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Alternative Strategies for Closing the Supply/Demand Gap

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III. TECHNOLOGICAL

Alternative Strategies for Closing the Supply/Demand Gap*

J. GORDON MILLIKEN**

I. INTRODUCTION

This paper presents a conceptual framework for policy analysis to assist decisionmakers in future water supply planning for semiarid metropolitan areas where water resources are limited. These policy analysis principles can be applied by urban decisionmakers in areas of the United States where projected water demands seem likely to outstrip assured supplies.

Until fairly recently it has been possible to develop new water supplies to keep pace with the requirements of continuous urban growth. In many areas in the United States today, however, the continued concentration of population in urban industrial clusters is outstripping municipal efforts to develop additional water supplies. Water supply agencies face diminishing returns of water and increasing development costs. The problem of providing urban water resources grows increasingly complex, especially because it is interrelated with the issues of economic growth and environmental quality. Just when traditional sources of water are becoming exhausted resistance is growing to damming scenic rivers, to transferring water supplies from agricultural to municipal use in an era of world food shortage, and to constructing ever more remote water collection and transmission facilities as cities grow and compete for water.

The purpose of this paper is: (1) to present and discuss briefly several alternative water strategies, including some that are nontraditional such as wastewater reuse, which can be used by urban policymakers working to resolve the technological, economic, environmental, and social issues of municipal water

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* This paper derives from a forthcoming Denver Research Institute report, *Policy Analysis for Metropolitan Water Supply Planning* by Milliken, Taylor, Cristiano, Schooler, Creighton & Martz, prepared for the U.S. Environmental Protection Agency.

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supply; (2) to present a framework for analysis of these alternative strategies; and (3) to indicate a method for arriving at a rational least-cost decision based on this analysis.

The methodology proposed here is intended to lead to a thorough systems analysis (involving economic, social, and environmental considerations) of known alternative means to increase water supplies or to reduce water demands and to help select a least-cost mix of actions that will achieve a supply/demand balance throughout the chosen planning period. Techniques of cost-effectiveness analysis are recommended to help determine the least-cost actions that will achieve the desired goal of matching water supply and demand.

It should be emphasized that this methodology must be considered within the framework of overall community goals, *i.e.*, the desires of the citizens, as expressed through the ballot or other forms of political action, concerning the future of their community, which will differ from one community to another. It should also be recognized that a least-cost supply of water implies a weighing not only of economic costs but also of social costs which will differ from one area to another. Thus, a best solution for one metropolitan area will not necessarily be best for another.

II. ALTERNATIVE STRATEGIES FOR CLOSING THE SUPPLY/DEMAND GAP

The next section of the paper briefly discusses 10 alternative strategies for closing the water supply/demand gap in a metropolitan area. Two are strategies for reducing or alleviating demand: (1) conservation measures (voluntary or involuntary) and (2) changes in water pricing. The remainder are alternative ways of adding to the supply of water, increasing its effective yield, or reallocating it among users. Some of the supply alternatives may be effective in certain geographic areas but infeasible or inappropriate in others. They are described briefly in the following paragraphs.

Alternative 1—Water Conservation Measures

Conservation of water encompasses many activities: from encouraging people to fix leaky faucets through low key public relations campaigns, to requiring the installation of water saving devices in new households, imposing mandatory lawn watering restrictions, and limiting the service area of a water supply agency. Each measure is relatively inexpensive in economic terms, but as a measure shifts from "conservation" to "restriction" to "prohibition," in terms of the user, the political and social costs increase, as does the potential for a decline in the perceived quality of life. The impact of these costs falls directly upon an administrator's constituents whereas traditional means of increasing supply have their primary negative impacts on persons outside the service area. Therefore, conservation measures, other than encouraging wise use of water, are considered politically undesirable by most urban administrators, and their exact potential for effecting a reduction in demand is largely unknown.

Alternative 2—Water Pricing to Reduce Demand

If a water supply agency is seeking to motivate more efficient use of existing and future supplies of water, nothing is as simple, comprehensive, and effective as the pricing mechanism. The demand for domestic water exhibits some price elasticity; therefore, a change in pricing structure can be an effective option for reducing the supply/demand gap. In many respects it is an especially attractive option in that the market forces will encourage residents to reduce demand for unnecessary water voluntarily. The effects of implementing a new water rate structure are almost immediate, the environmental impact is relatively minimal, and the benefits to be derived in terms of optimal use of existing water resources and reduced demand for future resources could be quite substantial.

There are other potential advantages as well. Pricing structures can be used to distribute more equally the costs of providing water to those persons receiving the greatest benefits and can promote a greater degree of efficiency in the allocation of productive resources by relating water prices to the costs of developing new water supplies.

In general, other than increased administration, pricing techniques have few monetary costs attached to them. There are, however, substantial social and political impacts, as well as some legal impediments, which should be considered prior to implementing any new pricing structure.

Alternative 3—Water System Management

Some water-short metropolitan areas must store water provided in periods of peak supply to satisfy the water demands during the rest of the year. They may also face periods of shortage and the need for short term water allocation procedures during these periods. For these water-short areas it is very important to provide an adequate amount of available storage and to establish techniques to best manage that storage so that evaporation and distribution (conveyance) losses are minimized and so surface runoff is captured and stored for later use, rather than flowing by unused. Techniques of water system management that may increase yield include proper design and operation of storage facilities and reduction of conveyance losses. A third technique, reduction of evaporation losses, has not yet been proved effective.

Alternative 4—Diverting Additional Water Supplies Into the Study Area

Many U.S. cities obtain their municipal water supplies from rivers which run through the city, from lakes which border them, or from wells which tap groundwater. When these sources are inadequate, cities will "divert," or take water from rivers at some distance from the city and bring it through aqueducts to reservoirs serving the city. Even if an ample quantity of water is nearby the municipality, if the local water quality is poor because of pollution or mineral content, diversion of distant river sources may be used to obtain a cleaner, purer supply of water.

A municipality which contemplates a river diversion must first obtain rights to the water through appropriation or purchase. This can be a complex process involving negotiations with numerous landowners over the value of water and the damage caused by its diversion.

Once a water right is purchased or appropriated, the city must construct a physical system to collect the water through dams or diversion works; must transport it through canals, aqueducts, or natural river channels; and must construct storage reservoirs to accumulate and store the water for later use. Depending on circumstances, the water may be brought directly from the reservoir by aqueduct for treatment, stored in the reservoir until needed, or exchanged (*e.g.*, traded to another water user for an equivalent amount of water located more conveniently for the using city).

In the case of transbasin diversion the water must be transported from points of collection or storage in one basin through or over the basin divide to the other basin. This may require pumping to a higher elevation, tunneling under the divide, construction of siphons or pipelines to carry the water, or construction of additional storage reservoirs. Such facilities are costly, and so may be the acquisition of land to hold them.

Direct costs attributable to the diversion project, besides construction costs, are the continuing operating and maintenance costs of the water system. The secondary costs of diverting water include environmental effects and social costs. There may also be political costs in the source area, *i.e.*, the area of export.

Alternative 5—Reallocation of Agricultural Water Supplies

In many water-short regions the agricultural land adjacent to the metropolitan area is irrigated. It is possible, therefore, to reallocate or divert water from agricultural to municipal uses, and this change in water use sometimes accompanies a change in land use from agricultural to urban. The cost of reallocating agricultural water has usually been established through the market system. The direct monetary costs of reallocation are competitive with those of other techniques for increasing water supply, as there is a very high percentage of water currently used for irrigated agricultural purposes, and its value in use is lower than the current value of water used for municipal purposes. However, indirect costs which include the effect on agriculture and agriculture-related businesses of the diversion of irrigation water to domestic use are apt to be very high and to fall on a relatively small part of the population. Because of its high indirect costs, agricultural water reallocation should be carefully evaluated before being considered as an alternative.

Alternative 6—Using Groundwater

Nearly one-fifth of the water withdrawn for use in the United States come from groundwater. The water is found in two types of aquifers: shallow or unconfined, which are closely related to the surface flow of rivers, and confined or deep aquifers, which are recharged only through faults or fissures in the overlying layers of impervious rock. The principal advantages of using groundwater, as opposed to surface water, are that: the total volume in storage is enormous, the storage is available at "no cost" with no environmental damage, and groundwater does not suffer the high evaporative losses associated with surface transmission and storage. Other advantages of groundwater include the generally low temperature (*e.g.*, for industrial cooling) and comparative immunity from pollution and natural disasters such as earthquakes.

On the other hand, the disadvantages of using groundwater include the slow response and relative uncontrollability of the source, low water quality in some locations (due, for example, to dissolved solids), and the difficulty of treating or eliminating pollution once it has occurred. In some areas aquifer yields may not be great enough to provide sufficient water feasibly, or the cost may be exorbitant due to the depth of the wells which would be required.

Groundwater withdrawals which are balanced by recharge often constitute an attractive source of supply. Such withdrawals may exceed recharge during dry periods with the deficit being made up during wet periods. However, if long term natural recharge of the aquifers is insufficient to balance withdrawals, groundwater mining occurs. When this occurs, a natural resource is being used up, and the supply cannot be relied upon forever.

Alternative 7—Using Watershed Land Management Techniques

Wildlands (forests and associated brush and rangeland) are particularly important sources of water. Much of the U.S. streamflow originates from forested land as forests almost always occupy the higher elevations which receive the greatest amount of precipitation and yield substantially greater than average runoff. In the comparatively water-short Western United States it has been estimated that 90 percent of the usable water yield originates on the largely forested mountain watersheds.

In view of the significance of wildlands as water sources consideration should be given to managing these watersheds to enhance the water yield in areas which are short of water. In the United States it has been estimated that over 71 percent of the precipitation which falls on the watersheds is consumed locally and that only 29 percent reaches the streams; hence, it would appear that there could be significant potential for increasing streamflows. Such techniques are administratively feasible, as a major portion of the wildlands is publicly owned.

There are three groups of land management techniques which can be used to increase the runoff from watersheds. These are:

1. Localized snowpack enhancement by means of snowfences;
2. Modification of the vegetation within the watersheds;
3. Elimination of riparian vegetation.

The first technique is aimed at increasing the stream runoff from alpine areas and from brush and grassland. The second is effective in forest and brush areas. The third technique is oriented more towards conserving water in streams and rivers during its transmission to beneficial usage but is also applicable within forest and brush areas.

Alternative 8—Precipitation Augmentation

Man has been modifying the weather for centuries. For example, the presence of a city changes the average temperature, cloud cover, and wind speeds with respect to those which would pertain if the city were not there. It is only relatively recently that man has considered deliberate modification of the weather with the emphasis on changing the patterns of precipitation of rain or snow in a given location—a subject area more precisely termed "precipitation inducement" or "precipitation augmentation."

The first step in the process of estimating the potential increase in watershed yields resulting from a precipitation augmentation program involves identification of the cloud characteristics pertaining to the watersheds from which the municipal surface water supplies are or can be obtained. If these watersheds are extensive, they will probably need to be divided for planning purposes into a number of separate tracts with relatively homogeneous characteristics. However, it must be appreciated that in a practical program the dividing lines between tracts will be somewhat variable, as the effects of seeding one tract may spill over onto adjacent tracts. Expert opinion should be sought on the potential for increasing precipitation, the direct cost of such an operation, and the increased runoff which can be expected. These data should include information about the seasonality of the increased supply and predictions of the magnitude of the increases for dry and wet years as well as years with average rainfall. Allowance should be made for suspending seeding during inappropriate or potentially dangerous periods. For example, in the Colorado Rocky Mountains seeding has been suspended during holidays and the big game hunting season.

Alternative 9—Desalinization of Brackish or Salt Water

Desalting seawater is costly and to date has been justified only where there are virtually no feasible conventional alternatives. In the Florida Keys, for example, several small plants have been installed. However, desalting saline groundwater or surface water could be an almost indispensable part of plans for locations where all sources are of low quality. To raise slightly saline water to an acceptable quality with regard to dissolved solids need not involve desalting the entire flow. A portion of the water could be desalted and used to dilute the remainder.

There are four types of processes currently available for desalting:

1. Distillation;
2. Crystallization (freezing);
3. Membrane processes (reverse osmosis and electrodialysis); and
4. Ion exchange.

Use of ion exchange is normally restricted to removing limited quantities of salts to enhance water quality, *e.g.*, to reduce hardness.

In planning for desalting as a basic water supply source data should be obtained on the quantities of water available and the total dissolved solids content of the various possible sources; the data should include detailed chemical analyses to aid process selection. For inland areas land costs for evaporation ponds, feasibility of deep-well injection, and likely well depth should be determined. Availability and costs of alternative energy sources should also be investigated.

Alternative 10—Reuse of Municipal Wastewater

The case for directly recycling wastewater from municipal and industrial sewage is increasingly gaining support in the United States today. Although some people may view the prospect of having treated wastewater come through their house-hold water taps with aversion, technology has made it possible to return wastewater to a quality level which, with few (though nevertheless important) exceptions, equals that of pure natural sources. While the cost of treatment is still relatively high, there is every expectation that it will decrease over the years as the technical processes are further refined. However, the most significant sources of support for the use of recycled water owe less to a technical ability to purify wastewater than to a number of other considerations having to do with problems of developing new "fresh" water supplies and of disposing of municipal and industrial wastewater.

The task of dealing with domestic and industrial wastewater becomes more onerous as population continues to concentrate in urban areas. The volume of such waste is increasing; it includes ever greater levels of pollutants; and it is difficult to dispose of. This waste is not only an aesthetic problem; it has led to the pollution of conventional sources of drinking water: both surface water and, in some cases, groundwater. Moreover, providing both for new water supplies and for safe effluent disposal has been made more difficult by recent changes in the public's attitude toward the environment. These changes, largely reflected in Environmental Protection Agency rules and regulations, have imposed restrictions on the development of new water supplies and on the unregulated disposal of untreated municipal and industrial wastes. It is not surprising, then, that recycling which takes wastewater and processes it into usable water supplies is being proposed as a solution to the problem of both fresh water supplies and used water disposal.

III. FRAMEWORK FOR ANALYSIS OF ALTERNATIVES

A conceptual framework for the rational analysis of alternatives is essential to the decisionmaking process. There are three prerequisites to establishing the analytical framework. One is to determine the water supply/demand gap for the metropolitan area over a multiyear period which extends as far as the chosen planning horizon. Another is to array all possible alternative techniques for closing the gap and to separate these techniques into their natural subdivisions (*i.e.*, their stages, or progressive degrees of application). The third prerequisite is to determine for each subdivision of each technique the direct and indirect effects of its adoption. This task involves identification of the parties-at-interest, that is, the organizations or identifiable groups of persons who share a common interest and who are significantly affected, for better or worse, by the application of a specific technique. The third task also involves an identification and assessment of the economic, social, and environmental impacts which result from application of a particular technique. Each of these prerequisite tasks is briefly outlined in the following sections of this paper.

A. *Determining the Supply/Demand Gap for Municipal Water*

The determination of the supply/demand gap for water in a municipality requires judgment, historical data, and a knowledge of the principles of risk analysis. In simplest terms, the relationship of water quantity to time is projected for both supply and demand over a chosen period of years.

Because water demand fluctuates as a function of annual climate, it is necessary to establish a series of confidence limits, showing the extent to which demand can be expected to differ (plus or minus) from the mean no more often than one year in 10 (*i.e.*, 90 percent confidence level), no more often than one year in 20 (*i.e.*, 95 percent confidence level), and no more often than one year in 100 (*i.e.*, 99 percent confidence level). The confidence levels can be established by statistical analysis of past years' per capita water demand. Since the supply/demand gap is most significant when demand is greater than average, it is necessary to show only the confidence levels above the mean.

Water supply also varies as a function of annual climate. Furthermore, water supply will increase over the baseline supply as assured future developments of new supplies are completed. (For planning purposes those potential developments that are not absolutely certain should not be shown.) The average year water supply (*i.e.*, the amount of water which the supply system will generate in a year of average climate) is determined first. Superimposed on the average (mean) supply are a series of confidence levels, showing the extent to which supply can be expected to differ (plus or minus) from the mean no more often than one year in 10 (*i.e.*, 90 percent confidence level), no more often than one year in 20 (*i.e.*, 95 percent confidence level), and no more often than one year in 100 (*i.e.*, 99 percent confidence level). These confidence levels can be established, at least for the baseline supply, by statistical analysis of hydrologic (*i.e.*, water flow) records of the supply system. Confidence levels for future developments increasing the supply system can usually be estimated by hydrologic records of flow in the new additions or by engineering judgment. Since the supply/demand gap is most significant when supply is below average, it is necessary to show only the confidence levels below the mean.

When the water supply and demand curves are superimposed, as in Figure 1, it is possible to detect gaps during certain time periods. In Figure 1, for example, it appears that a supply/demand gap appears during years of average demand and average supply soon after year 2005. That is, the curve D-D lies above curve S-S after that year. The height of the gap (*i.e.*, the cross-hatched area of the figure) represents the severity of the water supply gap.

Even though no gap may occur between the average supply and demand curves, there still can be a strong likelihood of a shortage during certain years. If climate variation causes a relatively hot, dry year every 10 years and during this year water supply is at a 10-year low while demand is at a 10-year high,[1] the water supply gap will be significantly increased. Figure 2 illustrates this.

Some gaps may occur only in extreme cases, *e.g.*, when the 95 percent confidence level in demand overlaps with the 95 percent confidence level in supply or when the 99 percent confidence levels overlap. The overlapping of the 95 percent curves can, by definition, occur no more often than one year in 20, and the likelihood is still lower that the low supply and high demand curves will occur simultaneously. However, this possibility may still occur frequently enough that the policymaker will wish to plan for it. For extremely unlikely cases, *i.e.*, the overlapping of the 99 percent curves, it is probable that the policymaker would accept the risk rather than spend money to avert

1. The probability of the 10-year low supply coinciding with the 10-year high demand is less than 1.0 percent, due to variability of climate. Yet it is not an unlikely case since the same hot, dry conditions which produce one tend to produce the other. It may be appropriate to plan for this worst case and to use the possibility that the years do not coincide as a form of safety factor.

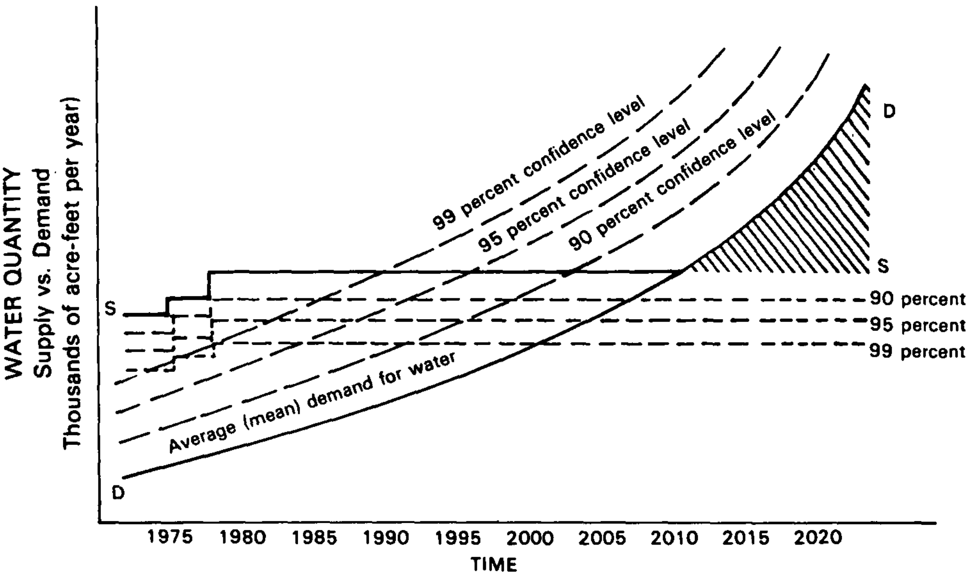

Figure 1. Water Quantity vs. Time, with Demand and Supply Curves Superimposed

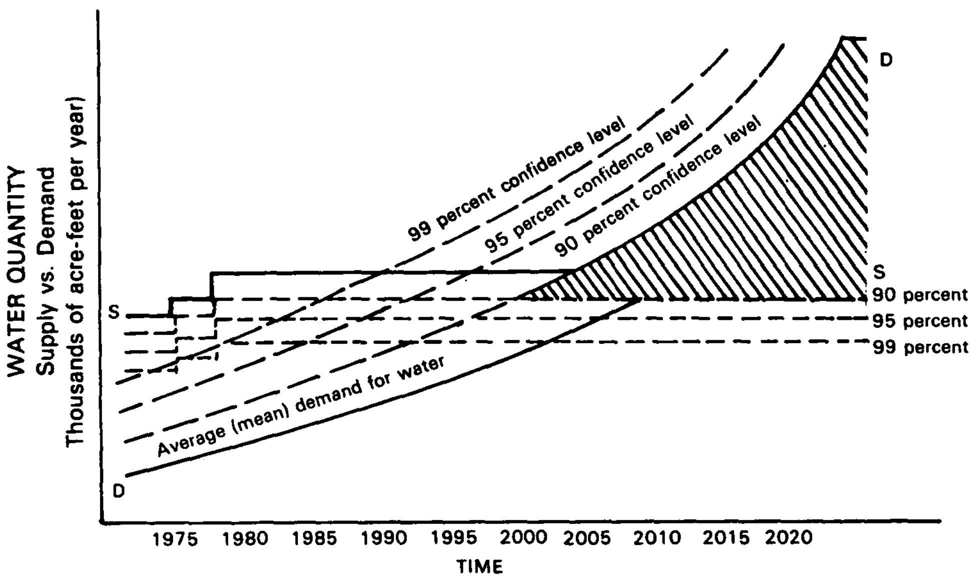

Figure 2. Water Quantity vs. Time, with Demand and Supply Curves Superimposed, Illustrating the Supply/Demand Gap Which Could Occur During One Year in Ten (Assuming Coincident Low Supply and High Demand)

this unlikely shortage. Certain undesirable alternatives (*e.g.*, severe water use restrictions that limit use to drinking and cooking) could be reserved for such unlikely contingencies.

Perhaps the single most important decision made by the water resources policymaker is that of deciding how much risk to avert in developing alternative ways to reduce the potential supply/demand gap. In this decision the policymaker must be guided by a knowledge or probability and particularly by a familiarity with risk analysis. Risk analysis permits a manager to understand the range of possible gains and losses from a proposed action and to avoid actions which may lead to disastrous outcomes, even where the predicted (probable) outcome is favorable.

B. *Arraying Alternative Techniques for Closing the Gap*

A suggested method of approach is first to eliminate techniques which are completely impractical in the study area of interest (*e.g.*, desalting sea water in Denver, orographic weather modification in California's Imperial Valley). Second, each technique should be analyzed to subdivide it into its various subtechniques or its various degrees of application. For example, watershed land management can be divided into subtechniques of snowfencing, forest cutting, modifying watershed vegetation, and controlling phreatophytes. Each subtechnique has different effectiveness in augmenting water supply and has different direct costs and impacts. Thus, each should be analyzed separately.

Similarly, some techniques have natural stages or degrees of application which should be analyzed separately. For example, conservation should probably begin with a first stage of voluntary public information conservation programs, which have a low cost in relation to the quantity of water which can be saved and few, if any, undesirable secondary effects. The next stage might be the voluntary installation of cost-effective water saving devices, followed by a stage of mandatory installation in newly-constructed houses and buildings. Water use restrictions represent more advanced degrees of application of the conservation technique and should be subdivided into stages according to the severity of the restrictions: (1) limited restriction of lawn watering hours; (2) a severe restriction on watering to the minimum quantity necessary for lawn and tree health; and (3) prohibition of all but inside house uses.

C. *Determining Effects of Each Technique on Parties-at-Interest*

For each technological or policy action which may be taken there are several identifiable groups of persons whose common interests are affected. These have been termed parties-at-interest and have been categorized roughly as follows:

1. Parties internal to the affected industry (or activity);
2. Suppliers and customers of an affected industry (or activity);
3. Government, at different levels and in certain roles, *e.g.*, taxer, regulator, or keeper of social welfare;
4. Affected bystander, *e.g.*, those concerned with resources, wildlife, recreation potential, or aesthetic effects.

The basic question used to identify parties-at-interest is:

> What are the goals of identifiable social or cultural or locational groups which lead them to perceive problems differently, to set different priorities for solving problems, or to respond differently to a particular policy/program?

For municipal water supply planning involving 10 alternative techniques to close the supply/demand gap, the authors of the University of Denver Research Institute (DRI) report have analyzed and identified 20 distinct parties-at-interest. These include an affected industry (water supply agencies), customers of the affected industry (residential, industrial, and commercial water users), government (metropolitan area political officials, Forest Service, and public health officials), and affected bystanders (environmentalists and several others). The vertical axis of Figure 3 lists the 20 parties-at-interest, subdivided into five parties-at-interest in most policy decisions, and 15 parties-at-interest in some decisions. The horizontal axis of Figure 3 lists the various alternative techniques and distinct subtechniques to close the supply/demand gap. The first column distinguishes between effects of increases in water supply and effects of specific techniques.

The DRI report next analyzed the impacts[2] which application of each of the various techniques would have on the various parties-at-interest. By consensus judgment these impacts have

2. In earlier DRI research on environmental policy analysis, impact was defined as a change from the present state of things or from the way things are clearly evolving. Any impact may be either positive or negative depending on the interests, values, or goals of different parties-at-interest. It may fall on individuals, economic entities, social or political institutions, or cultural characteristics.

<table>
<tr><th rowspan="2">ALTERNATIVE TECHNIQUES TO CLOSE SUPPLY/DEMAND GAP / PARTIES-AT-INTEREST</th><th colspan="5">Parties-at-Interest in Most Decisions</th><th colspan="15">Parties-at-Interest in Some Decisions</th></tr>
<tr><th>Water Supply Agencies</th><th>Residential Water Users</th><th>Industrial and Commercial Water Users</th><th>Metropolitan Area Political Officials</th><th>Environmentalists</th><th>Wastewater Treatment Agencies</th><th>Power Supply Agency</th><th>Forest Service</th><th>Public Health Officials</th><th>Downstream Water Users</th><th>Present Groundwater Users</th><th>Surface Water Rights Holders</th><th>Farmers and Stockmen</th><th>Agri-Dependent Sectors of the Economy</th><th>Transbasin Development and Water Conservation Interests</th><th>Still Water Recreationists</th><th>Moving Water Recreationists</th><th>Hunters</th><th>Metropolitan Area Developers</th><th>Water Project Construction Sector</th></tr>
<tr><td>Reuse (Dual system)</td><td>++</td><td></td><td>+</td><td>+</td><td>++</td><td>+</td><td>+</td><td></td><td>|</td><td>:</td><td></td><td>|</td><td></td><td></td><td></td><td></td><td>|</td><td></td><td>|</td><td>++</td></tr>
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<tr><td>Groundwater Withdrawal (at recharge rate)</td><td>+</td><td></td><td></td><td></td><td>++</td><td></td><td>+</td><td></td><td>|</td><td>+</td><td>|</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>+</td><td>+</td></tr>
<tr><td>Condemnation of Water Rights</td><td>|</td><td></td><td></td><td>|</td><td>:</td><td></td><td></td><td></td><td></td><td>+</td><td></td><td>:</td><td>|</td><td>:</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Construction of Transbasin Delivery Facilities</td><td>+</td><td></td><td></td><td>+</td><td>:</td><td></td><td>+</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>:</td><td>+</td><td>|</td><td>|</td><td></td><td>++</td></tr>
<tr><td>Construction of Water Collection and Storage Facilities</td><td>++</td><td></td><td></td><td>+</td><td>:</td><td></td><td>+</td><td>+</td><td></td><td>++</td><td></td><td></td><td></td><td></td><td></td><td>++</td><td>:</td><td>|</td><td></td><td>++</td></tr>
<tr><td>Chemical Substances on Reservoir Surface</td><td>|</td><td>|</td><td></td><td></td><td>:</td><td></td><td></td><td>|</td><td></td><td>|</td><td></td><td></td><td></td><td></td><td></td><td>:</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Reservoir Lining</td><td>+</td><td></td><td></td><td></td><td>:</td><td></td><td></td><td>|</td><td>|</td><td></td><td></td><td></td><td></td><td></td><td></td><td>:</td><td></td><td></td><td></td><td>+</td></tr>
<tr><td>Canal Lining</td><td>+</td><td></td><td></td><td></td><td>:</td><td></td><td></td><td></td><td></td><td></td><td>|</td><td></td><td></td><td></td><td></td><td></td><td>:</td><td></td><td></td><td>+</td></tr>
<tr><td>Optimum Management Strategy</td><td>++</td><td></td><td></td><td>+</td><td></td><td></td><td></td><td></td><td></td><td>+</td><td></td><td></td><td></td><td></td><td></td><td>|</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Surcharges</td><td>+</td><td>|</td><td>|</td><td>+|</td><td>+</td><td></td><td></td><td></td><td></td><td>:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Peak Responsibility Pricing Meters</td><td>+</td><td>|</td><td></td><td>+|</td><td>+</td><td>+</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Progressive Rate Structure Assuming</td><td>+</td><td>+|</td><td>:</td><td>+|</td><td>+</td><td>+</td><td></td><td></td><td></td><td>+</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Marginal Cost Pricing</td><td>|</td><td>:</td><td>:</td><td>|</td><td>+</td><td>+</td><td></td><td></td><td></td><td>+</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>|</td><td></td></tr>
<tr><td>Retroactive Installation of Residence Meters</td><td>+|</td><td>:</td><td>+</td><td>:</td><td>++</td><td>+</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>+</td><td>++</td></tr>
<tr><td>Limit Service Area</td><td></td><td></td><td></td><td>+|</td><td>+</td><td>+</td><td>|</td><td></td><td></td><td></td><td>:</td><td>|</td><td>|</td><td>+</td><td>+</td><td></td><td></td><td>+</td><td>:</td><td>|</td></tr>
<tr><td>Water Use Restrictions (high)</td><td>:</td><td>:</td><td>:</td><td>:</td><td>:</td><td></td><td></td><td></td><td>|</td><td>+</td><td>|</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>:</td><td></td></tr>
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<tr><td>Water Use Restrictions (low)</td><td>|</td><td>|</td><td>|</td><td>|</td><td>+</td><td></td><td></td><td></td><td></td><td>+</td><td>|</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>|</td><td></td></tr>
<tr><td>Installation of Water Saving Devices</td><td>+</td><td>|</td><td>|</td><td>|</td><td>+</td><td>+</td><td></td><td></td><td>|</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>|</td><td>+</td></tr>
<tr><td>Voluntary Public Information Conservation Program</td><td>+</td><td></td><td>|</td><td>+</td><td>++</td><td>+</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Any Technique to Increase Water Supply</td><td>++</td><td>+</td><td>++</td><td>+</td><td></td><td></td><td></td><td></td><td>+</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>+</td><td></td></tr>
</table>

Legend:
- ++ Very favorable impact
- + Favorable impact
- +| Mixed good and bad impacts
- | Unfavorable impact
- : Very unfavorable impact
- (blank) No significant impact

Figure 3. Matrix of Impacts on Parties-at-Interest

been identified and weighted in gross terms according to significance.

IV. EVALUATING AND DECIDING AMONG ALTERNATIVES

The first step in the evaluation/decision process is to determine the effectiveness of each technique in terms of quantity of water produced (in added supply or reduced demand) annually. Where effectiveness is uncertain, a technique such as expected value or sensitivity analysis should be used to convert all effectiveness measures to an equal degree of certainty.

Next, all techniques should be arrayed on the effectiveness scale in terms of number of acre-feet of water which the technique could produce annually in the study area.

For each technique all associated costs and effects should be recorded:

1. Direct cost in dollars per acre-foot annually;
2. Indirect economic effects in dollars per acre-foot annually where possible to estimate;
3. Social effects, *i.e.*, quality-of-life effects;
4. Environmental effects;
5. Energy effects;
6. Political aspects;
7. Legal uncertainties;
8. Technical uncertainties.

A. *A First Trial Solution*

The next step in the process is to propose a tentative solution to the supply/demand gap by adopting a combination of techniques whose combined effectiveness in acre-feet of water provided annually equals the magnitude of the supply/demand gap in a given year. Theoretically, since any proposed solution will be compared with all other possible solutions before one is selected, it should not matter what combination is used to begin. However, to simplify comparisons and perhaps also to begin closer to the ultimate solution, it is suggested that the first tentative solution be made on the basis of least-direct cost.

Once the least-direct cost combination of selected techniques with their associated costs and effects is arrayed, the policymaker can identify certain costs which seem excessive. For example, the trial solution may include groundwater withdrawal involving a moderately high use of energy, a risk of land subsidence, and a possible loss of amenities caused by well drilling throughout the metropolitan area.

B. *Improving the Trial Solution*

The next step in the process is to look for an alternate technique to substitute for one in the trial solution. For example, if groundwater mining were rated at 60,000 acre-feet a year on the effectiveness scale, the policymaker might substitute a brackish water desalting plant also rated at 60,000 acre-feet a year.[3]

Should this substitution be made? First, the changes in costs and effects due to the substitution must be analyzed. Using hypothetical figures, the direct cost for groundwater mining may be $70 per acre-foot while brackish water desalting costs $170 per acre-foot. The indirect economic effects involving short term and long term construction and operating employment vary for the two techniques. The effects on quality of life, the environment, energy use, and political aspects also differ. Table I displays these differences as a policymaker might view them.

Table I shows that the substitution of brackish water desalinization would cost $100 times 60,000, or $6 million annually in direct cost. This would be partially offset during the first 18-month construction period by stimulated construction employment of $10 million which would produce, directly and through a multiplier effect on the local economy, jobs and tax revenues. The operation of the desalting plant would also provide more, permanent jobs. However, the heavy capital and operating costs of the desalting plant make it clearly inferior to groundwater mining on the basis of quantifiable direct and indirect economic effects.

In cities concerned about "urban sprawl," groundwater mining, which encourages further horizontal urban development, is particularly undesirable. In other cities, where residents desire the amenities of lawns and gardens and decentralized, low-density housing, use of groundwater is more acceptable, particularly as it reduces the cost of water collection and distribution systems.

3. It is not, of course, necessary that an alternative have exactly equal effectiveness to be substituted. An alternative with limited effectiveness could be substituted for a *portion* of the trial solution. For a desalting plant rated at 30,000 acre-feet a year might be substituted for half of the planned 60,000 acre-foot groundwater mining program.

TABLE I.

TYPICAL COMPARISON OF ALTERNATIVES

(Note: All quantitive data are hypothetical; they will differ from one metropolitan area to another)

	Groundwater Mining	Desalinizing Brackish Water
1990 Effectiveness:	60,000 acre-feet/year	60,000 acre-feet/year
1990 Cost/acre-foot	$70	$170
Indirect Economic Effects:	Stimulated basic employment in well-drilling: $3,500,000 income over 3 years	Stimulated basic employment in constructing plant: $12,000,000 income over 18 months Capital cost = $35,000,000
	Continued employment in maintenance of pumping plants, $100,000/year	Continued employment in operation of desalting plant: $300,000
Quality of Life effect	Encourages horizontal urban development	Small, if any
Environmental effect	Risk of land subsidence Depletion of nonrenewable resource	Depletion of brackish water resource Problem of brine disposal through deep well injection
Energy effect	Moderately energy intensive in operation 1,500 kwh/acre-foot Energy used in well drilling	Energy intensive in operation 3,500 kwh/acre-foot Energy used in plant construction
Political aspects	Considerable concern by present groundwater users over lowering of water table	Some concern over cost risk
Legal uncertainties	Risk of not obtaining state approval of aproriation of groundwater Risk that groundwater may be ruled to be directly connected to surface source.	Question over right to appropriate brackish water. Risk of disapproval of method used to dispose of residual brine (e.g., deep well disposal)
Technical uncertainties	Yield of formations varies widely, hence cost is uncertain Quantity stored is most uncertain and hence duration of supply is not known As drawdown continues, pumping cost increases.	Little is known as to plant cost and reliability due to limited experience with plants. Substantial future cost reductions are anticipated

	Groundwater Mining	Desalinizing Brackish Water
Effect on Parties-at-interest:		
Water supply agencies	±	+
Metro political officials	+	0
Environmentalists	-	-
Power supply agency	+	+
Public health officials	-	0
Downstream water users	+	0
Present groundwater users	--	0
Metro area developers	+	0
Water project construction sector	+	++

Each alternative method has environmental drawbacks: desalinization depletes a visible but little-valued resource of brackish water; groundwater mining depletes an invisible but valuable resource. The problems of brine disposal and possible land subsidence, additional environmental problems, are somewhat difficult to compare in severity.

The effects on parties-at-interest vary, and it requires a subjective analysis to determine which is superior for society as a whole.

Faced with the differences shown in Table I, the policymaker would weigh the possible effects according to criteria chosen for applicability to the specific metropolitan area. By identifying and isolating the effects of the proposed substitution, the policymaker can judge it according to any of several values: reduced risk of horizontal urban development, greater direct cost of $6 million per year, increased energy expenditure of 120 million kilowatt-hours (KWH) per year, etc. Correctly, it would be judged according to all of the factors listed in Table I interpreted through the subjective criteria of the policymaker. The policymaker should consider all the various possible substitutions until it is clear that, according to the criteria selected, the optimum solution has been found.

The analysis technique described herein has an important advantage: it permits the policymaker to measure the direct dollar cost of any proposed substitution of one technique for another. By doing so, the policymaker can place an approximate minimum dollar value on a normally nonquantifiable effect, such as preservation of an environmental feature, if these are the key factors in the substitution decision. It is this aspect of the analysis process which is critical; only by weighing all costs can an optimal decision be made.