundwater, and suggests ways to prevent them in the future.*

Keywords: *Water supply, water quality, infrastructure, developing countries, groundwater, post analysis.*

Introduction

Urban Demographics

The explosion of the urban population in developing countries has been well documented. Moreover, urban growth has far outpaced the general growth of populations in all countries, both developed and developing. Figure 1 illustrates the world's population figures for the last 300 years (Primedia References, 1998). Table 1 shows the increased percentages of urban population for several selected countries. The increase in urban population is not limited to developing countries, however; the urbanization for developed countries has stabilized somewhat in comparison to the developing countries. It is also evident that in many countries, the percentage of people living in urban areas is much greater than those living in rural areas (United Nations, 1997).

The effect of urban growth has placed a severe strain on the infrastructure in urban environments, especially on water supply and wastewater treatment. The water decade of the United Nations was to highlight some of these problems. The results were mixed. Perhaps the most significant result was merely to bring the water problem to the attention of the general publics. (We use the plural of public to emphasize that populations are not homogenous but made up of groups with quite different interests and priorities.)

Water quality as well as quantity is a problem in urban environments. In spite of significant improvement resulting from the United Nation's "water decade," among the ten risk factors contributing to the highest number of deaths worldwide, inadequate water and sanitation ranks third. In developing countries, diarrhea is caused by polluted water and also ranks third among the causes of deaths (WHO, 1999).

Merely getting a water outlet to groups of houses or shacks taxes some urban areas, let alone bringing water into each dwelling. Even though there may be water treatment for the metropolitan area, if the delivery pipes are surrounded by zones inundated with human or other biological wastes, there is always the opportunity for pathogens entering the water delivery system downstream of the treatment plants.

Rural Demographics

The water supply problem in rural areas is much simpler but no less important. Poor water supplies in villages contribute, in part, to the migration to the cities, notwithstanding the need for improving the health of these populations. Unfortunately, the attention to village water supplies is often ignored because of cultural and economic conditions. Economics may indicate a greater cost effectiveness for water supply projects in urban areas because a greater number of people may be served with a given capital investment. Also, it is not uncommon in developing countries to have a cultural prejudice against villagers, looking at them as second class citizens.

Groundwater Development in Developing Countries

Rural Water Supply Problems

While detailed data are not available for most developing countries concerning the source of water for various demographic areas, the data for developed countries may be, to some extent, transferable. In the United States,

Table 1. Percent of Urban Population

Country	*Percent Urban 1990*	*Percent Urban 1995*
Brazil	74.7	78.4
China	26.1	30.1
Egypt	43.9	44.6
Iraq	71.8	74.5
Japan	77.4	78.1
Jordan	68.0	71.4
Mexico	72.5	73.4
Sudan	26.6	31.4

for example, almost all of the rural water supplies come from groundwater (Pezeshk et al., 1994). Certainly for any village not located by a perennial stream, shallow hand-dug wells are the most common sources of water.

By far, the most prevalent problem with hand-dug wells is contamination from pathogens. These come from both surface sources directly, and indirectly from the human and animal wastes that infiltrate into the aquifer from "outhouses" and feed lots or areas of animal concentration.

It is much simpler to cover these wells and install hand pumps than to conduct a groundwater study to determine the direction of flow and ensure that the areas of human and animal waste deposits are downstream of these shallow wells. While there has been work done on developing and installing low-technology wells in rural areas, the fraction of villages supplied with a minimal protected groundwater supply is still very small.

Besides the water quality difficulty, the problem of water availability is especially severe in arid and semiarid countries. For example, in drought-prone areas of Africa, some villagers are forced to walk miles for water. Sometimes the droughts cause the water table to fall so much that deepening existing wells by hand becomes infeasible. In other areas where surface water sources have dried up, the water table may be so deep that only drilling rigs can reach it. Lack of capital, both locally and nationally, usually precludes drilling such deep wells.

Urban Water Supply Problems

In addition to the quality concerns stated previously, water supply problems in urban areas are threefold. First, the source of water may be limited; second, the increasing cost of delivery networks and treatment facilities (increasing infrastructure) may be infeasible because of limited capital; and third, inefficient delivery systems may waste up to 50 percent of the water being supplied.

One example of supply constraints is Mexico City, where the overdraft of groundwater is having serious structural consequences. The overdraft is causing considerable subsidence as well as creating concern for what will happen in the future. A similar problem is occurring in Saudi Arabia, where the depletion of deep aquifers is prompting studies on the need to import water from desalinization plants in the Persian Gulf.

There are several important considerations concerning groundwater and the growing need for additional water in urban areas. First, the concept of "sustainable yield" that has been touted in the developed countries needs to be made a part of water policy in developing countries. As the limits of the earth's resources and fragile environment are being recognized more and more, engineers are being asked to design systems that can be sustained indefinitely.

The concept of "safe yield" has been in the literature for decades, but the definition of safe yield never assumed an indefinite future, though some engineers thought it should. Now, the concept of sustainable yield is clear. This is, of course, directed to renewable sources, so (for example) an aquifer needs to be managed in such a way that it may be a source forever. Another example is agricultural lands. These also need to be managed with an eye to the indefinite future. If soil erosion is allowed, obviously agriculture production will decrease, and perhaps cease, in the future

It is diffict to take a long-term view when people are starving or there is a critical need for water merely for sustenance; however, if this perspective is not implemented, it will only become more difficult to implement later. If aquifers are being over pumped or being polluted, action needs to be taken sooner rather than later, no matter how painful present action may seem.

Wellhead protection programs need to be implemented. The concept of residence time along with remediation measures needs to be studied. Water laws to support sustainable yield policies need to be passed. Even more important, institutions need to be set up or reorganized to carry out these policies and laws. These institutions will, of course, need the regulatory power to control the permitting of new wells and to regulate the extraction of existing wells. It may be that limiting the distribution of water would be an effective way of controlling the exploding urban populations. Several cities in the United States have used limited utility hookups as a means of limiting their populations. Whether such ac-

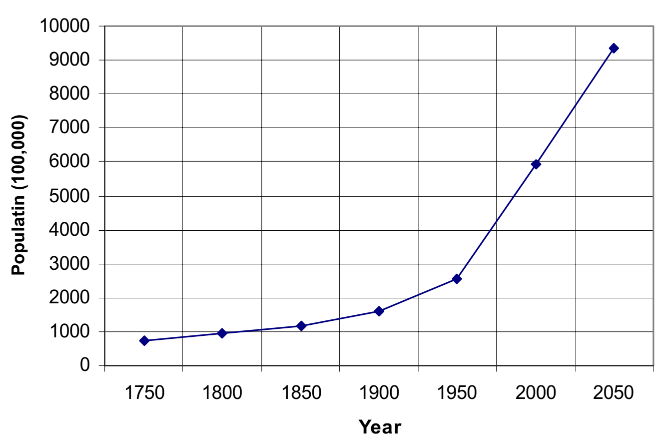


Figure 1. World and population growth.

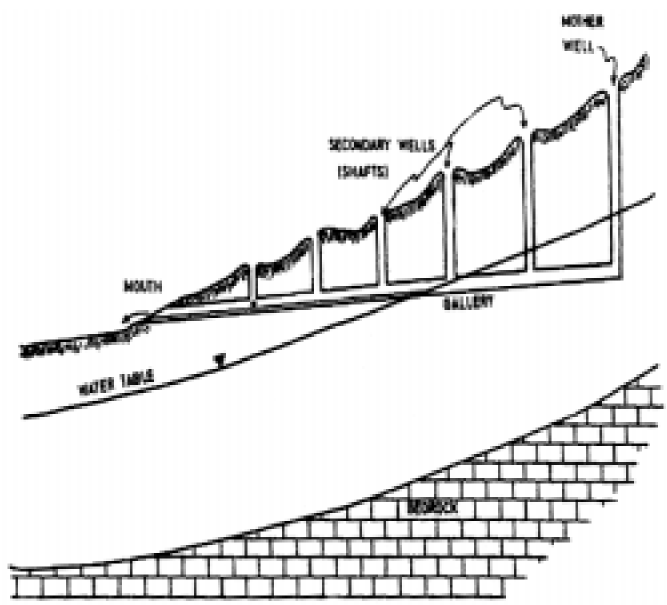


Figure 2. Typical qanat construction.

tion would work in developing countries is problematic.

A second action that needs to be implemented is aquifer storage and recovery (ASR). Using aquifers as storage reservoirs has proven successful in many areas. With surficial aquifers, artificial recharge may be conducted merely by spreading or other non-energy-intensive means. There is extensive experience in artificial recharge, but this technology has only begun to be utilized in many areas of the world.

Lessons from Water Projects in the Developing World

The Problem of Inappropriate Technology

Another problem has been importing technology from a developed country into a developing country that does not have the trained personnel to maintain the equipment. Having the latest technology is appealing, especially if the local governmental official in charge has been educated in a developed country and has seen the latest technology working. It is natural to want the best for one's country; however, it is not always apparent how much technical support is required to operate and maintain the technology.

In one situation, a complex pumping station was purchased and installed with automatic controls, a type of SCADA system that was delivered without any training being part of the contract. After this was discovered, there was no budget for the training, so the system sat unused for several years. After funding was obtained to train operators, there was no one to maintain the system. Finally, the water distribution was operated by hand. Even then, there was no maintenance conducted on the pumps. The procedure was to run pumps and other equipment until they broke down and then replace them with new pumps. This, of course, was not cost effective, but it resulted from not having the technical personnel to support the water supply system. (This and other un-referenced examples are from verbal communications that were given in confidence.)

There has been much written about "appropriate technology," meaning technology that can be operated and maintained by available local talent. Though not directly connected with urban water supply, the author was involved in a conjunctive use project in which a limited surface water supply was augmented by a groundwater system. In spite of a promising geotechnical report, the first and most important well failed to produce the needed discharge. That is, the well produced 9.5 liters per second (lps) instead of the planned 20 lps.

In Iran, qanats are still being constructed, and the thought came to wed the ancient qanat technology with that of modern drilling methods. Qanats are one of the amazing technological success stories of the ancient world. Simply, they are a series of hand-dug wells over a gently sloping hand-dug tunnel. They start with a "mother well," usually hand dug in an alluvial fan that intersects the water table. Because the slope of the near-horizontal tunnel is less than the slope of the groundwater table, it transports water for hundreds of meters (or in some cases over a kilometer) to a village or irrigation project in the semiarid valley (see Figure 2).

Gallery wells are shallow, large-diameter wells in which small-diameter screens are jacked horizontally into the aquifer from the base of the large-diameter well (see Figure 3). Obviously, this cannot be done from a normally drilled deep well.

The concept was to have a qanat digger hand-dig a vertical well alongside the deep-drilled well while the well is pumping and dewatering the aquifer. When the dynamic water level (the surface of the cone of depression) is reached, the qanat digger starts digging a horizontal tunnel as long as possible. This tunnel acts similarly to the horizontal screens used in collector wells (see Figure 4). The pumped well supplies an artificial slope to the groundwater table so the qanat-like tunnel may operate.

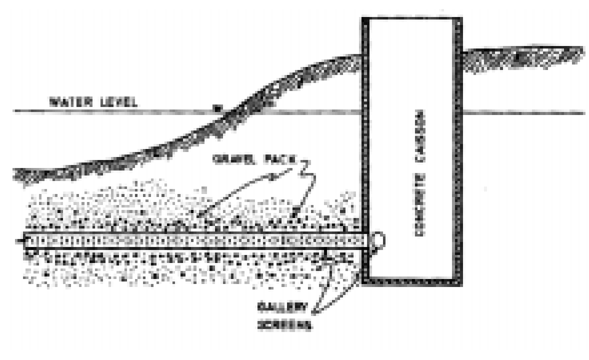


Figure 3. Typical collector well construction.

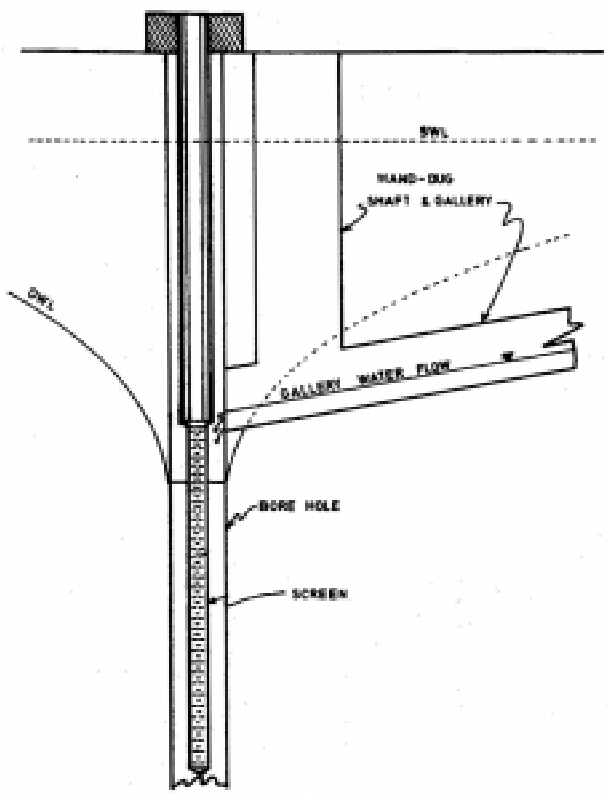


Figure 4. Schematic of a hybrid well.

The hybrid well was successful: the discharge increased from 9.5 lps to 19.9 lps. This is an example of utilizing local technology to deliver water (Helweg, 1973).

A second example is taken, interestingly enough, from the United States. There are semi-arid areas where electrical power is not available and water is needed. Many developing countries are located in such areas, so techniques developed in any semi-arid environment would probably be transferrable.

The characteristic of semi-arid areas is that precipitation comes all at once and is highly variable; that is, the water may be available but not at the right time or place. The purpose of many water supply projects is to rectify the time and place of water availability. Surface reservoirs have been the traditional means of storing precipitation in order to deliver it to where and when it is needed.

The problem with small reservoirs is that they suffer excessive loss through infiltration and evaporation. Actually, there has been considerable research on decreasing evaporation losses from large reservoirs, none of which has proven successful.

The problem of infiltration was solved by lining the reservoir with plastic film; however, controlling evaporation was still a problem. Research at Colorado State University dealing with irrigation showed that just one inch of gravel mulch almost eliminated evaporation from the soil. Unfortunately, gravel does not float. Though it sounds counter-productive, the plastic-lined reservoir was filled with a uniform sand, over a perforated outlet pipe. Then gravel mulch was placed on top of the sand. Actually, with a porosity of over 30 percent, a sand-filled reservoir still had considerable storage (see Figure 5) [Helweg and Smith, 1978].

One beneficial side effect of this "artificial aquifer" is that the water entering the pipe is usually potable because the sand filters pathogens and even some viruses. A number of these artifical aquifers have been constructed around the world. They require some maintenance, such as not allowing any vegetation to grow out of the reservoir surface and keeping cattle, etc., off the gravel mulch.

Recommended Action

First, engineers from developed countries (actually any engineer working in a different culture) need to be trained in cultural anthropology. If only one book were to be read, probably the *Silent Language* by Hall (1959) is still the best. More recently, ethnographies have been written for almost every major culture in the world. These are available from the various ministries of foreign affairs or, in the United States, the State Department.

With this cultural sensitivity, engineers working in other cultures can better judge whom to rely on for data and advice. Whenever appropriate, contracts should direct the planners to look for ways to integrate local technology into their plans and insure that the final implementation plan is feasible over the immediate future.

Another need is for engineers and technical staff in developing countries to receive more training in managing scarce resources and the newer technical solutions that can fit into their culture. Training in political and social leadership is another need that includes engineers from developed as well as developing countries. Frequently, the engineer is the one most qualified to make technical decisions, but many times these decisions must be made through a government agency. If engineers are not in positions of authority, their input may not receive the necessary attention.

Finally, technology transfer is often best accomplished between developing countries rather than from a developed to a developing country. Web resources are a cost effective (if not costless) way to do this. *Water Interna-*

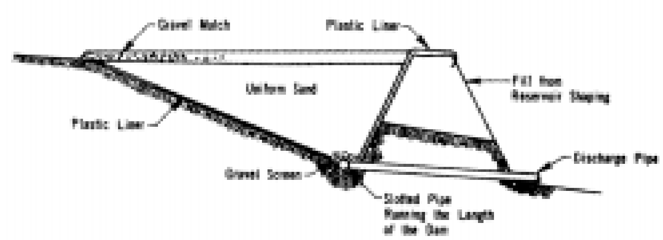


Figure 5. Schematic of an artifical aquifer.

tional has taken leadership in this area (see December 1999 issue), but the scope of the work needs continual expansion.

The Benefit of Efficient Operation

In most developing countries, capital is the main constraint. With some of the newer optimization methods and advances in water supply designs, almost no-cost practices may be used to greatly increase the efficiency of water delivery systems. For example, an engineer may optimally design a groundwater system (both well and pump), thereby saving the client precious capital (Helweg, 1982; Helweg and Jacob, 1991). Another no-cost measure is the optimal operation of a municipal water supply system by the order in which pumps and wells are turned on (Helweg et al., 1991; Pezeshk, Helweg, and Oliver, 1994; Pezeshk and Helweg, 1994). Another example is the optimal construction of "tanks," small reservoirs used in India for rural water supply (Helweg and Sharma, 1983).

The point of these examples is to remind engineers to look beyond the standard water supply practices of developed countries when designing water supply projects in developing countries. However, as important as the engineering design of projects is, of much more importance are political, institutional, and anthropological considerations.

Recommended Action

Contracts should call for non-structural measures to be implemented whenever appropriate. Prior to planning for structural measures to solve water supply problems when adequate infrastructure is in place, studies should be conducted to see if the needed increase in water supply may be achieved by, for example, improving system operation.

Funding agencies need to resist the political pressure to construct large projects whose main purpose is to be a monument to some political figure or party. Of course, in some cases, this cannot be helped, especially when the project may be part of an international water sharing agreement; nevertheless, upgrading an existing system is frequently more cost effective than constructing a new one.

There seems to be a worldwide trend toward privatization. It remains to be seen if this trend will produce more capital for new projects. It appears that in many places, privatization has produced a greater efficiency in operation. This trend merits observation.

The Problem of Institutional Analysis

The importance of institutions has been mentioned, but more needs to be said. An appropriate institutional analysis needs to be conducted (Helweg, 1985). For example, in India, the non-governmental farmers' organization has more influence than the official government agriculture agency. If the design engineer is not aware of this, he or she may have government support, but if the non-governmental institution is not supportive, the project may have little chance of success.

Knowing what institutions are involved, or may become involved, in a project is closely related to conducting some sort of ethnography (Helweg, 1985). Understanding the culture in which the project will be implemented is crucial to the long-term success of the project. For example, a major irrigation project in Iran was never fully implemented because the project only called for primary canals to be designed and constructed. The secondary canals and farm delivery systems were never completed because the indigenous culture had no history of irrigation, nor were there institutions in place to manage the water distribution. An important study of the effect of neglecting culture is the book *Blossoms in the Dust* (Nair, 1962). This is an anthropological study of failed projects in India showing the consequences of neglecting the cultural environment in which the projects were developed.

Recommended Action

For major projects, the contract should either supply an institutional analysis or have a budget to conduct one. It is almost always better to utilize existing institutions than to attempt to construct new ones. Interagency rivalry must be anticipated and compromises struck before starting the project. "Turf wars" can destroy either implementation or subsequent operation. Unless the institutions are in place to sustain the project, both in operation and maintenance, the project will probably fail.

The Problem of Leadership

In the experience of the author, the most important ingredient to a successful project is the local person responsible for its implementation. This person is absolutely crucial. He (almost always a "he" in developing countries) needs to have the political connections needed to obtain the necessary permission and handle the bureaucratic red tape. He needs to be convinced that the project is important and also needs to be a stakeholder in the project. That is, he needs to be part of the planning and design process. The earlier he can be brought into the project, the better.

Recommended Action

Preferably, before bidding on a project, the consultant should have the key local person in mind. Obviously, such a luxury is rare. As soon as possible, this person should be located. Possibly, language in the contract would allow the engineering firm enough flexibility to influence the client to appoint the "right key person." Again, this must be supported by the institutional analysis, ethnography, and political insight collected by the engineering firm. There are no clear steps to finding this person, but at least the project manager should make the attempt.

The Problem of Unimplemented Plans

As stated, every country in the world, not only developing countries, has shelves (maybe rooms) of expensive plans that were never implemented. Some should not be implemented for various reasons. For some, the need or environment changed during the planning process. For others, the political support was lost. But for many, the planning process was not designed or carried out properly.

Most contracts call for an engineering firm to complete the planning study and then the design documents be let for bid to construction companies. Even though the contract with the engineering firm may call for supervision of the construction phase, there is a disconnect between planner and contractor. If the project does not turn out satisfactorily, lawsuits and other problems ensue.

Recommended Action

One of the fastest growing changes in the planner/designer/contractor problem is the "design-build" concept. With this, one of the parties is responsible for the total project from planning to design to construction. In this way, there is no question who has the responsibility. This seems an especially attractive model for developing countries. In fact, training for operation and maintenance is also becoming more a part of the original contract.

The Problem of Post Analysis

Arguably the most pressing problem with projects in developing countries is the lack of project post analyses. Post analysis is rarely done for two reasons. The first is that the client does not want to pay the additional cost, or does not even think of including a post analysis in the funding of the project. The second reason is that a post analysis, to be meaningful, usually needs to be conducted some years after the project is completed (Helweg, 1985). During this time delay, managers change, and the original incentives for the study may be lost.

Post analysis takes the original planning documents along with the resulting structural and institutional results and compares the results with the objectives and projections of the projects. Were the data collected sufficient? Why were the projections inaccurate? Are the projects performing as designed; if not, why not? It should be clear that answering these questions is critical to the improvement of future plans and projects.

Perhaps the most instructive post analysis was conducted by Arthur D. Little (1973) on the Missouri River Basin. This massive planning study was carried on over many years and is still not compete (nor will it ever be). Among the lessons learned in this study are the importance of basic data and the impossibility to predict the future. Interestingly enough, the benefit-cost analysis of the overall project turned out to be very close to what was predicted, but for completely different reasons (Helweg, 1985).

The reason post analysis is so important is that in order for mistakes to be corrected, they must first be identified. If there is no evaluation of projects or the studies that have never been implemented, how will anyone be able to learn from mistakes and successes? Though the World Bank has attempted work in this area, much more needs to be done.

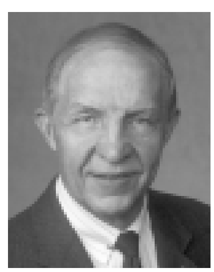
Recommended Action

The cost of post analysis should be part of the budget of every major planning project. The firm conducting the post analysis (say five years after the project is completed) should not be the firm that conducted the plan or the contractor that implemented the plan, in order to insure objectivity. In the initial contract for both the planning firm and the construction company, delivery items should include the necessary details with an eye to the future post analysis. If the money for the estimated cost of the post analysis is set aside in an interest-bearing account, the problem of inflation over time will, hopefully, be offset by the interest earned.

Conclusions

Solving the problems of water quality and quantity in developing countries has no single, simple solution. Such is the case even in developed countries. However, applying the lessons learned over many decades of water resources planning and construction can greatly improve the effectiveness of the water supply and the long-term welfare of the publics.

About the Author



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