Groundwater resource management and environmental protection

A case study of the Philippines

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Population and economic developmental pressures will continue to put increasing pressure on the environment, especially on scarce water resources. Meanwhile, large numbers of poor families in the developing countries still lack access to safe water. An integrated water resource planning and policy analysis framework is presented that permits the main issues and alternative options to be systematically considered and prioritized, especially problems arising from groundwater pollution. Basic principles of water resource economics are used to illustrate how the neglect of long-term environmental considerations jeopardizes the availability and quality of groundwater resources in the Greater Manila area. This paper contains a brief overview of drinking water and sanitation issues in developing countries, presents a policy-oriented analysis of a groundwater problem of great relevance worldwide, and demonstrates how the study conclusions might be implemented practically in a constrained developing country context.

The efficient and optimal use of our natural resources, including air, land and water, has emerged as an area of universal concern during recent decades. Major issues range from global and transnational problems like ozone depletion and acid rain, through national and subnational, down to local or project specific effects. This paper seeks to examine the subset of issues that arises in the area of environment and water resource management within a single country: the Philippines. This narrowing of the focus permits us to deepen the analysis, and to address such problems with policy tools available to national level decision-makers.

Recognizing the worldwide importance of rational water resource use, in 1980 the UN General Assembly proclaimed 1981–90 as the International Drinking Water Supply and Sanitation Decade. Governments were urged to provide all their citizens with clean water and adequate sanitation by 1990 – a formidable goal [6]. At the end of the Decade, it is clear that the original goals were reached by only a few countries due to constraints that include funding limitations, poor cost recovery, lack of trained staff, weak operation and maintenance and undue government intervention [11,23].

Future financial shortages in the water sector will be accompanied by physical resource scarcities and rising costs of exploiting new water sources. Increasing demand and discharge of waste threaten the quality of the world's limited water resources. Thus, one important challenge of the 1990s will be the large-

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scale implementation of sustainable water and sanitation programmes to poor communities in cities and rural areas worldwide. Agricultural needs are also competing more strongly with potable water.

Both financial and physical resource scarcities require future sector strategy to be based on sound economic management principles. About US$15 billion per year is the estimated investment required in developing countries to attain their water sector goals in the 1990s. The bulk of such funds will have to be mobilized within these often capital scarce countries.

Conceptual framework for water management

Integrated water resources planning (IWRP) approach

Because of the many interactions and non-market forces that shape and affect the water sector, decision-makers in an increasing number of countries have realized that water sector investment planning, pricing and management should be carried out on an integrated basis, eg within an integrated water resource planning (IWRP) framework which helps analyse the whole range of water policy options over a long period of time. While some elements of policy analysis and planning may be more centralized, policy implementation should rely as much as possible on the use of decentralized market forces, especially pricing (see case study which follows). Policy interventions will be required, for example, to internalize external environmental costs such as groundwater pollution, thereby bringing competitive market forces into play to limit the damage. The need for IWRP type policy coordination applies both to the industrial world and the developing countries.

Integrated water resource planning (IWRP), policy analysis, and supply–demand management are carried out within a hierarchical framework [10]. At the highest and most aggregate level, it must be clearly recognized that the water sector is a part of the whole economy. Therefore, water resource planning requires analysis of the links between the water sector and the rest of the economy. The second level of IWRP treats the water sector as a separate entity composed of subsectors such as potable water, sewerage and liquid waste disposal, irrigation, hydropower, navigation, flood control and so on. This permits detailed analysis of the sector with special emphasis on interaction among the different water subsectors, and the resolution of any resulting policy conflicts due to competition between different uses of the same water source. The third and most disaggregate level pertains to planning within each of the water subsectors. It is at this lowest hierarchical level that most of the detailed formulation, planning and implementation of water resource projects and schemes are carried out. In practice, however, the three levels of IWRP merge and overlap considerably; thus the interactions of water problems and linkages at all levels need to be examined carefully.

As outlined in the introduction, water–environmental linkages are receiving increasing attention, and these issues will cut across all three levels of the IWRP analysis. Explicit consideration of environmental impacts in the IWRP framework will help mitigate undesirable externality costs through both water supply and demand management policies.

The integrated water resource planning process should result in the development of a flexible and constantly updated water strategy which can meet diverse national goals. Such a strategy may be implemented through a set of water supply and demand management policies and programmes.

Issues in groundwater use

Groundwater is widely and increasingly exploited for potable water supply, especially in smaller towns and rural areas of the developing countries where it is normally the cheapest and safest option. However, environment related issues are emerging [5]. Three major problems associated with groundwater use are land subsidence, pollution and salinization. First, for urban water supply and industry, overpumping or mining of the aquifer frequently leads to problems of land subsidence, often resulting in the collapse of buildings and other surface structures [3]. The second issue, groundwater pollution, is critical in the industrialized world. It has received less consideration in developing countries mainly because very slow groundwater movement, and resultant pollutant migration from the land surface into the aquifer and the slow routing through the aquifer itself, delays the full impact of pollution often for decades [5,8]. The third major problem of groundwater resources is salinization [1,2,7,17,18,19].

The case study below assesses the effects of groundwater depletion and deterioration of aquifer quality due to seawater intrusion. The dynamics of saline water intrusion are shown in Figure 1 where there are two distinct liquids differing in density and relative immiscibility. There is a distinct brackish interface that demarcates the pollution, beyond which there is no migration of salt. Without human interferences the intrusion front can move either way, within rather narrow spatial limits depending on the amount of precipitation over a particular period. When the natural equilibrium is disturbed by human

vol. 15, no. 4

activities such as overpumping, the saline water body will move inland, replacing the depleted fresh water – with the progress of the interface determined mainly by the pumping rate. By contrast other types of pollution (eg the movement of agro- or industrial chemicals) are governed by the physical flow characteristics of the 'fresh' groundwater itself and the rate of chemical release, rather than depending mainly on the pumping regime. An analysis of such types of pollution will therefore differ from the one presented in this study.

Optimal use of an aquifer requires analysis of the effects of current pumping on both the level and quality of groundwater in future periods. This requires that costs to future users be accounted for in current pumping decisions. The marginal user cost or externality cost is the future cost to other users arising from current extraction by any given well-user. In one study, Cummings has broken down the user cost into several components: the marginal value of water in storage, the marginal cost of water use in terms of capital consumption and the marginal cost of salt intrusion [4]. The marginal costs of land subsidence and other effects also may be included.

However, groundwater has the characteristics of a commonly owned property. When water is pumped by many individuals who act independently rather than collectively, there are strong incentives to ignore the marginal user cost. This normally results in economic inefficiencies since too much water is pumped too soon. Therefore the establishment of a regulatory framework that imposes rules on all users to offset externality costs is in the long-term interest of all, provided the costs of regulation are not excessive [13].

Case study: water resource management in the Philippines

The Metropolitan Waterworks and Sewerage System – background and groundwater user [21,22]

The provision of water supply and sanitation services in the Philippines has improved considerably over the past two decades. By the end of 1987, about 63% of the population had access to safe water, including 31% which was served by piped systems. Although absolute service levels are improving, the quality of service in the areas covered is often poor, with low water pressures throughout and rationed service in some areas. The National Water Resources Council (NWRC) is responsible for formulating policies for the water supply sector. The Metropolitan Waterworks and Sewerage System (MWS) was established in 1972 to provide water supply and sewerage systems in or around Metropolitan Manila. The MWSS Service Area (MSA) of about 150 000 ha includes Manila and another four neighbouring cities and 32 municipalities.

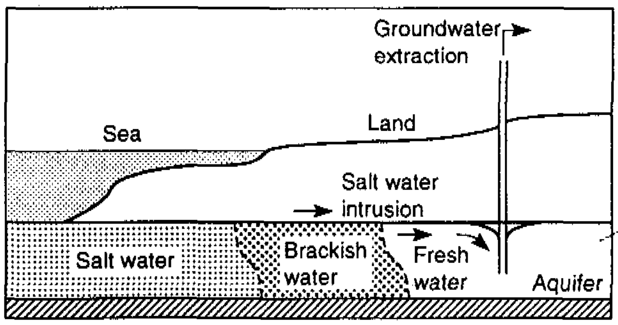

Figure 1. Schematic diagram of salt water intrusion in an aquifer.

Sector development in Metropolitan Manila depends on funds self-generated by MWSS, government equity contributions, and foreign or local loans. The Government's general policy is to develop systems based on a community's financial ability and willingness to pay for them. Accordingly individual house connections are usually provided in the larger urban areas, and some standpipe systems are provided on the basis of the willingness of users to pay for them. Wells with hand pumps are provided in the rural areas.

Groundwater use in the Manila area has grown so rapidly that for the last 30 years natural recharge was far exceeded, resulting in 'mining' of the aquifer. Because of its geographical location, another devastating effect of this depletion is the encroachment of saline sea water into the coastal aquifer. As mentioned earlier, depletion of groundwater and the concurrent deterioration of water quality constitute a significant economic loss to the society as a whole. Each groundwater user will continue to impose external diseconomies or costs on all other existing and future users [9].

Curtailing use of groundwater for existing industrial users would have a negative impact on industrial production and employment. The largest users of groundwater in depleted zones have been identified by MWSS, and adequate transmission and distribution facilities are to be provided. If these problems were to persist, it would be necessary to enact legislation establishing more rigorous controls on water use, and allowing MWSS to charge for the use of groundwater, to reduce its excessive use and contribute to the financing of expanded water supply facilities in the MSA [22].

Modelling and economic analysis

The purpose of this section is to calculate long-term economic costs of groundwater use, over and above the cost of extraction. Those costs are additional external costs imposed by an existing user on all future groundwater users. Costs and prices are in constant mid-1984 terms, unless otherwise stated.

Groundwater depletion model. The physical model of the aquifer has been described elsewhere [16] and all withdrawals in the GMA are assumed to be made from this common aquifer. For convenience, withdrawals from the aquifer are lumped together with no further spatial disaggregation. A more sophisticated approach might involve analysis of a progressively advancing saline front and gradual salination of wells in different zones, but the physical data currently available does not permit such discrimination.

On the basis of the rather limited data and quite realistic assumptions, two scenarios shown in Figure 2 are compared, to estimate externality costs. The first or depletion case (Curve ABEFI) is the base scenario that would prevail if present policies continued [15,16]. The conservation scenario (Curve AJFH) would result from a centrally managed groundwater extraction policy. Clearly, other scenarios are possible, but data unavailability does not permit further fine tuning. Nevertheless, the contrast between the above two cases is sharp enough to draw some valuable policy conclusions.

In the depletion case, we start with a withdrawal level of 730×10^6 litres per day in year 0 (1984), and then the pumping rate is assumed to remain constant until year 6 when the yield declines linearly down to 620×10^6 litres in year 16. Finally a very rapid decrease sets in with withdrawals dropping to zero by year 26, due to a progressive mining of the potable water. As shown in the Appendix and illustrated in Figure 3, the average costs of withdrawals will rise linearly from US\$0.13/m^3 of water in year 0, to US\$0.22/m^3 in year 16, and finally to US\$0.27/m^3 in year 26 [14].

In contrast to the depletion case, we also explore a quasi-ideal conservation scenario in which groundwater use is controlled to reach safe sustainable levels eventually. The latter reflects a physical equilibrium stage where the sum of natural and artificial recharges equals total withdrawals. Although the conservation case is hypothetical it provides a useful practical benchmark for what might have been achieved with forethought had timely action been initiated early enough. In this alternative, extraction rates are assumed to decline linearly from an initial 730×10^6 litres in year 0 to 200×10^6 litres in year 16, which is the estimated safe sustainable yield for potable water, based on

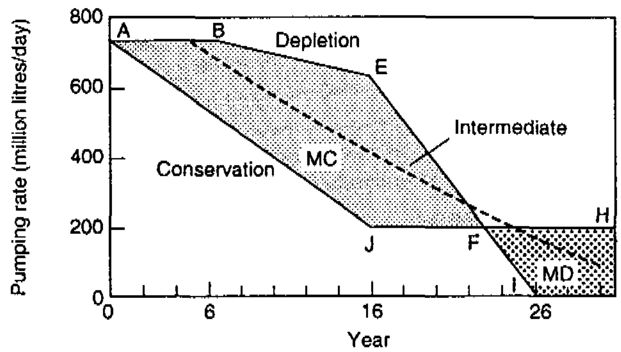

Figure 2. Effect of alternative groundwater use policies.

the physical model of the aquifer. Once the equilibrium stage is reached, pumping can continue at this rate indefinitely into the future without mining the aquifer. The costs of withdrawals are estimated to remain constant at US\$0.13/m^3 throughout (see the Appendix).

Quantification of economic externality costs. To compare the two cases, we note that the total volume of water to be supplied (from both the aquifer and the MWSS system) is the same in each scenario. Thus, consumption benefits derived by water users in both cases are identical, and only the costs are different. As shown in Figure 2, the total water supplied is indicated by the area under the curve ABEFH. To meet the total demand, the MWSS system must supplement the groundwater supply with the amount MD (starting in year 23), in the depletion scenario. Similarly, to satisfy the same total demand, MWSS must supply the amount MC (starting in year 0), in the conservation case. The MWSS system draws water from sources other than the aquifer under consideration.

In Table 1, costs of groundwater withdrawals in the depletion cases are compared with the costs of pump-

Table 1. Estimation of economic externality costs due to groundwater depletion.

(1) Depletion case	
Present discounted value of costs of supplying water (from the Appendix)	406.87 (million US\$)
(2) Conservation case	
Present discounted value of costs of supplying water (from the Appendix)	377.56 (million US\$)
(3) EC	
Difference in costs: (1)–(2)	29.31 (million US\$)
(4) QD	
Present discounted value of total groundwater withdrawal in the depletion case	2444 (million m^3)
(5) UEC	
Long-run economic externality costs due to depletion: (3)/(4)	0.012 (US\$/m^3)

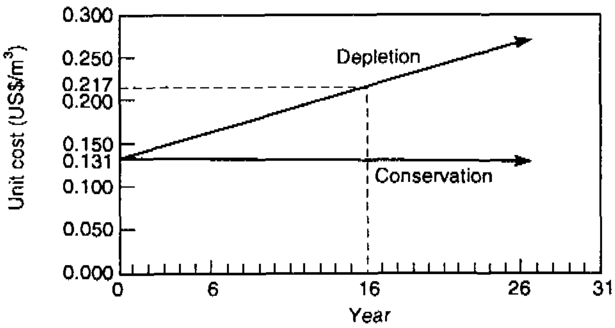

Figure 3. Long-run supply costs for the depletion and conservation scenarios.

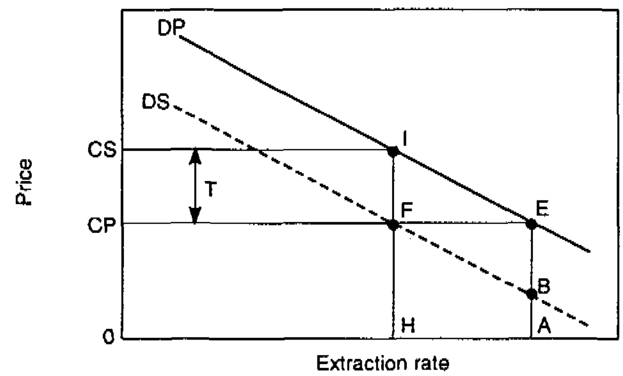

Figure 4. Demand for groundwater.

ing in the conservation case, including additional net costs to supplement the groundwater shortfall from MWSS pipeborn supplies – based on the average incremental cost or AIC of MWSS supply (see the Appendix). The present discounted value of the difference in costs between the two cases is assumed to be a long-run measure of the economic externality costs (EC) incurred by following the depletion scenario, instead of the conservation case.

Such additional externality costs are incurred because of the consumption pattern followed in the depletion case. The present discounted value of total groundwater withdrawals in this case is also shown in Table 1. The ratio UEC = EC/QD provides an average measure of the long-term externality cost per m^3 of groundwater withdrawn, and also serves as a benchmark for a user charge that might be imposed on potential depleters, to compensate for the resulting loss of future benefits (if the conservation scenario had been followed). On the basis of the data available, the long-term externality cost estimate is given by UEC = US\$0.012/m^3 of groundwater pumped. We note that this average value of UEC may be higher if estimated some years later. If UEC increased over time – as the aquifer became more depleted – this should be reflected in the policy measures discussed below.

Policy implications. Little information is available about the consumption patterns and economic behaviour (especially water demand curves) of groundwater users. Nevertheless, it is possible to draw some policy conclusions, starting with a simplified static analysis. The more dynamic aspects introduced later will not change the essential logic of the arguments presented below.

A conventional downward sloping (private) demand curve for groundwater is shown in Figure 4. DP represents the aggregate willingness-to-pay of groundwater users – ie consumption volumes per year at various extraction costs – and the area under this demand curve measures the benefits of water use based on consumer perceptions, excluding environmental and externality costs. Ideally, if there was full information about the future consequences of aquifer destruction and private well-owners had a good awareness of societal implications, the use of groundwater should be governed by a social demand curve, DS. This curve lies below DP because society has to incur an additional economic cost (like UEC, estimated earlier) for every m^3 of groundwater extracted under the depletion scenario. The divergence between DP and DS could arise because a typical groundwater user may be ignorant or unconcerned about externalities. Alternatively, those who deplete most heavily in the early years and enjoy low extraction costs may not be the same persons who have to face the higher costs of pumping from a depleted aquifer in later years.

As mentioned earlier, the first best option for society would have been to somehow restrict groundwater pumping and enforce the conservation scenario – this would result in overall cost savings, UEC = US\$0.012/m^3 over the period of analysis. However, such an outcome is unlikely because policy options should have been introduced many years ago to achieve this result. Under present policies, the depletion scenario will occur, and in a typical year users will extract a volume OA at a cost CP (Figure 4). There is an economic efficiency cost BE associated with the marginal unit of water used, because the extraction cost exceeds the consumption benefit to society. Ideally, if DS governed water use, the benefit of marginal consumption FH would exactly equal CP. Suppose, as a second best option, that a user tax T = UEC = IF = BE was imposed, raising the private cost to CS = CP+T. Then groundwater extraction would decline by AH, and marginal benefits and costs would be equalized, resulting in economically efficient water use.

If we introduce the time dimension, our analysis becomes somewhat more complicated. As shown in Figure 2, the reduced pumping AH will give rise to an intermediate groundwater extraction scenario, resulting in a different value of UEC. Nevertheless, the initial value of UEC is small relative to CP, and if the elasticity of demand is small (steeper slope for DP), this adjustment will be small. Finally, through an iterative process, it will be possible to arrive at a self-consistent set of values for CS, CP, UEC and pumping rate. The efficient (second best) tax, TE, is likely to be somewhat lower than the original UEC. We note that more sophisticated dynamic analysis is possible, since the demand curve DP, the cost CP, and tax T can all vary over time. Further, as the saline front gradually advances inland, greater spatial disaggregation also could be attempted – if the data were available to determine extraction rates, costs and user charges by zone.

From the viewpoint of public finance, an average user charge of US\$0.012/m^3 will yield present valued revenues of about US\$29.31 million in the depletion scenario. If UEC increased over time, then revenues would be greater. These resources could be used to develop alternative MWSS water resources to replace the failing aquifer.

Policy options

General rationale. Legally, all waters in the Philippines belong to the state, and the use of this water is a privilege granted to citizens by the government. From the socio-economic viewpoint, the water resources of the Philippines are a public good, to be allocated and utilized for the optimal benefits of the entire nation. The government has a special responsibility to regulate water use, particularly where shortages exist or could occur in the future. Groundwater use in the Manila area has grown rapidly over the last 30 years. The extraction rate exceeded the natural recharge many times, resulting in sharp declines of the water table and intrusion of sea water, especially in the coastal areas. Further overpumping will extend the irreversible degradation of the groundwater quality inland, and therefore reduce the benefits available to future groundwater users. The effects of lowering the groundwater table and consequently salinizing the aquifer, both impose significant economic losses on society as a whole. Such costs arise because of the increasing pumping costs, and even more importantly because of the decrease of the water quality due to salination and the progressive abandonment of wells. In other words, each current groundwater user imposes external diseconomies or costs on all future users as long as the actual withdrawal scenario persists.

Therefore, the government should adopt rational policies for managing groundwater in the GMA. Soundly designed groundwater user charges and associated water management measures would help to restrict groundwater use in the GMA. Such a policy package could also raise revenues so that other sources of water supply could be developed in the future (especially through extension of the MWSS pipeborn system), to supplement or replace (in the form of artificial recharges) declining groundwater availability.

Precedents for groundwater management and existing measures. Groundwater laws exist in developed countries such as the USA and in several developing countries such as Mexico and Mali. Within the Philippines, charges are levied for developing and exploiting various natural resources such as minerals, forest products and water for electricity generation.

In the specific area of groundwater, several water districts like Cebu and Batangas have recently imposed user charges. Existing groundwater management measures relevant to the GMA are described in the Philippine Water Code (issued by the National Water Resources Council) and the Republic Act No 6234 of 19 June 1971, creating the MWSS. However, the penalties are in general too low and not enforced well enough to address the issue of the rapid depletion and salinization of groundwater resources in the GMA.

Policy implementation issues

Thus, a new package of groundwater management measures is needed which is consistent with and supplements the existing laws mentioned above. The new measures should include the definition of critical groundwater areas in the GMA, licensing of well drillers, requirements for drilling permits, specifications for construction, maintenance and sterilization of wells, metering and reporting requirements, user charges, limits on pumping (where necessary), the return of cooling water to the aquifer and contamination controls. Coordinated use of all these policy tools would achieve the best results.

Drilling and licencing fees. All new well-owners ought to be charged a drilling fee to obtain the right to drill. In addition, there should be an annual licencing fee if the well is to be operated. The approved permit to pump water should specify the construction specifications, allowable volume and the user fee to be paid, based on piezometric head and salt content of the groundwater.

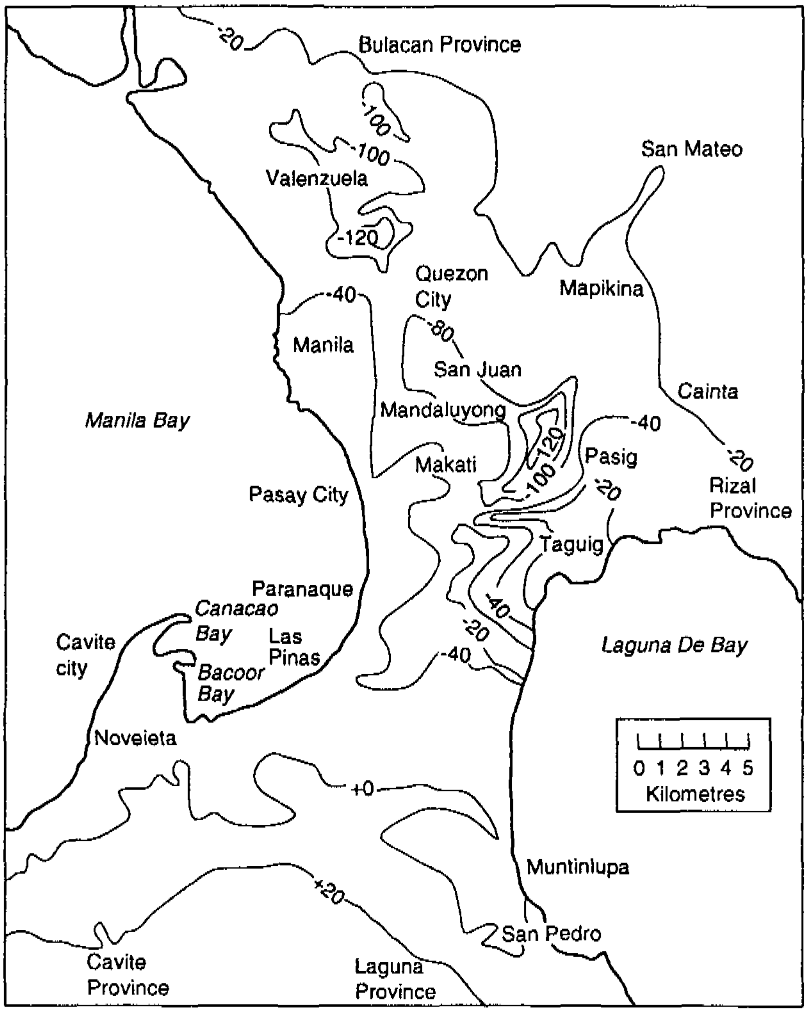

Figure 5. Map of piezometric surface (hydraulic head in metres below sea level) for the Manila Bay Aquifer System, Greater Manila area, 1982–83.

Controls and other regulations

The government should impose a system for safe well abandonment. This is a difficult objective, as it requires knowledge of all active wells. However, if all wells are abandoned properly by filling the bore completely with impermeable material (cement or clay), the protection of the fresh water part of the aquifer will be enhanced by lessening the likelihood of new points of downward flow of saline water. Had this procedure been followed since the early days of groundwater development in the GMA, the saline water would have progressed far less than is the case today.

In the critical areas characterized by a low piezometric head and/or a high salt concentration in the groundwater, a surcharge (in addition to the user charge) might be imposed on withdrawals above 'normal requirements', if alternative MWSS supply is available. Steps could also be taken to prevent man-made pollution of the aquifer. Rivers and stream channels, which feed the aquifer by percolation from their beddings, are the recipients of waste products from overland runoff, from effluent discharge of industries, city dumps and sanitary landfills. While provisions for pollution control already exist at the national level, regulations more specific to the GMA should be specified and strictly enforced.

Conservation, redistribution and recharge. MWSS has operated a water supply system based on a policy of conjunctive use of ground and surface waters. Groundwater is used in the outlying areas beyond the Central Distribution System (CDS), and it is used also within the existing CDS to supplement surface water. In 1980–81 it was estimated that groundwater contributed about 40% of the supplies for the GMA.

A study estimated that groundwater extraction in 1982 of 740×10^6 litres would be reduced to about 615×10^6 litres or less by 2000 [15]. The pumping pattern would have to be redistributed away from the overdeveloped 'cones of depression' in Valenzuela and Makati (see Figure 5). The probable progressive decline in groundwater pumpage in the GMA would continue into the next century, possibly stabilizing at a level of 200×10^6 litres.

For all practical purposes, the existing depletion of groundwater storage extends over the entire GMA. Figure 5 is a map of the piezometric surface of the GMA for 1982 showing that the surface is below sea level in all but the extreme northeastern portion, which is less than 10% of the area. Furthermore, west of the North Expressway, the piezometric surface is 40–100 m below sea level. Between the provinces of Bulacan and Rizal on the one side and Manila Bay on the other side, the piezometric surface lies 60–120 m below sea level. From Makati to Pasig, the level varies from 100–140 m below sea level. In most of the GMA the depletion of groundwater is widespread and severe, and the fresh water levels are so low that the salt water intrusion will continue to damage the aquifer for years to come. Additionally, the withdrawal of groundwater from anywhere west of Laguna de Bay and southward, adjoining Cavite Province has a negative effect on the piezometric surface in the GMA and eventually must be controlled.

Serious damage to the aquifer has been caused by salt-water intrusion laterally and downward along the coastal GMA from Valenzuela to Cavite City; in the Marikina Valley, upwelling from depths of 200 m or more; and, more recently, laterally along the boundary of Makati and Mandaluyong.

In summary, the withdrawal of groundwater must be reduced and redistributed through the GMA as soon as practicable. The highest priority areas to receive alternate water supplies and to reduce groundwater pumpage are Cavite City, the so-called Valenzuela cone, the Makati–Mandaluyong cone, Pasay City and Paranaque north of Sucat Road, and coastal Las Pinas. Cavite City will receive water from the south (Cavite Province), causing a shift in groundwater pumpage to a more favourable area for withdrawal around Noveleta. The other places named should be served by the newly developed surface water source while groundwater pumpage reductions must be made concurrently. A surcharge on the normal groundwater user fee on pumpage above some 'normal level of depletion' could motivate large users of water to reduce or eliminate groundwater withdrawals and purchase water from MWSS.

Laguna de Bay is a large area to the southeast, serving as a source of fresh-water recharge to the aquifer because of favourable differences in piezometric levels. Natural recharge also occurs from the highlands in the south, east and northeast, as well as some reaches of streams that cross the GMA during the rainy season. However, because of the relatively low permeability of the aquifer system in most of the GMA, efforts to encourage additional natural recharge may not be successful. One might experiment with artificial recharge wells in Makati, utilizing cooling water from high-rise business establishments and apartment buildings to replenish the aquifer. The used cooling water should be chemically compatible with the aquifer, and unused wells could be used as injection sites [20]. If this approach was successful, later experiments could be tried using water from the Central Distribution System (CDS), when available. At that time MWSS wells could be utilized as recharge wells. A similar experiment also could be tried along the coastal GMA to determine if a fresh-water mound or ridge could be built to control the inland migration of salt water. Finally, the government could monitor the water level and quality in wells within the GMA as groundwater pumpage is shifted away from the deep cones of depression.

Determining and enforcing user charges. Any realistic pricing framework must incorporate both economic efficiency and equity considerations. On socio-political grounds, one may distinguish between household users who would be withdrawing relatively small amounts of water for their basic needs, and industrial and commercial well owners who would be pumping large volumes of water as an input into a profit-making productive activity. This discrimination would apply only to the user charge – all well owners should be subject to drilling and licensing fees.

At the same time, users in the vicinity of the brackish interface (see Figure 1) have to be more cautious as to their extraction rate of the groundwater. Exceeding a critical maximum pumping rate causes a 'sucking upward' or upconing of salt water, hence terminating the use of the well. The users close to the interface therefore will face an additional externality cost due to income foregone associated with reduced pumping to avoid upconing. Due to excessive pumping by users located at some distance from the interface, the salt water front will continue to progress inland forcing the closer users gradually to decrease their pumping rates and eventually to abandon their wells.

If information were available, spatial price discrimination or zoning (based on distance away from the brackish interface) might therefore be warranted. In the same context, one could argue for dynamic pricing over time. However, no discrimination in the sense of 'zoning' is considered in the present study due to data limitations. Determining user charges can be done on the basis of category of user. Some guidelines for doing so follow.

Household users. Based on the socio-political argument that all citizens are entitled to their basic water needs, two basic alternative measures of relief from user charges for household well owners are proposed:

(i) Exemption from the user charge up to 50 m^3/month per household (based on basic needs allocation of 6 m^3 per capita/month, and assuming eight persons per average household); with the normal user charge being levied on all pumpage exceeding 50 m^3/month.
(ii) Exemption from the user charge for all consumption, provided the well casing diameter is below some critical size (say 13 mm).

While both measures encourage conservation of groundwater, alternative (ii) would be easier to implement. It avoids the problems of metering, billing and collecting payments from many small groundwater users.

Industrial and commercial users. This category of user, which would be using the water for profitable activities, should be charged the full rate (based initially on US$0.012/$m^3$, estimated earlier) on all withdrawals.

Other user charges. Earlier certain areas were identified as critical zones, based on piezometric head and/or salt content of the groundwater. Therefore, an additional surcharge on top of the normal user charge should be imposed, especially where an alternative MWSS supply is available. The level of surcharge should be high enough to encourage the well owners to shift to MWSS supply. Finally, additional charges may be imposed, based on the cost of disposal of groundwater that is pumped, including the actual costs of sewerage (where appropriate) and any other health or environmental costs associated with discharge. Enforcing user fees for industrial and commercial users is feasible because there are three basic methods of determining the volume of water extracted from wells: a water meter; the electricity consumption; and the pump capacity.

Conclusions

Population and economic development pressures will continue to put pressure on the environment, especially on scarce water resources. Many poor families in the developing countries still lack access to safe water, and despite modest gains during the International Water Decade, problems of financial and manpower resource shortages, and institutional weaknesses remain. Nevertheless, our understanding of water resource problems have improved significantly during recent decades. The integrated water resource planning and policy analysis framework permits the main issues and alternative options to be systematically considered and prioritized, especially problems arising from groundwater pollution.

A good example showing how the neglect of long-term externality costs jeopardizes the availability and quality of groundwater resources, is the case of the GMA aquifer. Among the measures that could be taken to slow down the overall groundwater extraction rate and, hence, safeguard water for future users and purposes is a system of user charges. Such a user charge should explicitly account for environmental and externality costs. In order to equalize marginal groundwater extraction costs and marginal consumption benefits to society, a user tax, equal to the long-run externality cost could be imposed per m^3 of groundwater withdrawn. A more detailed spatial and temporal disaggregation, considering the geographical advancing of the saline front and the depletion of the aquifer, should allow for a surcharge in addition to the defined user charge in critical zones.

The imposition of taxes based on user charges should be only part of a combination of various groundwater demand management measures to cut down groundwater use. A well designed package of groundwater resource measures would in addition raise revenues to develop other sources of water supply in the GMA to supplement or replace declining groundwater availability.

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Appendix

Tables A1 to A3, provide detailed information on the production costs for (i) groundwater (depletion and conservation cases); and (ii) the MWSS public water supply. The general approach used to estimate unit economic costs of water produced is to calculate the average incremental cost (AIC) of supply [13].

$$\text{AIC} = \frac{\text{present value of incremental costs of producing water}}{\text{present value of incremental water produced}}$$

Table A2. Average incremental cost (AIC) of MWSS water supply.

The present values of production costs and volumes (from Table A3) discounted to 1984 at a rate of 10%/year, in constant mid-1984 prices, are as follows:

1 Capital costs (US$ $\times 10^6$)	632
2 Operating costs (US$ $\times 10^6$)	77
3 Value of power and energy sales (US$ $\times 10^6$)	59
4 Net present value of costs (1+2−3) (US$ $\times 10^6$)	650
5 Water produced ($m^3 \times 10^6$)	2 801
6 AIC of water produced (US$/$m^3$)	0.23

Table A3. MWSS costs and production.

Year	Costs (US$ $\times 10^6$) Investment	Operating	Production ($m^3 \times 10^6$)
1982	4.04	—	—
1983	11.88	—	—
1984	11.59	—	—
1985	41.06	—	—
1986	80.88	—	—
1987	161.94	—	—
1988	185.76	—	—
1989	122.86	—	—
1990	43.26	4.86	9
1991	52.08	6.14	80
1992	56.97	7.53	160
1993	53.84	9.04	247
1994	52.54	10.53	336
1995	56.39	12.16	439
1996	43.30	13.89	541
1997	35.68	15.66	648
1998	34.70	16.61	697
1999	—	16.61	697
2000–2030	—	16.61	697

Table A1. Groundwater withdrawals and supply costs.

Year	Depletion case: Groundwater withdrawals (litres × 10^6/day)	MWSS supply (litres × 10^6/day)	Unit cost of groundwater production (US$/m^3)[a]	Production cost (US$ × 10^3/day): Groundwater	MWSS[c]	Total	Conservation case: Groundwater withdrawals (litres × 10^6/day)	MWSS supply (litres × 10^6/day)	Production cost (US$ × 10^3/day): Groundwater[b]	MWSS[c]	Total
1984	730	0	0.131	95.9	0	95.9	730	0	95.9	0.0	95.9
1985	730	0	0.137	100.1	0	100.1	697	33	91.6	7.6	99.2
1986	730	0	0.142	103.8	0	103.8	664	66	87.3	15.4	102.6
1987	730	0	0.148	107.9	0	107.9	631	99	82.9	23.0	105.9
1988	730	0	0.152	111.6	0	111.6	598	132	78.6	30.6	109.2
1989	730	0	0.159	115.8	0	115.8	565	165	74.3	38.3	112.6
1990	730	0	0.164	119.4	0	119.4	532	198	69.9	46.0	115.9
1991	719	0	0.169	121.7	0	121.7	499	220	65.6	51.1	116.6
1992	708	0	0.174	123.4	0	123.4	466	242	61.2	56.2	117.4
1993	697	0	0.180	125.4	0	125.4	433	264	56.9	61.3	118.2
1994	686	0	0.185	126.9	0	126.9	400	286	52.6	66.4	119.0
1995	675	0	0.191	128.7	0	128.7	367	308	48.2	71.5	119.7
1996	664	0	0.196	129.9	0	129.9	334	330	43.9	76.6	120.6
1997	653	0	0.201	131.5	0	131.5	301	352	39.6	81.7	121.3
1998	642	0	0.206	132.5	0	132.5	268	374	35.2	86.9	122.1
1999	631	0	0.212	133.9	0	133.9	235	396	30.9	91.9	122.8
2000	620	0	0.217	134.6	0	134.6	200	420	26.3	97.5	123.8
2001	558	0	0.223	124.4	0	124.4	200	358	26.3	83.1	109.4
2002	496	0	0.228	113.0	0	113.0	200	296	26.3	68.7	95.0
2003	434	0	0.234	101.4	0	101.4	200	234	26.3	54.4	80.6
2004	372	0	0.239	88.7	0	88.7	200	172	26.3	39.9	66.2
2005	310	0	0.244	75.7	0	75.7	200	110	26.3	25.6	51.9
2006	248	0	0.249	61.9	0	61.9	200	48	26.3	11.1	37.4
2007	186	14	0.255	46.0	3.3	49.3	200	0	26.3	0.0	26.3
2008	124	64	0.260	32.2	14.9	47.1	200	0	26.3	0.0	26.3
2009	62	138	0.266	16.5	32.1	48.6	200	0	26.3	0.0	26.3
2010 to infinity	0	200	0.271	0	46.4	46.4	200	0	26.3	0.0	26.3

[a]Unit cost of production rises steadily for groundwater withdrawal (depletion case) [14].
[b]Unit cost of production is constant at 0.132 US$/m^3 for groundwater withdrawal (conservation case) [14].
[c]Unit cost of production is 0.23 US$/m^3 for MWSS supply, from Table A2.
Note: Output is the same in both depletion and conservation cases.