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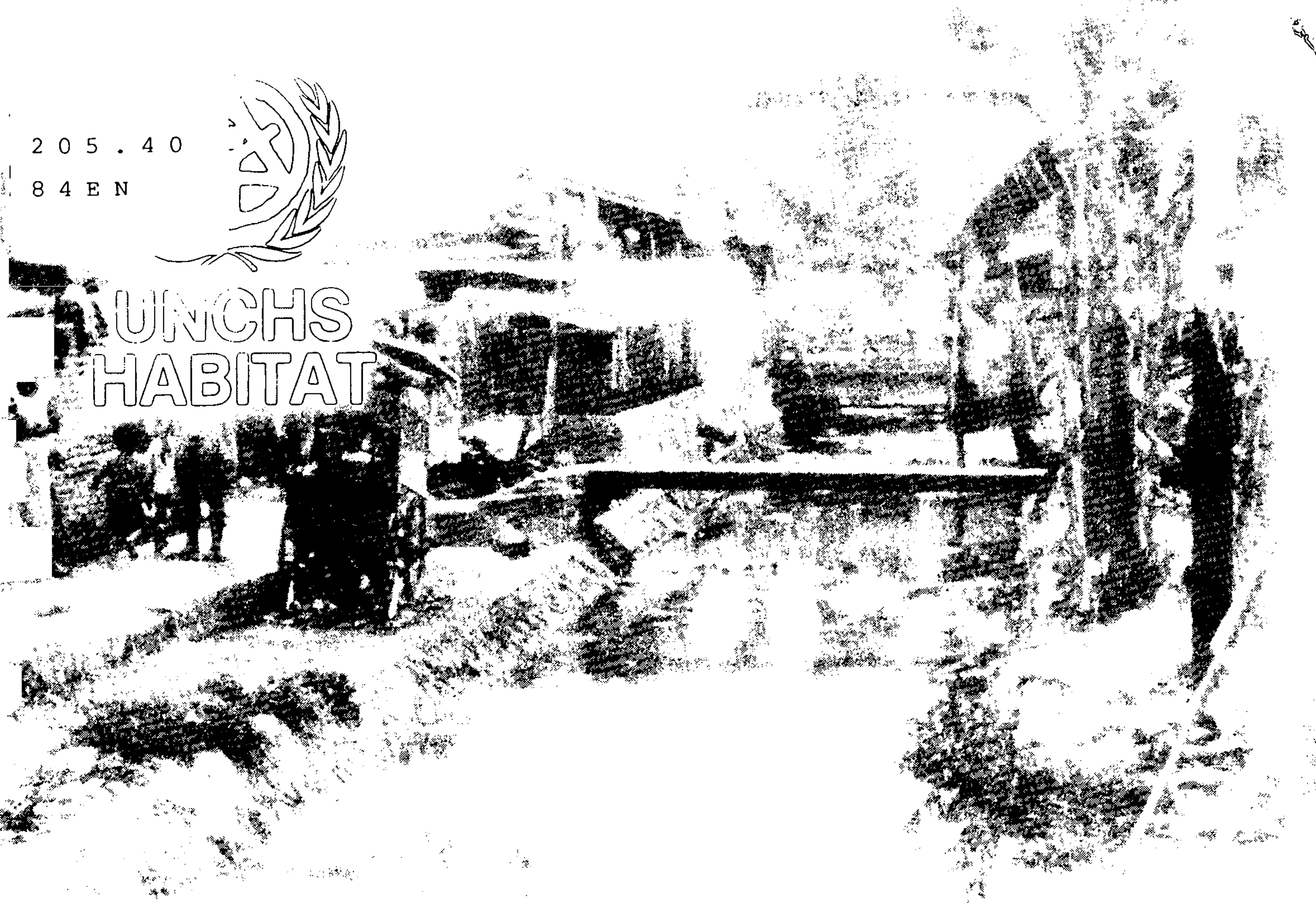

ENVIRONMENTAL ASPECTS OF WATER MANAGEMENT IN METROPOLITAN AREAS OF DEVELOPING COUNTRIES

ENVIRONMENTAL ASPECTS OF WATER MANAGEMENT IN METROPOLITAN AREAS OF DEVELOPING COUNTRIES: ISSUES AND GUIDELINES

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Chapter 1

INTRODUCTION

This study identifies the environmental issues of metropolitan water management and provides relevant guidance to metropolitan planners. The discussions presented here are believed to have applicability to urban water development in general. The metropolitan focus increases the visibility of issues and addresses one of the most critical concerns in metropolitan development: water.

The provision of potable water to ever-increasing urban and metropolitan populations is a priority concern. However, doing so in an environmentally sound manner is equally important. This implies, on the one hand, attaining an acceptable quality of potable water, and, on the other hand, protecting the source of supply both quantitatively and qualitatively. Simultaneously, attention has to be directed to wastewater treatment, the utilization of wastewaters and to the provision of adequate drainage systems.

The volume of metropolitan demand for potable water as well as the volume and composition of wastewaters call for decisions with implications far beyond urban boundaries, significantly affecting economic sectors and human well-being in the hinterlands. Thus, there is need for a regional focus in metropolitan water management decisions.

The majority of the metropolitan areas have appreciable deficits of potable water supply and large backlogs of sewerage and drainage infrastructures. They all make use of the nearest water course or the sea for wastewater disposal. Most have already used up all local freshwater sources of water supply. They have practically monopolized the use of water resources nearby so that the non-urban water needs, such as for irrigation and recreation, can only be met residually. The new sources of water supply needed to meet the demands of these growing metropoles are located at increasingly farther distances and/or more difficult abstraction sites requiring projects with very high capital, operation and maintenance costs.

The amount of water available to metropolitan areas, as well as its quality, has a significant impact on the health of the inhabitants. The microbiological quality of the water available for consumption directly affects the incidents of such enteric diseases as dysentery cholera and typhoid, while the quantity available in the household can determine the level of sanitation practices, and subsequently, the incidence of water-related infection such as shigellosis and trachoma. In addition, surface waters can serve as habitats for disease vectors, such as the mosquitoes that transmit malaria and yellow fever, the flies that transmit onchocerciasis (river blindness) and sleeping sickness, or for intermediate hosts for other infective agents which is the case for schistosomiasis. The adverse public health conditions arising from those diseases can be extremely grave, and in many areas of the developing world, they limit socio-economic development through mortality and debilitating morbidity.

The management problems regarding potable water supply, sewerage and drainage for metropolitan areas are many, including:

(a) The limited availability of investment funds for infrastructure development, expansion, operation, maintenance and replacement;

(b) The difficulties involved in establishing self-financing organizations supported by adequate manpower, free from excessive political pressure and able to levy appropriate charges for water, sewerage and drainage services;

(c) The establishment of equitable pricing policies and rate structures enabling the provision of water, sanitation, sewerage and drainage services to the low-income sections of the metropolitan areas.

The management problems are likely to become more acute owing to the economic difficulties the developing countries are currently facing e.g. high rates of inflation and unemployment, balance of payment deficits, large debt repayment obligations, and the constrained availability of investment funds. Tighter fiscal and monetary policies imposed upon the developing countries will result in considerable delays of infrastructural investments, including water-related projects. These delays will not only inflate project costs but will also lead to a bunching-up of future projects requiring much higher levels of public expenditures not likely to be available. The result will be further project delays and degradation of the water supply, sewerage and drainage services. The current economic scenario and the high rates of metropolitan growth, combined with current deficits of water supply and large backlogs of sewerage and drainage infrastructures will tend to accelerate the water-related conflicts and aggravate the issues over a short period of time.

Large urban and metropolitan areas have severe local and regional impacts on the environment because of high densities of populations, concentration of industrial and commercial establishments, and complex production and consumption activities. The functioning of urban systems requires a continuous supply of goods and energy from outside and generate large amounts of solid, liquid and gaseous wastes and discharge. The rapid and haphazard pattern of growth in developing country urban areas often overtax the natural assimilative capacities of local and regional water, land and air spaces. Thus, there is need to provide environmental guidance to urban planners to facilitate the effective management of water.

Basically, this study consists of two sections dealing with water supply and wastewater, drainage and sanitation. The water supply questions are examined from the viewpoint of quantity and quality of supply, emphasizing environmental considerations. The section on wastewater, drainage and sanitation also maintains the environmental emphasis and focuses on questions of treatment systems and reuse of wastewaters. These two basic sections are followed by a section on policy issues focusing on standards of service, appropriateness of technology, organization and management, and drainage basin management. In order to illustrate the extent of water supply and wastewater problems that may result from massive urban growth, a case study of Mexico City is annexed to the main study. The case study is organized parallel to the main report, focusing on water supply and wastewater, drainage and sanitation questions followed by a section on policy issues. In order to provide detail on environmental implications, two special sections on environmental health and socio-economic implications of water supply and wastewater utilization have been added. Throughout the case study, the importance of examining urban/metropolitan water issues from a regional persepctive has been emphasized.

Chapter 2

WATER SUPPLY

Water sources

The major sources of water supply to metropolitan areas are surface-waters and ground-waters, which are interrelated. Other less commonly used sources include rainwater, desalinated seawater and reclaimed wastewater. Large urban areas generally depend upon regional resources, as water needs can seldom be met from sources within the political boundaries of the urban communities. Even the exploitation of ground-waters within a metropolitan area draws from recharge areas and aquifers that extend far outside. The quantity of water available depends on the topography and geological characteristics of the region as well as the rates of precipitation and evaporation. Ground-water sources tend to be more stable than surface sources, responding slowly to long-term variations in precipitation and ground-water resources can sustain surface flows during dry periods. So-called "conjunctive use" calls upon surface sources during rain seasons, which permit the replenishment of ground-water reserves, and then draws upon ground-water sources in dry periods. The quality of both types of water resources may be variable, with surface-water being much more subject to pollution and contamination. Ground-water resources, in contrast, are somewhat protected by the overlying soil layers, but once contaminated, are extremely difficult, if not impossible, to restore to their original quality.

Surface-water bodies act as an important and unique habitat for aquatic plants and animals, provide for the spatial distribution of sediments and nutrients, and act as reactors for the cycling of nutrients through the microbial degradation of organic matter and the subsequent assimilation of the end-products into higher orders of plants and animals in the food-chain. Although the rates of these processes can vary depending on environmental conditions, there are limits to the amount of wastes (organic matter) that can be assimilated by a system without inducing major changes in the quality of the water and the ecological balance. These limits depend on the physical characterisitcs of the water body, the type and amount of wastes introduced, and the quality required of the water source for existing and prospective uses. This balance is site and situation specific, but its determination is essential for the optimum management of the water resource.

While water resources can play a major part in increasing the potential returns from almost every socio-economic activity, they are also vulnerable to the wastes generated by these activities. The introduction of pathogens from human waste is a common and severe problem in the developing world, making the source unfit for human consumption without extensive and costly treatment. Agricultural and forestry projects can create problems associated with the introduction of sediments from erosion, and nutrients and toxic chemicals from fertilizer and pesticide applications. Industrial activity can generate large amounts of wastes of various types, including toxic organic chemicals and heavy metals. The use of water for cooling purposes is common in many industries, and the introduction of heated water into natural waterways can severely affect aquatic biota.

Water resources affect the potential for the socio-economic development of a region. While the hydrological cycle ensures, in general, the annual recharge of resources, the amount of recharge, however, can drastically fluctuate depending on climatic conditions in the region. The sustained use of this resource is dependent on the development and implementation of policy that will match the degree of exploitation to the rate of recharge and will minimize the degradation in quality of the water source through the proper control of development activities. Failure to manage water resources properly can result in grave consequences ranging from the need to import water from other regions at great cost to the total abandonment of an area.

Management of water resources on a regional basis relies on co-operation between development sectors for the most efficient use of the resource. The reuse of municipal or industrial wastewaters as a water source for another activity, such as agriculture, is a sound policy. Land-use planning can reflect this water resource situation. For example, the upper regions of a river basin, while most appropriate as a source of water for a region, can be developed for forestry but are not appropriate for extensive industrial activity that requires large amounts of water and produces large volumes of wastewater. This type of regional planning and policy formulation will only be possible, however, when the water supply resources of a region are studied and managed as a single, yet dynamic entity.

Selection of water source

The selection of a water source depends on its quality, yield, accessibility and cost. Water for drinking has to meet certain microbiological and chemical quality standards. The degree of treatment required to bring a particular waste source to the desirable quality standard will be reflected in project costs. Quality should therefore be given special consideration in source selection. Efforts should then be made to prevent the subsequent contamination of the sources through land-use planning, pollution control regulations and effective monitoring and enforcement.

The seasonal variations in the yield from a source is an important consideration in source selection. Sources which demonstrate large fluctuations in supply may not be able to meet demands without the provision of storage facilities. The distance from the source to points of demand will also influence the relative costs of development.

The selection should be based on the estimated total cost of development, including both capital costs of construction and operation and maintenance. The costs of monitoring and treatment need to be included, and these costs can be quite high for polluted sources. Cost comparisons must be made on a common basis, by annualizing capital costs and adding them to operation and maintenance costs or capitalizing operation and maintenance costs and adding these to construction cost. Realistic values for life (which can be up to 40 years for sources) and interest rates need to be included in the computation.

Surface-waters characteristically demonstrate wide variation in both the quality and quantity available at any point in time. If a source is subject to fecal contamination, serious epidemics of water-borne diseases can result. Chemical contamination from industrial sources or from the run-off containing pesticides used in agriculture can also have a serious detrimental effect on public health. For surface sources, at least disinfection but generally more extensive treatment will be required before the water can be used for human consumption.

Ground-water is usually suitable for human consumption without treatment. It can be abstracted through wells or springs. Springs are generally easy to develop but their yields are small. Wells require a substantial expenditure of capital for their construction and operation depending on their depth and yield. Severe problems can result from over-exploitation of ground-water resources as permanent damage to the aquifer may result. Care must also be taken to ensure that contamination is not introduced as aquifers have very little potential for self-purification.

Rainwater is collected from roofs or other catchment areas and is stored to meet certain demands. The quantity available on a sustained basis will depend on the amount and variation in precipitation as well as the volume of storage available. Given the type of catchment area required, the collection of rainwater as the sole source of water will rarely be feasible in a metropolitan setting. While rainwater is generally pure, contamination can occur from contact with dust or bird-droppings on the catchment surface or in the storage container. It can however be a useful source pending the installation of a piped system.

Seawater may occasionally be considered as a water source when other sources do not exist or the quantity required for use is low. Seawater will require some degree of desalination, a very expensive process.

The reclamation of wastewater may be feasible for some non-potable urban, industrial or agricultural uses. There are even instances where reclaimed wastewater blended with fresh water has been used for drinking purposes. However, these options are mainly appropriate in arid areas and, because of complexities of treatment, are seldom applicable in developing countries.

Quality of water supply

The two major concerns of an urban water supply are the quality and quantity of water provided to the inhabitants.

Microbiological quality

The microbiological quality of water reflects the risk of water-borne infections such as typhoid and cholera. Given the large number of pathogens potentially existing in a water supply, direct testing for their occurrence would incur extraordinary costs. As such, analysis is carried out for only one or two indicator organisms which are found in large numbers in human feces. The absence of these organisms is used as circumstantial evidence in inferring the absence of pathogenic organisms.

The risk of water-borne infection is controlled by setting standards for the occurence of indicator organisms. These levels are obtained through the use of sources which are protected from fecal contamination and the treatment of other sources to destroy or remove potential pathogens and indicator organisms. Microbiological quality is maintained through the surveillance of the distribution system to minimize the risk of subsequent contamination. The maintenance of residual chlorine throughout the system assures that adequate disinfection has taken place. Routine testing for micro-organisms is used for quality control operations.

Chemical quality

While the presence of some chemicals can directly affect human health, many others may act to make water less palatable through the production of tastes and odours. Some chemical constituents can also severely restrict industrial and agricultural uses of the water. While a major issue in the industrialized world is the presence of synthetic organic chemicals, these are as yet of little significance in developing countries. Chemicals of concern are heavy metals and certain minerals, such as fluorides, which are acutely toxic. High salt content interferes with palatability.

As with microbiological contamination, potential problems are mitigated through the use of standards which regulate the maximum allowable concentration of each chemical. While these standards will vary with each specific water-use, standards for drinking water should provide the basis of such regulations. These standards can be met through the choice and management of appropriate water sources, as well as through the treatment of water. Periodic monitoring of the concentration of those potentially harmful chemicals known to be present should be carried out.

Physical quality

The physical characteristics of a water source also affect its suitability for human consumption. Temperature, colour, and turbidity all strongly influence human perceptions regarding the purity of drinking water. Excessive turbidity can also seriously interfere with the effectiveness of chlorine as a disinfection. Source protection, management and treatment are all viable options in controlling these problems.

Development options for quality control

The quality of the water can be maintained through the protection of the source, maintenance of the integrity of the transmission and distribution system, and if needed, through the treatment of the water prior to distribution. The main purpose of water treatment is to render the water safe for human consumption. This primarily entails the destruction or removal of pathogenic micro-organisms present in the raw water. Secondarily, turbidity must be removed due to its interference in the disinfection process, as well as for aesthetic reasons.

The simplest form of treatment is quiescent storage which can remove micro-organisms through settling natural attrition, though complete removal depends on the time of storage and temperature. Such storage, however, is not sufficient to assure safety without disinfection. Coagulation with chemicals followed by sedimentation is effective in reducing turbidity, although under normal operating conditions the removal of bacteria will not be so complete as to assure safety.

Slow sand filtration is a simple water treatment technology that can effectively reduce the concentration of micro-organisms by 1 to 4 (90 per cent to 99.99 per cent). Removal is accomplished through a combination of straining, sedimentation, absorption and microbial degradation. The microbial layer which develops on the filter particles will eventually, after some months, prevent the adequate flow of water, necessitating the removal of the top 1 to 3 cm of media. When excessive depths of sand are removed, the washed sand is replaced in the filter. Because of the low loading the area required for slow sand filters is large, but such filters are simple to construct and operate and require little sophisticated equipment. However, such units are not suited for treating turbid waters.

Rapid sand filters, which can treat turbid water at relatively high rates are usually used following coagulation and sedimentation. While effectively removing virtually all suspended solids, they do not remove micro-organisms, but depend upon disinfection to achieve this.

The disinfection of drinking water, chlorine, or other chemical components and processes can be quite effective in destroying most types of pathogens. Excessive amounts of turbidity however can interfere with the disinfection process. The operation of disinfection facilities depends upon having the chemical continuously available and the use of relatively complicated mechanical equipment. Failure of disinfection and lack of continuous supply of water under pressure are the principal reasons for unsafe water in developing countries.

Development options for the provision of adequate quantities of water

The demand for potable water will increase in metropolitan areas as they continue to grow and the exploitation of new sources of water is routinely believed to be the only alternative for meeting this demand. However, the unit costs of additional water supplies will tend to increase because of higher capital, operation, distances and/or lower elevation - the latter being applicable to metropolitan areas located at high altitudes. Thus, the majority of the metropolitan areas will be facing increasing marginal costs for additional water supplies from new sources.

Two obvious, but so far neglected, alternatives to high-cost, new water source development are the reduction of current rates of water-use and the reduction of system losses. Rates of water-use in the modern sections of metropolitan areas range from about 200 up to 600 litres/per/capita/day (lpcd). Through the use of various conservation measures, there is considerable scope for the reduction of such high rates of water-use. For example, the industry can be persuaded to build toilet reservoirs of smaller capacity. Educational campaigns in schools, newspapers, and through television can increase the consciousness of the people to use less water and to prevent waste by, for example, quickly repairing faucets.

The irrigation of lawns and car-washing with potable water can be restricted or banned. Water may be rationed by supplying it either on alternate days or within certain hours of each day. Excessive water-users can be discouraged by a steep increase in differential tariffs. Owners of single houses with large gardens can be encouraged to build cisterns to store rain-water from roof and garden catchments.

Enormous benefits can flow from an enlightened conservation programme. For instance, if a campaign in Mexico City results in a reduction of current water demand by 10 per cent, water-saving of about 26.0 cubic meters per second (cumecs), equivalent to 30 per cent of the water supply required for a medium growth scenario for Mexico City can be achieved. The capital cost of supplying this amount of water from new sources would be in the order of US$450 million. In contrast, the annual savings resulting from non-expenditure on operation, energy and maintenance costs of such a project would be at least as high as its capital cost over a period of 20 years.

Besides cost savings, reduction of metropolitan water-demand releases the amount of water saved for other uses. Investments needed for the reduction of metropolitan water-demand are a fraction of the total costs of new water source exploitation and have very high priority in policy, plan and programme formulation for metropolitan water supply and management.

Water losses tend to increase as water supply and distribution systems expand. A major reason for this situation is the competition between increasing costs of operation and maintenance of the old distribution system. Political pressures and investment demands for the operation and maintenance of existing systems inevitably receive a lower priority in terms of manpower, equipment and financial resources when compared to system expansion. Unless a clear policy decision is made to reverse this trend, system losses will continue to increase as the systems expand.

In the absence of extensive measurements, it is difficult to make firm estimates of losses from water distribution systems. Available estimates suggest that the distribution system losses vary from between 20 to 40 per cent of the water supplied to metropolitan areas. Taking the average system loss as 30 per cent, a one-third reduction in the loss should be a feasible target to achieve over the next 10 to 20 years. Measures for reducing system losses consist of improved maintenance, renovation and replacement of critical elements of the distribution system (electro-mechanical equipment such as pumps, motors, valves; flow-and pressure-measuring devices along the primary and secondary distribution lines) and the establishment of special emergency squads for the detection and prevention of losses from the water distribution system.

The maintenance of critical elements of the distribution system should be carried out at three levels: maintenance for operation e.g. washing, lubrication, fuel or electric supply; preventive maintenance, e.g. periodic inspection and replacement of certain spare parts, and corrective maintenance, which involves equipment repairs. The failure of a maintenance programme results from either insufficient preventive maintenance due to lack of inventory control and spare parts or from equipment operating beyond its useful life. Renovation involves major repairs and overhauling and frequently is the result of inadequate preventive and corrective maintenance. Replacement of electro-mechanical equipment at the end of its useful life, e.g. between 15 to 20 years, will reduce excessive operation and maintenance costs and unplanned interruptions in supply. Maintenance of flow-and pressure-measuring devices is essential if losses are to be detected before they become visible.

The quantity of water available should ideally be sufficient to meet the demands of the users. If the amount of water supplied is insufficient, the pressure in the distribution system may be reduced to the point where contamination can enter the system through pipe joints. The amount of water demanded depends upon the level of service provided and socio-cultural conditions. Multiple house connections combined with the use of flush toilets and other water-consuming appliances result in large demands of up to 200 to 400 lpcd. Areas served by yard taps or centralized public standposts demand far less water, down to 20 to 40 lpcd.

It is essential that realistic estimates be made of the demand in the area under consideration, recognizing that different parts of the area may exhibit different demands. Parts of the system, such as the transmission mains and treatment facilities, need to be designed for the days of greatest demand; this maximum day-demand is normally in the order of one and a half to two times greater than the average. The distribution system must be designed for the peak demand, which can range from two to five times the average. Distribution pipes and storage facilities are sized to ensure adequate pressure during peak demand periods. The daily and peak demand factors should be carefully assessed for every particular situation. Overestimation of these factors will lead to the over-design of systems and unnecessary additional costs.

Chapter 3

WASTEWATER DRAINAGE AND SANITATION

Wastewater

The three components of metropolitan wastewaters are urban storm runoff, non-urban storm runoff (coming from the surrounding higher lands) and wastewaters produced by the domestic, service and industrial sectors. Urban and non-urban storm flows have a high-peak character. The drainage and sewer systems of metropolitan areas carry a mixture of storm flows and domestic and industrial wastewaters. The domestic and industrial wastewater flow has a fairly high volume and low seasonal variability and thus dampens the high temporal variability of storm flows. The two major reuse alternatives for the wastewater flows of metropolitan areas are agricultural irrigation downstream and the substitution of selected uses of potable water through the reuse of treated waste.

The concentration or strength of wastewater or sewage is usually expressed in terms of its biochemical ocygen demand (BOD). The oxygen demand is a gross and indirect measure of the total organic load contained in wastewater and it represents the amount of oxygen required by bacteria to oxidize the various organic components in the water. The BOD is normally measured by allowing a sample of polluted water, diluted if necessary, to stand at 20°C for five days and then determining the amount of oxygen consumed. This allows the estimation of biodegradable matter contained in the sample of wastewater. Another often-used measure is chemical oxygen demand (COD). The COD can be measured very quickly but does not give any information on the proportion of the waste that can be oxidized by bacteria either in treatment facilities or in the receiving waters. The ratio BOD/COD of urban domestic sewage is normally around 0.5 but the value in any given case depends on local conditions such as the presence of industrial wastes.

The strength of wastewater is related to the levels of consumption. High water consumption (300-400 l/cap/day) results normally in weak sewage (BOD:200-250 mg/l) whereas low water consumption (50-150 l/cap/day) as encountered in most developing countries will generally result in strong sewage (BOD: 400-1000 mg/l). The BOD is an important parameter for estimating the degree of harm that may be caused by wastewater discharged into a receiving water body, as it can be used to measure the impact on the oxygen content of the concerned water bodies. If BOD discharges are excessive, the dissolved oxygen may be reduced to a point, generally about 4 to 5 mg/l, below which it has a detrimental impact on aquatic life. If all of the oxygen is depleted, the water body becomes anaerobic, and presents a serious health hazard.

Other characteristics of wastewater which are important to assess for potential hazards are the presence of pathogenic organisms and toxic chemicals. In addition, nitrogen and phosphorus, which are present in all wastewaters, are essential plant nutrients, but when excessive, may result in the eutrophication of surface-waters, thereby seriously affecting their quality as a source of water or as a recreational amenity. A quasi-optimal nutrient level results in the increase of the fish population in a water body.

Sanitation systems

The purpose of a sanitation system is to reduce the spread of enteric pathogens through the collection, treatment and/or disposal or utilization of human excreta. Sanitation systems can be divided into two major categories: those that treat or dispose of the wastes on-site, and those which transport the waste to a central facility for treatment. These systems can be further distinguished by whether they are designed to collect and treat wastewater (requiring that water supply be available) or only manage human excreta. Such systems are classified as sewered or non-sewered, respectively.

On-site disposal

On-site sanitation technologies, where appropriate, are the most economical. When properly constructed and maintained, they can effectively prevent the contamination of the environment by waste-borne pathogens. The non-sewered dry systems require the simplest technologies comprising of some method of direct disposal of human wastes into a pit from which the liquid element drains away and the solid portion decomposes. The decomposed material is either removed from the pit for use as soil conditioner or else the pit is covered up and a new pit dug. Special provision must be made for adequate time and a high enough temperature to ensure pathogen destruction which will permit the utilization of the night soil without creating public health problems.

The wet systems require water to wash the wastes into the disposal pit and a water seal to guard against insects and odours. The pour-flush toilet is a very simple design requiring only about 2 l per flush. Standard flush toilets using approximately 15 to 20 l require more elaborate disposal techniques. The septic tank is a large vault which allows the settling and degradation of solids, the effluent being disposed of through a soak-away or a series of drain pipes in the soil. The on-site wet systems generally require much greater land areas, making them unsuitable for high-density urban areas. Consideration must also be given to the potential contamination of nearby water-wells by way of wastes draining through the soil. While pathogens will generally be eliminated quickly when passing through soil, short-circuiting may allow pathogens to travel great distances.

Special attention should be paid to the risk of groundwater pollution through on-site sanitation systems. In general, the unsaturated zone of most soils is a very effective wastewater purification system, having the ability to remove micro-organisms and degrade organic components. However, the degree of this purification process is influenced by local factors such as soil characteristics and the seasonal fluctuation of the groundwater table. The pollution impact of on-site disposal facilities also depends on population density and other hydrogeological conditions such as the topography of the surrounding area, the flow and recharge pattern of the groundwater, and the degree of confinement of the groundwater. In view of the complexity of the factors involved and the importance of groundwater as a water resource, the potential pollution risk and possible technical alternatives should be carefully considered.

Off-site disposal

Off-site disposal involves the transportation of the wastes to a facility for its treatment and/or disposal. Dry systems rely on waste collection via buckets or specially-equipped suction trucks for transport to the disposal facility. While this type of system may be feasible for high-density areas for which sewers are too costly, there are many problems associated with the organization and logistics of the collection operation. However, such collection may offer an interim alternative pending the construction of a sewerage system.

The transportation of wastes via sewers is the most common system found in developed countries. The cost of construction of a conventional sewer system and treatment facilities can be prohibitively high for developing countries. If the sewer is to serve areas using low-volume pour-flush toilets, small-bore sewers may be a more economical solution. As sewers are designed to flow by gravity, the costs of the sewer network depends not only on the size of pipe and distance covered, but on the required depth of excavation as determined by the topography of the service area. Care must be taken in the planning of sewerage and treatment systems since the discharge of large quantities of waste can cause severe environmental degradation as well as public health problems.

Sewerage systems are often the only feasible option for metropolitan areas. However, particular emphasis must be placed on staged construction and on the fact that insufficient operation and maintenance may make a sewerage system the single most costly element of infrastructure.

Untreated wastewater effluents of large urban settlements or large industrial complexes may have a very deleterious impact on the receiving water body and cause serious health risks to people using such polluted wastes for drinking, bathing or irrigation. Adequate treatment and disposal of sewerage is therefore a major element of off-site sanitation.

Forms of treatment

While many forms of treatment are available, the most appropriate technologies for developing countries are those which rely on biological processes with a minimum of electro-mechanical equipment and simple operation and maintenance procedures.

Waste stabilization ponds are in most cases the most appropriate treatment facility. They comprise of a series of ponds in which treatment occurs through natural, physical, chemical and biological processes; no expensive mechanical equipment or energy inputs are required, and their maintenance is simple. Although ponds are the most economical and least mechanized of all known treatment technologies, when properly designed they provide a high-quality effluent and reduce pathogen levels more effectively than through the use of more sophisticated technologies. The only major disadvantage of ponds is a mandatorily long retention time of approximately 20-30 days and their large area requirements. In warm sunny areas, up to about 4000 m^2 of land per 1000 capita are required; the land requirements for 50,000 and 5,000 people would be about 0.2 and 2 million m^2 respectively. Savings in space (9 per cent to 80 per cent) are possible through the aeration of the ponds. However, this will represent an increase in energy costs and operation and maintenance.

Even if land is relatively scarce, there is a strong argument for the initial use of stabilization ponds in the first phase of a staged sanitation system. As the sewer system is extended and the wastewater quantity increased, the treatment capacity can easily be enlarged without using new land (which may have become even more scarce) through a phased upgrading to more sophisticated treatment systems.

For aerated ponds or aerated lagoons motor-driven surface aerators are used to speed up the treatment process and reduce the detention time to about four days. Aerated and unaerated ponds are normally connected to one or two maturation ponds which are responsible for the removal of sludge and the reduction of most of the pathogens. They provide an excellent environment for fish-breeding.

Oxidation ditches are in principle similar to aerated lagoons. The wastewater is circulated in a channel by rotating brushes which drive the water forward and mix oxygen into the water at the same time. The effluent from the channel is led to a sedimentation tank for sludge removal before disposal. This type of facility can normally be operated with detention times of only about one to three days. The space requirements are smaller than for the previously-described ponds but they need more complex machinery and give rise to much higher energy, operation, equipment and maintenance costs. Further, the pathogen reduction is very low compared to pond treatment. The concept of integrated ponds is detailed in the next section.

Stages of treatment

Wastewaters can be treated either through conventional or unconventional processes. The conventional treatment processes used today are modified and improved versions of processes developed in Europe and the eastern United States in the early twentieth century. They involve the use of chemicals and are highly mechanized, energy-intensive processes which can be carried out all year-round, often under a shelter in the cooler and wet climates. They involve four sequential stages:

(a) Primary treatment removes from the raw sewage by plain screening and sedimentation about 90 per cent of large settleable and floatable materials and between 40 to 70 per cent of suspended solids.

(b) Secondary treatment reduces the amount of organic matter through bacterial action, oxidation and synthesis. The most common methods are the trickling filter and the activated sludge processes. Secondary treatment typically removes 90 per cent of suspended solids, 90 per cent of biodegradable organics, 60 per cent of non-biodegradable organics, 50 per cent of pathogenic bacteria and most of the viruses.

(c) Tertiary treatment involves the removal of the remaining suspended and colloidal solids, non-soluble biodegradable organics and soluble nitrogen and phosphorus compounds through any of several filtration systems or other methods.

(d) Quarternary treatment is of a different character and is applied when specific components of wastewater are to be removed or when a wastewater quality standard is desired. They are not normally included in the treatment of domestic wastewater discharging into unpolluted water bodies.

For a given plant capacity, the cost of conventional treatment approximately doubles with each stage. Thus, secondary treatment costs twice as much as the primary treatment and tertiary treatment costs twice as much as secondary treatment. Costs increase even faster for the fourth and fifth stages and for example, electrodialysis and reverse osmosis may cost from 15 to 30 times as much as the primary treatment where the cost of evaporation and condensation is largely a function of energy costs. Although the costs of each treatment stage doubles for a given capacity, the unit cost of treatment stages decreases as the capacity of the treatment plant increases, i.e. larger plants have lower unit treatment costs. Because metropolitan areas produce large volumes of wastewaters, unit treatment costs are lowered considerably by building larger plants. The relatively inexpensive primary or secondary treatments may be adequate for many uses such as agricultural and green irrigation and some industrial and commercial uses.

Within the context of wastewater treatment, the concept of "unconventionality" is interpreted to suggest that treatment need not be complex and expensive and that natural processes can supercede energy-intensive, high-technology processes with substantial savings in capital, operation and maintenance costs and with comparable results. For instance, among the preceding unconventional treatment processes that range from simple holding lagoons to oxidation ponds, the integrated ponding process involves a system of at least four earthwork cells in series. In each cell one or more treatments, disinfection and disposal functions occur. The major requirement and the cost item of the system is marginal land and a major degree of efficiency may often be attained at little more cost than the expense of conventional primary treatment. Thus, where land is available, integrated ponds are an attractive alternative for wastewater treatment systems of all sizes, particularly in the warmer and water-short regions where reclamation and reuse of wastewaters up to the tertiary level would be preferable to disposal into the river or the sea.

The location of outfalls from sewers or treatment plants should be carefully chosen considering water supply intakes, bathing, and clothes washing sites or beaches, recreational areas, and shellfish areas. Sewage from coastal towns is often discharged into tidal estuaries or the sea via long outfall pipes. Usually little treatment is required if the pattern of local currents and tidal movements ensure that the wastewater is adequately diluted and carried out into the open sea.

In metropolitan areas, treated wastewaters can be used instead of various categories of potable water. Considering the increasing marginal costs of new water supply projects as against the decreasing marginal costs of conventional treatment plants (as plant capacity increases) and the even lower costs of integrated ponds, reuse of treated wastewaters must be considered as a major alternative to new water supply projects.

Reuse of wastewater and night soil

One relatively new development in the industrialized world which has considerable potential for the metropolitan areas of the developing world is water reuse or the reclamation of wastewaters for non-potable uses. The collection of sewerage wastewaters and their treatment for reuse is very little different from that required for treatment for disposal.

Reclamation for reuse has the following very clear advantages:

(a) The reclamation of the wastewater for reuse reduces its pollution potential, thereby reducing its impact on water courses below the metropolitan area;

(b) Many water uses in urban areas include urban irrigation for parks, gardens, lawns, and vegetation strips along roadways. The use of scarce fresh-water for these purposes denies this water for other uses that require a higher quality. The use of reclaimed wastewater not only reduces the demand for high-quality water, but also makes good use of the nutrient content of the wastewaters which are particularly valuable for irrigation.

Wastewaters have an appreciable economic value in agriculture in the urban hinterlands due to their high organic matter and macro-and micro-nutrient contents. As a result the farmers might not need to use fertilizers or at least reduce the quantity being used. This lowers the cost of crop production and provides a higher margin of profit. The positive aspects of the storage of organic matter and nutrients in soils and their utilization by crops and the increase in the water retention capacity of soils can be offset by their probable negative impacts on soils, surface and groundwaters and on human health either through the transfer to humans of heavy metals and toxic elements and salt accummulating on soils or through the disease problems caused by pathogens. Consequently, the following measures should be considered as integral elements of any wastewater irrigation project:

(a) Appropriate studies of soils, wastewater and crops characteristics should be carried out to ensure continuous efficient production;

(b) Medical and veterinary services should be provided at a level higher than those for fresh-water based irrigation projects;

(c) Appropriate sanitation facilities and safe drinking water should be provided for the local population;

(d) A monitoring programme and periodic surveys should be a part of the project operation for the early detection of any adverse impacts.

Night soil and sludge derived from vault latrines, septic tanks or other sewage treatment processes contain large amounts of essential nutrients and fermentable components. They are therefore potential resources for:

(a) Composting and agricultural application;

(b) Biogas production; and

(c) Fish culture.

Biogas plants using human and animal fecal material are a well-known and accepted technology in several Asian countries and it is estimated that more than 100,000 small-scale plants are in operation in this region. However, their use in urban settings in other regions has yet to be established. The successful operation of this system depends on a complex series of environmental, socio-cultural and economic considerations.

Industrial wastewater

Although the volume of industrial wastewaters is relatively small in developing countries, the local hazards to the environment and public health are often high, since the disposal of industrial waste is usually not well-controlled and residences are allowed to develop in the immediate vicinity of industry. These wastewaters can contain a very wide variety of pollutants and toxic substances and their discharge rate or flow pattern may vary considerably depending on the industrial activity and the different processes which are employed. For most industrial processes, the major characteristics of industrial wastewater pollution are high BOD and COD, suspended solids, acidity, heavy metals and organic chemicals. Food, drink, paper, tanning and textile industries tend to discharge heavy organic pollution with high BOD. Metal finishing, chemical and plastic industries discharge chemical pollutants including heavy metals and other toxic chemicals which can be very hazardous.

Control measures for industrial wastes include:

(a) Land-use planning to segregate industrial and residential areas and to locate industries at sites where their hazardous impacts are minimized;

(b) Regulation and legislation by means of discharge or effluent standards forcing the industry to treat or pre-treat their wastewaters and encouraging the recycling of waters;

(c) Discharge of wastewaters into public sewer systems and their combined treatment with sewage. This method should only be applied if the wastewater does not contain any chemical pollutants which may be hazardous to biologicaal treatment processes. Otherwise, such pollutants must be removed by appropriate pre-treatment at the source.

Storm-water drainage

Most cities in developing countries have some existing system of storm-water drainage in order to drain water accumulating from heavy rainfalls and to prevent flooding. Usually, the drains are roadside ditches rather than underground sewers and are often also extensively used for all sorts of solid waste disposal. In areas without adequate sanitation they may also be contaminated with excreta. Accumulated wastes in storm drains therefore pose high potential health risks. Discharges from such polluted storm drains may also result in serious pollution to the receiving water body.

Therefore, the storm-water drainage system has to be carefully surveyed and its role and impact must be carefully considered. A well-maintained and regularly cleaned storm-water drain system becomes a feasible means to dispose of gray-water (not fecal contaminated wastewater) in the initial phase of a staged programme. Later, the drains may be replaced by sewerage systems.

Urbanization of an area increases the area of impervious surface such as houses, paved streets, parking areas, etc. Therefore, the runoff during rains increases accordingly and results in considerable higher flows necessitating adequate storm drainage. Also, because greater flows result from such development, the risk to those who build in the flood plains is greater. Extensive drained areas with largely impervious surfaces in urban settlements also reduces the recharge capacity of the local groundwater aquifers, thus decreasing dry-weather stream flows and underground water resources.

Chapter 4

POLICY ISSUES

In the planning of water supply, sanitation and storm-water drainage drainage systems, the following issues should be carefully considered:

(a) Standards of service;

(b) Appropriateness of technology and social and cultural acceptances;

(c) Organization and management; and

(d) Watershed management.

Standards of services

There is a strong interrelation between the standard of service of water supply (a standpost, yard or house connnections) and the level and type of sanitation (a pit latrine pour-flush or conventional flush toilets) to be provided, which in turn affects the impact of urbanization on both the immediate and the regional environment The level of water supply service not only affects the demand of water per capita but also the amount of wastewater which must be treated and safely discharged. On the other hand, a high level of sanitation as provided by conventional sewerage systems requires adequate quantities of water for flushing wastes and therefore demands a high standard of water supply. Even sanitation using pour-flush toilets requires a relatively high standard of water service to ensure the proper utilization of these facilities. Water supply with conventional house connections and sewerage systems are only economically feasible in core downtown areas and in some high-income commercial and residential areas in developing countries. For most other areas, lower levels of service represented by yard connections, public standposts, communal bath houses, and on-site sanitation facilities, followed by a gradual upgrading to a higher level 'is the most appropriate approach. Accordingly, planning decisions as to levels of service are important to the environmental impact of metropolitan development. The higher the level of service provided to the residents of the metropolitan area, the greater the impact on the regional water resource, both in terms of the quantities abstracted and in the polluting waters discharged. Also, pressures on land are a function of levels of service, with higher levels of service requiring greater land areas for water source development and for water and waste treatment.

Household rates of water-use in metropolitan areas range from about 20 lpcd in low-income sections using standpipes to over 600 lpcd in high-income areas where houses with large gardens predominate. The installation of yard connections increase water use to about lpcd; house connections and simple indoor plumbing, including flush toilets increase it to about 100 lpcd. As a result, the poorest 40 per cent of the population usually account for about 10 to 20 per cent of total water use, and the remaining population for between 30 to 60 per cent. The majority of the poor are squeezed out of the centre of the metropolitan area and live on the fringes of the city, usually on higher grounds with marginal lands. Consequently, it becomes much more expensive to supply water to them. Because the cost of a water distribution system normally accounts for between 50 and 70 per cent of the total cost of water supply and because the length rather than the diameter of the pipe is the major determinant of cost, distribution systems should not be over designed. This is especially important in serving the low-income sections of metropolitan areas. Because conventional sewerage systems require a minimum rate of water-use of about 100 lpcd, other sanitation facilities such as pit-latrines and their variations should be utilized for wastewater and excreta disposal until rates of water-use reach the required level of sewerage.

Besides good hygiene and the sanitary disposal of excreta, ample quantities of safe water are necessary for the control of water-related diseases. This fact and the value judgements regarding the equitable use of services usually lead to a subsidized supply of water to low-income sections of the metropolitan areas as reflected by differential tariff structures. Because the amount of water used is so low in sections, there is normally no need to measure individually the quantity used.

Appropriateness of technology

Experience suggests that the use of affordable and technically appropriate technologies tailored to local needs and constraints are essential for the continued success of any water supply and sanitation project. Special attention should be paid to community low-cost on-site waste disposal facilities. School teachers and local community leaders can play a significant role in the introduction of these technologies to the community. When water and sanitation needs can be acceptably met by relatively low levels of service while still meeting all the health standards of such systems, the impact of the metropolitan area development on the natural resources of the region will tend to be correspondingly low.

Organization and management

The water and sanitation sector constitutes an area of key policy issues with regard to metropolitan organization and management because a metropolitan government is seldom in a position to obtain its water supply entirely from within its boundaries, to say nothing of the impact of these wastewaters on areas far downstream from the metropolitan area. In fact, because many metropolitan areas are on the coast, located near estuaries, the impact of pollution on international waters may be a major concern.

Metropolitan government has often served by taking a lead in establishing regional organizations in which the metropolitan government is the largest actor. This will help to avoid conflicts over the rights to waters in the region and will help in the planning of wastewater disposal facilities so that their impact in the region outside the metropolitan areas can be minimized.

Several forms of organization have been found to be appropriate, two of which are of the greatest interest:

(a) The first is the regional organization that draws its membership from all of the local authorities within the region, the region often being based upon hydrological boundaries or where this is not feasible, on political boundaries;

(b) The second is the local organization whereby the local authority serving the core of the metropolitan area undertakes to provide all of the services to the outlying communities within the region, based upon a series of contracts with other local authorities.

Each of these approaches has its drawbacks but one or the other is better than allowing each individual local authority and metropolitan area to go its own way.

The benefits from a regional approach to metropolitan area problems in the water sector are considerable.

(a) With each local authority seeking to acquire its own water supply, some may have to seek it at long distances or may have to be satisfied with a water source of poor quality with the consequent increased costs in rendering the water safe. By integrating all of the needs into one larger system, all of the communities in the metropolitan areas as well as other communities in the region can, be more economically served because it would be more cost-effective to go longer distances for a large supply than for a series of small supplies.

(b) The service that can be rendered by the agencies responsible for water supply and sanitation from a larger industry are likely to be superior to those services than can be provided in smaller communities;

(c) The staging of improvements of service can more readily be implemented on a larger regional basis;

(d) Financing can be much more easily achieved within metropolitan areas; and

(e) The development of a given resource can be much better managed on a regional basis, particularly in providing services to the more rural areas of the region. A commitment to the people throughout the area will do much to minimize adversary relations between the city and the country.

Watershed management

Urban development in water supply watershed locations degrades the quality of water supplies and endangers public health. Rational watershed management has therefore become an important factor in protecting water sources. Watershed management strategies incorporate a variety of planning measures within an entire catchment area to guard against contaminants, sediments and flood hazards. The development of a watershed management programme consists of five basic steps:

(a) Problem analysis. Evaluation of existing and emerging pollutants and their sources and estimation of their importance. Sources of pollution include:

(i) On-site sanitation facilities;

(ii) Discharges from sewerage systems and wastewater treatment facilites;

(iii) Stormwater runoff from urban and industrial areas;

(iv) Industrial waste discharges;

(v) Leaking from solids and hazardous waste disposal sites;

(vi) Transportation (highways, railroads, pipelines);

(vii) Agricultural and forestry activities;

(viii) Mining; and

(ix) Natural erosion.

The importance of each source depends on factors such as the amount of discharge, its concentration and toxicity, the location of the pollution source, and available appropriate water treatment techniques.

(b) Direction-setting. Formulation of basic goals to ensure the continuous supply of raw water of adequate quality and quantity minimize flood hazards as well as increase recreational opportunities and enhance agricultural resources.

(c) Selection of control strategies. The strategies include:

(i) Land-use planning and management; and
(ii) Physical control measures such as water and wastewater treatment.

Rather than devising ways to remove pollutants from water or reduce flood levels by structural means, land-use planning and management seek to prevent pollutants from being generated at locations where they may pose a hazard. Similarly, preventing development on flood plains avoids creating a problem and is preferable to the use of structural measures to protect endangered populations. Physical control measures are effective ways of dealing with existing, known hazards, but not of preventing new hazards from emerging.

Land-use planning and management include land-use practices (regulatory activities such as zoning, subdivision regulations, and special sensitive area regulations) that reduce the potential hazards by establishing the most appropriate locations for human activities; and site development and operation practices (building construction characteristics, stormwater control measures, waste-handling procedures, etc.) that reduce potential hazards by regulating the way activities are conducted at a site.

The selection of control strategies should be based on their efficiency and cost-effectiveness under local conditions, as well as representing a balanced mix of structural and institutional measures. Special attention must be paid to the fact that land-use planning and management are long-term, preventive measures that often minimize the long-term cost to society of dealing with hazards. Also, land-use measures tend to be more effective in preventing problems from occuring by intervening early or in the development process rather than in solving existing problems.

(d) Programme design and implementation. This step includes the acquiring of financial resources and manpower, manpower development, and choosing the course of action and measures to be introduced based on selected stragegies. The implementation of such programmes, and their introduction, adoption and enforcement require effective institutions and a willingness on the part of the public and officials to initiate and sustain such programmes. Some obstacles to effective programme design and implementation are that:

(i) Hazards are not perceived as problems;

(ii) Local officials or administrators are not interested in the problems;

(iii) There is a lack of trained manpower and technical expertise;

(iv) There is a lack of adequate information; and

(v) The institutional resources to deal with problems are insufficient.

(e) Programme monitoring and evaluation. These should be viewed as an integral part of the overall watershed planning and management effort. The collection of the data necessary to measure the consequences of a programme should begin at the outset of the programme and is therefore part of the planning process.

Chapter 5

CONCLUSION

Urban growth exerts high levels of demand on regional resources, including water. Although accelerated urbanization is one of the basic projected trends for human settlements, the mode of development of urban areas need not be taken as a fait accompli. Should certain modes of development pose serious negative impacts on regional resources and increase competition in the development of various sectors, new strategies of growth must be sought. This will require an integrated early assessment and planning process, and abandonment of the crisis-management type of planning now common.

Technical solutions to problems of water supply wastewater disposal, drainage and sanitation are inadequate on their own since financial institutional, manpower, social and environmental constraints often make the execution of technical solutions unfeasible. Moreover, it is insufficient to evaluate these constraints from a project perspective alone, as the implications of sectoral activities, based on the utilization of resources such as water, reach areas far removed from urban boundaries and impinge on many other resources and sectors.

Current water supply and wastewater disposal technoligies have reached a high level of development. However, there is need to improve their performance under operating conditions in developing countries as well as to simplify some processes so as to enable operation by unskilled personnel. Additional focus is needed on the use of low-cost materials and equipment in construction and maintenance. Activities in this respect could concentrate on the implementation and simplification of water treatment systems, a review of the performance of sewers under low-flow conditions, research on small-bore sewers, the investigation of appropriate energy sources for mechanical equipment used in infrastructure projects, and the study of the environmentally sound use of wastewater for agricultural use and groundwater recharge.

Neither the regional and national nor the intersectoral implications os single infrastructure problems can be ignored in an urban and metropolitan context. Yet, despite a growing recognition of these interdependencies, insufficient information is available to specify, for instance, water supply strategies for metropolitan areas and their impact on regional water resources, soils, crops, or the city-based environmental impacts on health, subsidence, etc. There is, therefore, need for metropolitan authorities to identify, collect and analyse relevant data on a systematic basis and to anticipate the environmental as well as other developmental impacts of water supply and wastewater disposal strategies. The choice, from among technically feasible and environmentally sound modes of water supply and wastewater disposal strategies, must be based upon careful economic and financial evaluation, given the existing social, cultural and political constraints.

ANNEX

CASE STUDY: WATER SUPPLY AND WASTEWATER DISPOSAL IN MEXICO CITY

Introduction

Mexico City completely covers and extends beyond the 1,500 km^2 Federal District in the south central portion of the Valley of Mexico, including portions of the States of Mexico and Hidalgo. The most recent estimate of the population is 16 million, increasing annually by 700,000. The projected population in 2000 is 26 million.

Urban development in Mexico City has caused environmental problems and has had environmental impacts throughout the Valley of Mexico. Of the many environmental problems, water supply and wastewater disposal are considered the most critical. The current demand for water exceeds supplies within the Valley of Mexico, requiring water importation from other river basins. The amount of wastewaters for disposal cannot be optimally absorbed within the metropolitan zone and, therefore, must be transferred to other river basins. The magnitude and mode of water supply as well as wastewater disposal creates a series of primary and secondary environmental impacts within the city and its hinterlands, requiring the adoption of innovative policies.

Three geographical areas are of particular importance with regard to water supply use and disposal - the Upper Lerma River Basin, the Valley of Mexico and the Tula River Basin. The 8,640 km^2 Upper Lerma Basin is one of 10-sub-basins of the Lerma River. A water-transfer project, initiated in 1952, has 236 wells pumping 20 cubic metres per second (cumecs), of which 11.7 cumecs (58.5 per cent) are exported to Mexico City via interbasin pipeline and open conduits. The Valley of Mexico also provides water for the metropolitan area and, until recently, was the sole source of ground-water for the city through a series of well-fields to the north and south of the city. These well-fields supply 43.5 cumecs or approximately 77 per cent of the 56.5 cumecs used in the metropolitan area. The 12,960 km^2 Tula River Basin is approximately 100 km north of Mexico City and is a part of the Panuco River watershed with a discharge into the Gulf of Mexico near Tampico. The bulk of a 51.9 cumecs wastewater discharge from Mexico City flows into this river basin through a series of canals, tunnels and deep drains. Wastewater discharge includes urban surface runoff (7.5 cumecs), non-urban surface runoff (8.3 cumecs) and urban industrial wastewaters (36.1 cumecs). The major portion of this wastewater is directed towards government-established irrigation districts. Irrigation District 03 comprising 44,898 ha (439 km^2) is the largest irrigation district in the Tula River Basin.

History

A series of flood protection, water supply and waste-water disposal engineering works have been implemented to keep pace with the continuous growth of Mexico City. Measures which stimulated city growth include pre-Columbian dykes and aqueducts, colonial drainage tunnels, modern drainage canals and tunnels, deep wells with extensive pumping, and large interbasin water-transfer projects.

In 1325, the Aztecs arrived in the Valley of Mexico and established their capital city, Tenochitlan (now Mexico City) on a low-lying plain surrounded by lakes. Water drainage in this high valley (2,240 m) is blocked by a ring of mountains, causing surface-waters to flow toward lakes which used to surround the Aztec capital. Before the Spanish conquest in 1521, Aztec kings had constructed dykes to reduce flood damage and aqueducts to import water from nearby mountain springs. The moderately saline lakes were not potable water sources for the entire year.

Heavy floods continued to inundate what is now Mexico City following the conquest. Especially heavy floods in 1604 and 1607 provoked the colonial government into constructing the Nochistongo Tunnel which in 1608 became the first artificial water drain in the valley. After a brief period, the tunnel collapsed, sealing the valley once again. By 1768, the tunnel had been converted into a deep drainage trench which is still draining wastewater towards the Tula Valley.

After Independence in 1810 floods became severe and frequent. The Government of Mexico constructed the Gran Canal and the Tequisquiac Tunnel, completed in 1900. The Gran Canal is a 47 km open canal large enough to accommodate 100 cumecs peak flows during the rain season. The canal flows north to the Tequisquiac tunnels (a second tunnel was added after 1900), and water passes through the tunnel to the Tula Basin.

Until 1913, city water supply was limited to private and municipal wells within the city. Then, the first of three well-fields began pumping water from a zone southeast of the city. The number of deep wells has increased steadily, and, at present, 1,130 public and private wells draw water from the Valley of Mexico aquifer. The rate of withdrawal is greater than the aquifer recharge rate and consequently, the volume of water in the aquifer is being reduced. The massive well-fields in the Valley of Mexico could not continue to meet the water demand of the growing metropolis, and an interbasin transfer from the Upper Lerma Basin went into operation in 1951. Over 230 upper basin wells now supply 11.7 cumecs of potable water to the metropolitan area.

The adverse and cumulative environmental impacts of inadequate water management measures (supply and discharge) have created severe economic and social problems within the metropolis and rural hinterlands. The costs of proposed water projects will create additional economic and social pressures and the Government of Mexico is now devoting considerable study to the feasibility of maintaining the present rate of growth in the metropolitan area.

Water supply characteristics

Since the turn of the century, ground-water pumping has been an easy and inexpensive method of supplying Mexico City with potable water. However, the expanding city necessitated increased extraction from limited aquifers, and the depth to the ground-water level increased as the rate of extraction became greater than the rate of aquifer recharge. Land also began to subside as water was extracted, causing extensive damage to buildings, roads and utility networks. Some areas of Mexico City have subsided more than 8 m since 1900, with old parts of the city, housing historic cathedrals and monuments, being most seriously affected. Portions of drainage canals close to the city have subsided to lower levels than the canal terminals, so that pumps must now be used in place of gravity to move wastewaters to disposal areas.

In order to keep pace with increasing demand without adding to land subsidence, water had to be imported from other basins. The upper Lerma River Basin was tapped for the Mexico City water supply in the early 1950s. Originally, water was drawn from wells and springs, but the springs soon failed, and additional wells were drilled for Mexico City water. The well-system was expanded in the late 1960s, and shortly afterwards, extraction surpassed recharge capacity to the point that ground-water levels went down and land subsidence became evident.

The rates of ground-water extraction and associated land subsidence have kept pace with city growth. In addition to disrupting water and sewer conduits, subsidence has lowered some areas to the point that sewer discharge cannot be accomplished solely by gravity, and storm flows must be pumped into the badly-damaged drainage system. These factors led to the construction of the expensive Deep-Drainage System which was began early in the past decade and whose construction is expected to continue for at least another decade. This system consists of a network of large-diameter deep tunnels up to 200 m below the city surface, and it is the most recent but not the last expense associated with ground-water mining in support of Mexico City's growth.

There are several economic impacts resulting from ground-water mining in the Valley of Mexico. These are:

(a) High investment costs (owing to strict design requirements for buildings, roads, bridges, subways and sewer works);

(b) High maintenance costs for building and infrastructure;

(c) Repair costs for past and future damage resulting from subsidence;

(d) High costs for disposal of urban runoff, such as for the Deep-Drainage System;

(e) High costs of pumping for water supply and wastewater disposal;

(f) Increasing water-treatment costs associated with the deteriorating quality of ground-water.

The effects of these economic impacts are seen in the increasing costs linked to the expansion and operation of the metropolitan area and increasing costs for goods and services within the urban zone.

Because of the attempt to lessen subsidence in the Vally of Mexico through the transfer of water from the Lerma Basin, the problems of ground-water mining were effectively transferred away from Mexico City to be borne by the citizens of the Lerma Valley. For instance, a study conducted in 1969-1970 found that aquifer recharge in Lerma was 11 cumecs - a rate of mining of 36 per cent. Land subsidence was already in evidence, and surface-water sources had failed. The study concluded that, if 1970 pumping rates prevailed, the piezometric level (depth to water in a well) would drop by 18 m in six years. Ground-water mining continued, however, at rates greater than in 1970, and, at present, 236 wells pump approximately 20 cumecs - a mining rate of 75 per cent. Of the 20 cumecs, 11.7 go to Mexico City.

Ground-water mining in the Valley of Mexico has produced serious negative impacts which have been partly offset by economic growth in the Valley. This has not been true in the Lerma Basin, where the benefits accrue to Mexico City and the negative impacts are borne locally. The people in the Lerma Basin could be regarded as subsidizing the growth of Mexico City by bearing the costs and uncertainties of ground-water mining in their own region and paying increased maintenance and pumping costs as water-levels in their wells recede.

Wastewater characteristics

Stormwater discharge of the Nochistongo Trench has increased surface-water availability in the Tula Basin. However, storm flows are of short duration, with seasonal and annual variability of peak flows. During the short but intense rains, discharges of 100 cumecs have been measured, while dry season flows are a small fraction of this figure. Annual fluctuations are common and are large in magnitude. For instance, in one 17-year period, the range of discharge from the Nochistongo Trench varied from 1,013,000 cu.m to 157,409,000 cu.m. The Gran Canal provides an assured supply of large volumes of wastewaters, and, despite the low quality, farmers use it for irrigation. The present area irrigated by wastewaters is about 76,500 ha and two projects totalling 27,500 ha are presently under way. Projects for at least another 23,000 ha are programmed for completion by 1986, and 10,000 ha are planned for future development, to utilize the projected increase in wastewater discharge.

A comparison of available and projected figures on the water balance of the Tula Basin between the years 1980 and 2000 leads to the follwing conclusions:

(a) In 1980, wastewater inflow was nearly three times the local surface-waters of the Tula Basin, and it will likely be over four times by 2000;

(b) In 1980, the volume of water used in the Tula Basin was 190 per cent of the total local water supply and this will likely increase to over 250 per cent by 2000;

(c) Irrigation in the Tula Basin is dependent on the wastewaters of Mexico City, and this dependence will substantially increase.

Wastewaters have an appreciable agricultural value, owing to a high content of organic matter and nutrients and have allowed farmers to cultivate a wider range of crops than would have been feasible under rainfed conditions, resulting in higher crop production and farm incomes. In Irrigation District 03, the largest irrigation project in Tula, farmers do not need to use fertilizers, which increases their margin of profit. However, wastewaters flowing into the district also contain heavy metals, toxic chemicals accumulate in the soil and are absorbed by crop plant tissues and consumed by humans or grazing animals, resulting possibly in ill-health or death. The severity of impacts is related to wastewater quality, soil type, availability of potable water, sanitation facilities, medical support and veterinary services. Boron, cadmium, chromium, lead, mercury, zinc and arsenic are present in Mexico City wastewaters. Although boron is injurious to plants, the crop yields of District 03 do not indicate boron toxicity problems, perhaps owing to the moderately high boron tolerance of crops selected for cultivation in the district.

Three large drainage conduits convey wastewater to the Tula Basin. The Gran Canal drains the southern and eastern portion of Mexico City, the Interceptor Poniente drains the western sections, and the Emisor Central carries wastes from the central areas of the city. The Gran Canal predominates (67 per cent of the discharge), especially in terms of irrigation, since the waters of the Emisor Central are not used for this purpose. Two small reservoirs, Endho and Requena, were constructed near Irrigation District 03 to regulate water flow and to store excess water during the rain season.

The chemical and biological quality of Gran Canal wastewaters deteriorate during high-flow periods between July and September. These waters are regulated at the Endho Reservoir where they are mixed with surface runoff and wastewaters from small settlements. Wastewater of a better quality from the Interceptor Poniente is mixed and regulated at the Requena Reservoir. Both reservoirs improve water quality through oxidation and sedimentation based on retention. While water from the Requena Reservoir is suitable for irrigation, and water from Endho is suitable only for moderately salt-tolerant crops, overall, the quality of irrigation water from the Tula Basin reservoirs range from suitable to marginal, depending on location and season. However, all district irrigation-water carries excessively high concentrations of coliform bacteria from human and animal excreta. Pathogenic organisms from excreta are likely to be present, and, if the water is ingested directly or from unwashed vegetables, disease can result in the district.

The continuous use of wastewater has resulted in a slight increase of soil salinization (5.3 per cent of the total area has salinization problems - a 1.0 per cent increase between 1974 and 1979), but, given the long history of irrigation (70 years), the amount of salinization is remarkably low. Serious salinity problems should not be expected, because 85 per cent of the district soils are sandy, and heavy applications of water have leached salts below the plant-root zones. Wastewater irrigation has improved cation exchange and the water-holding capacity of the soils, owing to the high organic content of the water (300 ppm or 6.6 tons per ha). The effect of using this water is similar to that of applying animal manure or crop-residues to well-drained soils to improve water retention or to clay soil to increase permeability.

Elevated concentrations of zinc, chromium and nickel have been measured in district tomatoes; cadmium, zinc, copper and nickel have been found in squash-, and milk from the district contains cadmium, chromium and lead above levels recommended by the World Health Organization. Although these elements are highly toxic to humans, no toxic effects have been reported from Tula. However, the best available data are more than 10 years old and industrial discharges from Mexico City have dramatically increased in recent years. Thus, toxicity problems may be more serious than indicated and certainly pose a future hazard and systematic chemical testing of plant and animal tissues is necessary, in order to determine the health hazards from wastewater irrigation in the district.

Wastewater has contaminated all surface-water and the concept of fresh surface-water in Irrigation District 03 is no longer relevant, because all open wells, springs, agricultural drains and natural water-courses have been polluted, especially by coliform bacteria from human or animal excreta. Both deep wells and shallow aquifers contain levels of coliform in excess of international standards for human consumption, but low-income smallholder farm families have no alternative to the use of contaminated sources and are consequently subject to wide-spread gastrointestinal infections. Despite these dangers, the density of medical and veterinary services is no better in the district than those normally found in irrigation projects using safe water.

The decay of profusely-growing water plants and sedimentation in the Requena and Endho Reservoirs are accelerating eutrophication and reducing reservoir volume. At present, only storage space below the drain-level is being lost. However, losses from live storage are only a matter of time, and, eventually, the reservoirs will become completely filled with sediments. Runoff waters will pass through the reservoirs without reasonable detention time and mixing, and eventually the quality of outflow will not differ from the quality of inflow. Since wastewater quality is expected to deteriorate and the expansion of irrigation will diminish the availability of leaching water, soil salinization and the accumulation of toxic elements will increase unless new reservoirs are built or the volume of existing ones is maintained or increased.

Health impacts

In the Valley of Mexico, water generally does not move about freely by natural means. Rivers, lakes and small water bodies have either disappeared or been converted to other uses. Water is pumped from one area, transmitted to another area for use and then pumped in a third area. In each of these three areas, health impacts are noted, although not systematically documented. At present, many houses in the Upper Lerma Basin are without a domestic water supply adequate for nutritional needs or small-scale agriculture. It is likely that water for cleansing and cooking has diminished in quantity as well as quality, and that there has been an increase in water-related diseases. The metropolitan area is a congested city with all the health hazards which are associated with densely-packed human populations. The unsafe management of water and waste creates additional health hazards, but it is difficult to separate water-related diseases from other types. Potable water supplied to Mexico City has deteriorated in quality, owing to contamination at the sources, although a recent programme for water treatment has reduced the health risks of incoming water. It is equally important to devote treatment efforts to wastewater discharge, as this water is known to be contaminated by human excreta or industrial wastes.

The removal of wastewaters is done through open conduits, often former small rivers of the hydrologic network and now open sewerage channels. These channels flow through densely-populated areas, some without reliable sources of potable water. Under these conditions, it is reasonable to expect high levels of gastrointestinal disorders. A preliminary study carried out by UNCHS (Habitat) indicated, for instance, a wide range of morbidity of enteric diseases reported to the clinics with the number of cases per 100,000 inhabitants ranging from 261 to as high as 1,579 in 1979. A slight decline in such diseases has been observed in 1981 - the most recent date for which information is available - attributable in part to an intense government campaign to provide all city residents with access to potable water. This campaign has been spectacularly successful in spite of the high costs and rapidly expanding populations, and, in 1980, 97 per cent of the city population had some type of potable water service. In addition, improved water-treatment projects were successfully implemented.

The wastewater discharge of Mexico City received by the Tula River Basin is laden with pathogens, toxic chemicals, salts, heavy metals and other pollutants and arrives untreated after passing through the biggest industrial zone of the nation. The water is used for large-scale and small-scale irrigation where irrigation techniques are of a rudimentary nature, either flooding within bunds or watering within furrows. Water is applied to fields throughout the year in large amounts, and humans and animals are freely and routinely exposed to the water as it is applied. Excess water either flows to agricultural drains or water courses before leaving the Valley via the Panuco River or percolates down through the soil to join the ground-water.

There is considerable potential for the proliferation of serious health problems, and not limited merely to the Tula Basin, because agricultural products from the area are distributed to several urban centres, including Mexico City. By law, wastewater irrigation is limited to cereal and forage crops but, by practice, it is not. Vegetable and fruit crops are also irrigated with wastewater, and the products are sold in Mexico City, returning chemicals and pathogens to the point of origin in different form. In the absence of systematic data, direct observation and analysis of what data exist lead to the conclusion that if environmental health conditions in the Valley of Mexico do not presently result in significant disease in the human population, there can be no guarantee against this for the future.

Before disease becomes a significant factor in the wastewater management programme of Mexico City, there are proven techniques which can be used to reduce the risk or mitigate the extent of disease without resorting to large capital outlays. Wastewater treatment can occur where wastes are discharged or where it must be reused. For instance, it is possible to construct shallow lagoons to hold wastewater temporarily, while oxidation and sedimentation can take place, and there are large areas near the drainage network of the metropolitan areas where such lagoons may be built at low cost. The diversion of wastewaters into these lagoons for brief holding periods would improve the water quality of the discharge to the Tula River Basin and lessen risk to soils or health.

In Tula, many householders are forced to use contaminated water directly from canals or from shallow wells which are polluted by wastewaters. This water can be made safe through the use of small slow-sand filters sufficiently large for household use. The technology is quite simple requiring little more than a 200 l barrel, sand and a small amount of gravel. While these simple and inexpensive devices cannot produce germ-free water, they can remove up to 95 per cent of pathogens with minimal maintenance.

Socio-economic implications

Huge projects must be undertaken to bring water from other basins to the Valley of Mexico if the increasing demand is to be satisfied. The costs of these projects will be high because of the distance involved in the transfer (over 200 km) and the differential between the low-elevation sources and the high-elevation destination of use. There are questions as to from where the funds for capital construction will be derived. The water-supply projects were designed during a period of rapid economic growth powered by the development of the massive Reforma oil field concomitantly with spiralling prices for petroleum products. However, the expected level of revenues was not achieved, and foreign borrowing rose above expected levels. As a result, money is not available to maintain the pace of development projected for the water supply systems.

This national problem will have water-related repercussions at all social and economic levels. The aim of supplying water to all users at demand levels may have to be set aside and, in fact, since 62 per cent of water-use in Mexico City is for domestic purposes, a cutback in this service is most likely. The first group to be affected will be new migrants seeking water connections. It has been government policy to provide squatter areas with water service as quickly as possible, either through hydrants or trucked water with individual connections soon to follow, but, by necessity, this policy may have to be revised.

By and large, domestic water-use has not been measured with individual household meters, and thus household use can only be estimated for establishing water-use tariffs - a condition which favours heavy users who fill swimming pools, water lawns and gardens, or wash automobiles. In squatter areas, service may not coincide with need, so that people must purchase water from private vendors at relatively high prices. The metropolitan water authority is currently conducting a campaign to add meters to most households, in part as a water-conservation measure.

At present, there is no price differential for different types of industrial water-use, and the system is unable to match water supply quality to the quality required for use. As a result, potable water is being used for irrigation and industrial functions which do not require water of such high quality. Further, water reuse has not been encouraged by pricing mechanisms.

Indirect costs of the water-management system are estimated to be very high, but there are no figures on subsidence which would permit an indication of this indirect cost. Environmental-health data are not sufficient to estimate the extent of ill-health and it is not possible to establish the amount of reduction in productivity which could be attributed to poor environmental health conditions. Also, no calculation has been made of the opportunity costs of investing either money or water in other uses or other geographic areas.

Water-policy issues

The recurrent water crises observed in the history of Mexico City suggest that water supply has frequently lagged behind water demand. The growth of the city was first subsidized through industrialization and infrastructure-provision policies which justified expenditures for providing water. However, cheap water supply options are no longer readily available using the traditional formats of large reservoirs and water transfer. Yet, Mexico City will continue to grow, and this situation calls for an analysis of present and future options.

As of 1981, the metropolitan area was supplied with a volume of water equivalent to the continuous flow of 56.7 cumecs, of which 11.7 cumecs came from the Lerma Basin, 3 cumecs from surface water in the Valley of Mexico, 2 cumecs from the reuse of treated waste-water and 40 cumecs from regional aquifers. The pumped water from the acquifers consisted of 23 cumecs of infiltration and 17 cumecs of ground-water mining. The 1981 water supply of 56.7 cumecs for an estimated population of 15 million is equivalent to an average consumption of 327 lpcd, made possible by the unsustainable mining of the aquifers of the Lerma Basin and the Valley of Mexico. Recent studies indicate that ground-water pumping would need to be reduced by 7.4 cumecs in Lerma and 10 cumecs in the Valley of Mexico if land subsidence and ground-water contamination are to be checked.

Total wastewater effluent was 51.9 cumecs, of which 36.1 cumecs were urban and industrial waste and 15.8 cumecs were rainfall runoff (7.5 cumecs from urban areas and 8.3 cumecs from non-urban zones). A large proportion of the wastewater effluent from the metropolitan area is discharged untreated into the Tula Basin where it is used for irrigation. Available information indicates that there is adequate irrigable land in the basin to absorb all the wastewaters to be produced by the metropolitan area for the immediate future.

Scenarios of low and high population growth for the metropolitan area show increased water demand, based on the present norm of 360 lpcd, to approximately 95 cumecs for the low scenario and 110 cumecs for the high scenario for the year 2000. If the planned reduction in ground-water mining of 17.4 cumecs is taken into account, the 1981 water supply, reflecting a 600-year growth history, will need to be doubled in only 19 years for the low-growth scenario. The ongoing Cutzamala and proposed Amacuzac, Tecoutla and Orientes Libre water-transfer projects were conceived to meet these immense demands. However, these projects must transfer surface water from great distances (150-250 km) and low elevations (1000-1500 m). As a result, capital, operating, energy and maintenance costs will be extremely high.

These projects will impose opportunity costs on the river basins involved, owing to probable environmental impacts associated with large impoundments and diversions of river waters. The regions will also be deprived of the use of and economic gains from water diverted to the metropolitan area. But current economic problems will delay implementation of these projects, further increasing capital costs. However, until the projects are in operation, ground-water mining will continue in the Lerma Basin and the Valley of Mexico and most likely at an accelerated pace.

Water supply planning has traditionally had the narrow focus of adding capital projects to an existing system. However, as water supply sources diminish, other options are sought, often to the advantage of the environment, since conservation possibilities are then carefully considered. In this regard there is potential in the Valley of Mexico for a series of conservation options which may prove far more feasible than envisaged capital projects.

A reduction in the demand for water has been accomplished in cities elsewhere, and the accepted norm of 360 lpcd for Mexico City may be reduced by 25 per cent to 270 lpcd by 2000. This can be accomplished by implementing measures ranging from educational campaigns to forced rationing. If the 25 per cent reduction can be achieved, water demand of the low-growth scenario would be cut by 24 cumecs. The cost savings would exceed US$300 million at current prices excluding operational and maintenance savings.

Conservation techniques for domestic water-use have been pioneered in many countries with success. Dry or low-water-volume flush toilets are effective in reducing water-use, and low-volume spray nozzles for bathing, washing or irrigating cut down domestic and agricultural requirements. If prices on these devices are reduced through government intervention, their acceptance and use could occur rapidly, and, since domestic use consumes a large portion of Mexico City's water supply without producing an economic return, the government could be most effective in achieving water conservation by directing public education campaigns and other incentives toward this sector. Household water meters are also effective economizing mechanisms, if sliding-scale pricing is used, whereby minimal users pay low rates and prices increase as water consumption increases.

The ability to pay current user-rates is no justification for heavy water-use, as supply is being subsidized by the entire nation. If luxury use cannot be curtailed by pricing mechanisms, prohibitive legislation might be effective and equitable. In wealthy neighbourhoods, lawns and gardens are irrigated with potable water at a time when a considerable portion of the population does not have access to such water for drinking and cooking. Luxury irrigation and car-washing can be done with non-potable water without health hazards, but incentive programmes are not likely to be effective in reducing this type of water-use, so that it may be necessary to enact water-use regulations which curtail non-agricultural irrigation with water from water-authority systems. Lawns and gardens could still be maintained through the use of captured rainwater or grey-water from laundry or kitchen discharge.

Water conservation can also be achieved by reducing water distribution system losses, now estimated to be nearly 50 per cent. This estimate may be accurate, but, without an extensive metering system, reliable estimates are difficult to make. The water authority has increased the amount of money available for operation and maintenance in order to reduce seepage and leaks in distribution lines, but more maintenance will become necessary as old lines fail owing to age. It is inefficient to construct water transfer projects involving hundred of kilometers of large conduits only to lose the water through a faulty distribution system.

The reuse of treated wastewater is a potential alternative to new supply projects. Treated wastewaters could provide up to 22.5 cumecs which could be used as a substitute for potable water in agriculture and industry. Of the 22.5 cumecs, 4.5 cumecs could be used for agriculture after primary treatment and disinfection, 4.5 cumecs for the irrigation of city parks and recreation areas after secondary treatment and disinfection, and 10.5 cumecs for industry, commerce and service after tertiary treatment, leaving 3.0 cumecs for aquifer recharge after secondary tertiary treatment. Primary treatment and disinfection facilities are relatively inexpensive to construct and maintain, but secondary treatment plants involve increased capital and operating costs, and tertiary treatment becomes very expensive. However, wastewater reuse does allow managers to match appropriate water-use with the most inexpensive treatment method.

Ground-water in the Valley of Mexico can be recharged through the use of small dams. Rainfall is seasonal, and, during the brief rainy season, water which cannot percolate into the soil runs off as flood or storm-waters through the drainage system. A large number of small dams have been built around the metropolitan area to retain rainwater until it can be used or until it seeps into the ground-water. More small dams are planned and can be located in areas of high soil-permeability for maximum recharge.

Water harvesting from roofs and garden-catchments is applicable in areas where houses with gardens predominate and where cisterns can be built to collect rainwater. This measure can mobilize private savings to substitute rainwater for potable water supply, and it may be particularly effective if factories and warehouses can collect rainfall for use in commerce and industry.

Another option for water conservation within the Valley of Mexico is through ground-water recharge projects in the hills. The Valley of Mexico has lost 73 per cent of its forest cover since its conquest by the Aztecs in 1325 and 71 per cent of the land is in an advanced stage of degradation. Forest loss contributes to accelerated rates of runoff and decreased ground-water recharge, and nearly 2000 km^2 of the State of Mexico are classified as seriously or very seriously eroded with little or no vegetation to restrict surface-water flow. It is likely that another 1500 km^2 of eroded land are located in the adjacent states of Hidalgo and Tlaxcala.

If soil conservation measures were employed on this land, through grassed trenches built on hillside contours or strip reforestation, it would be possible to achieve a net recharge of 30 mm per year, a result equivalent to 3.3. cumecs. Secondary project benefits, such as improvement of wildlife habitats and recreation areas, timber production and improved forage, increase the value of such a programme.

The net result of the pending options offered as illustrations could be equivalent by conservation estimates to a saving annually of 52 cumecs, nearly equal to the present supply. This potential is just sufficient to meet the 95 cumecs demand of the low-growth scenario, if the first phase of the Cutzamala project is included.

Conclusion and recommendations for Mexico City Water supply and waste-water disposal

The impacts of ground-water mining in the Valleys of Mexico and Lerma will probably accelerate if past water supply policies are allowed to continue. On the other hand, changes in these policies will sharpen the competition between a policy for the reduction of ground-water mining for environmental protection and a water supply policy for sustaining the growth of Mexico City. It should be understood that the present problems of water supply and wastewater disposal of Mexico City have resulted from the growth of the metropolis. The present growth trend need not be regarded as a fait accompli in approaching sector specific problems. A long-term integral solution needs to take into consideration all aspects of urban development (economic, social, environmental) and balance them sustainably with the resources available. Alternative solutions to sector problems such as water should be considered in the overall context of urban and regional development and not be confined to isolated water-balance exercises. Some alternatives to water transfer projects to be considered for detailed evaluation are:

(i) The reduction of water demand by about 23 per cent, i.e. down to 270 lpcd, as soon as is feasible but no later than the year 2000;

(ii) The implementation of a large-scale programme for using treated wastewaters as a substitute for selected potable water-uses and for ground-water recharge;

(iii) The implementation of other water supply alternatives such as ground-water recharge through soil and water conservation measures on the hills and by small dams, and water harvesting from roof and garden catchments;

(iv) The assignment of a high priority to the reduction of ground-water mining in the Valleys of Mexico and Lerma.

A large-scale programme for the reuse of treated wastewaters within Mexico City and the Valley of Mexico would require that:

(i) In the short and mid-term, the expansion of the raw wastewater-based irrigation in the Valleys of Mexico and Tula be considered as a residual activity after the reuse of treated waters;

(ii) In the long run, the phasing-out of some irrigated agriculture to save wastewaters for treatment and reuse in Mexico City and the Valley of Mexico be evaluated as an alternative to building water transfer projects after the Cutzamala project. This recommendation is based on the following premises;

(a) The quantity of wastewater to be treated is large requiring large capacity treatment plants at decreasing unit costs due to the economies of scale inherent in such plants;

(b) Water transfer projects involve increasing unit costs due to their increasing distance and pumping heads.

(iii) Because of the possible phasing-out of some irrigated agriculture at enormous economic and social costs, any further expansion of raw wastewater-based irrigation in the Valleys of Mexico and Tula should be delayed until a serious study on the probable timing of such phase-outs is concluded.

The following measures should be considered as integral elements of any wastewater-based irrigation project, including existing ones or projects under construction.

(i) Medical and veterinary services for the project area should be at a level higher than those of fresh-water-based irrigation projects;

(ii) The whole population of the project area should be served with potable water;

(iii) The possibility of subsidizing the operation and maintenance costs of measures (i) and (ii) by a surcharge on either the water rates or sewerage charges of Mexico City should be considered.

(iv) The measures necessary for the study and assessment of the likely all-round impacts of the ongoing Zumpango irrigation project should be implemented without delay.

In conclusion, it is imperative that the impacts of the induced growth of Mexico City on the adjacent regions and on the rest of the country should be further systematically investigated as a major national economic issue.

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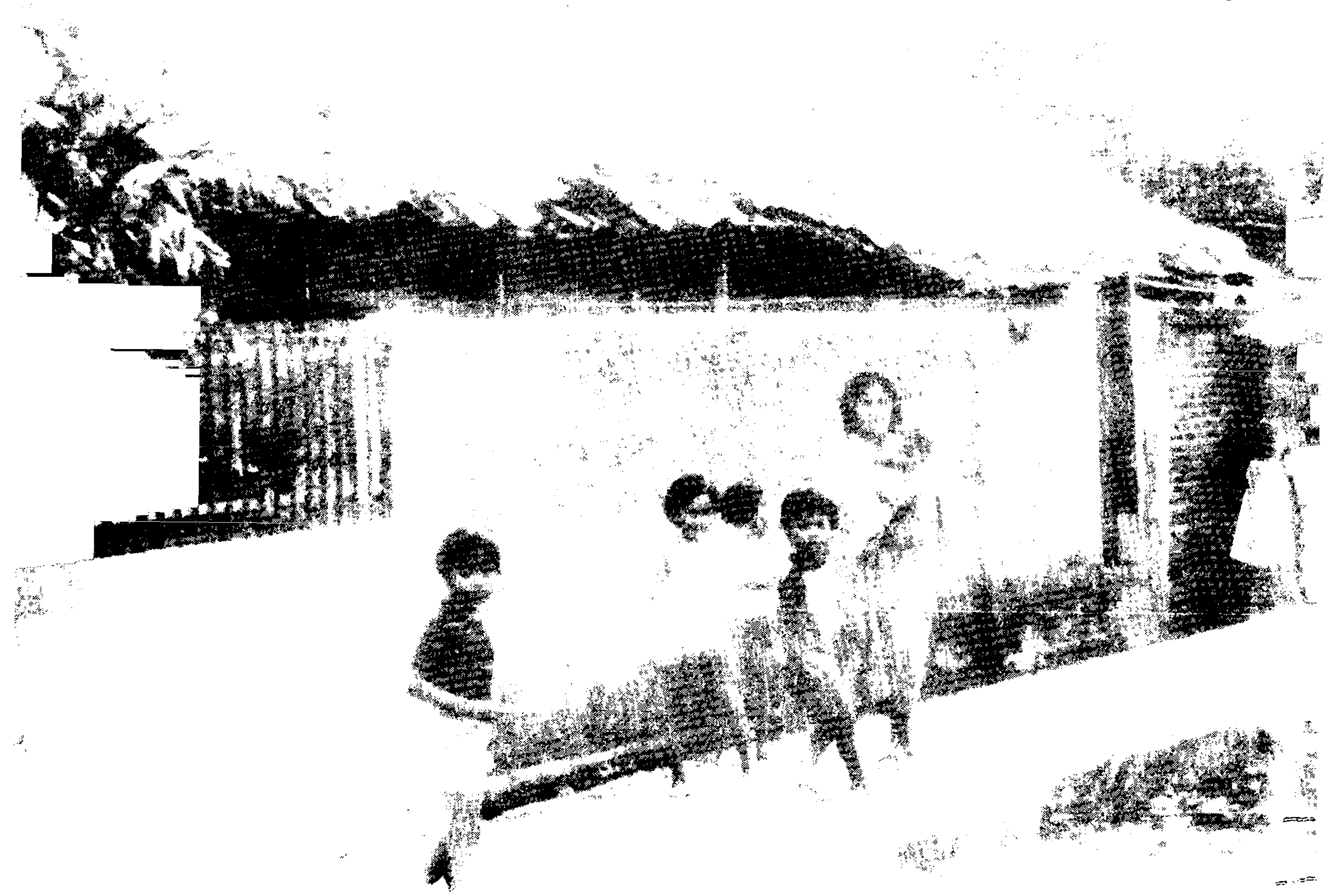

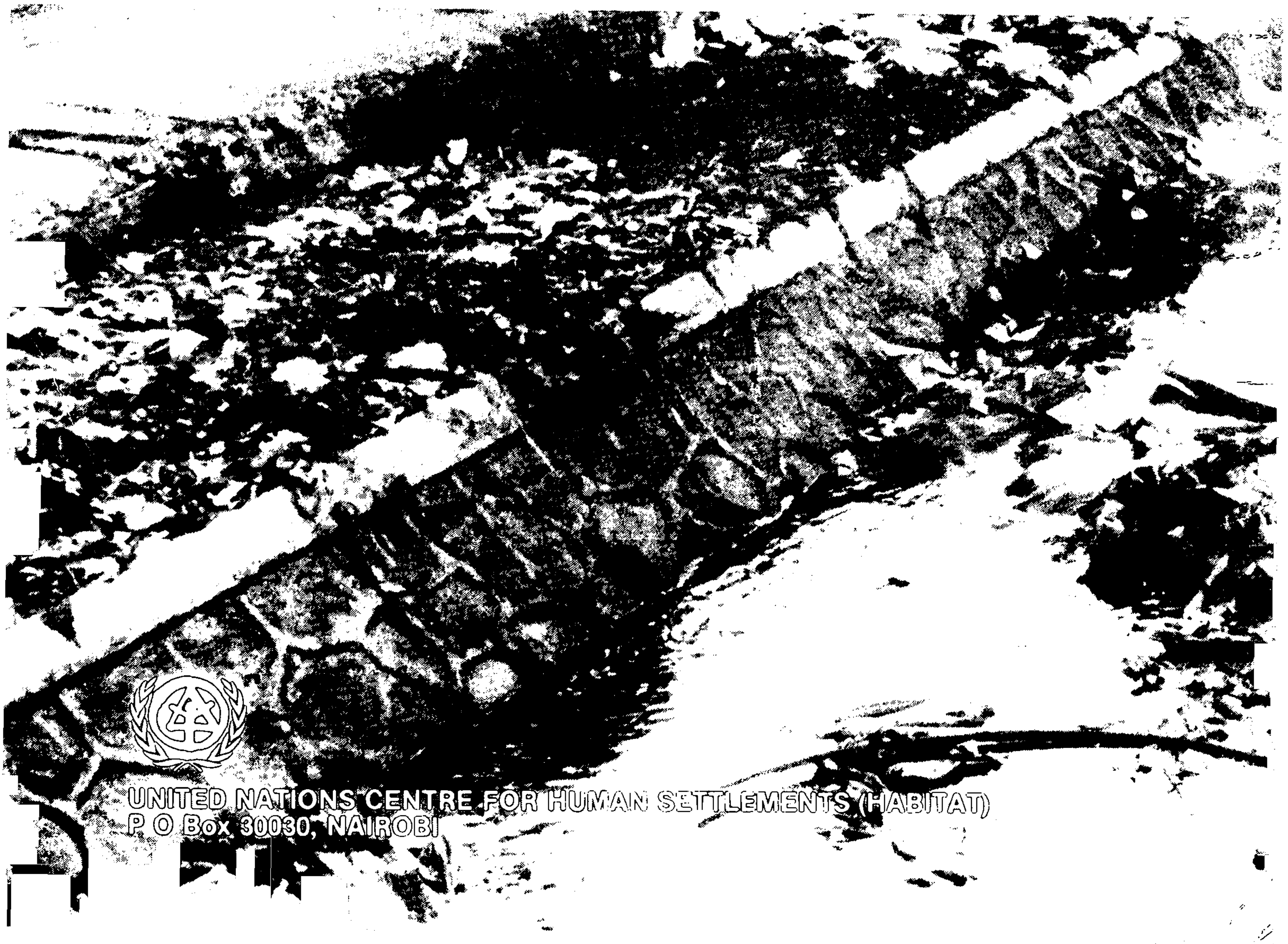

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