EVALUATION OF URBAN WATER CONSERVATION PROGRAMS: A PROCEDURES MANUAL

Prepared for

California Urban Water Agencies

by

Planning and Management Consultants, Ltd.
Carbondale, Illinois

with the assistance of

Brown and Caldwell Consultants
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FOREWORD

California Urban Water Agencies (CUWA) is an organization of the largest urban water providers in California, which serve water to metropolitan areas comprising about two-thirds of that state's 31 million population. CUWA was formed to work on water supply issues of particular concern to the large urban areas in California. Among those concerns is water use efficiency; in particular, urban water conservation.

CUWA has conducted several projects on water conservation and drought management, and is the sponsor and manager of the California Urban Water Conservation Council. This council is the broad-based organization which administers the 1991 Memorandum of Understanding for Best Management Practices in Urban Water Conservation, the agreement that forms the basis of progressive conservation programs for the large majority of urban Californians.

It is recognized by all water professionals that the science of design and evaluation of water conservation programs has lagged behind the interest in, and need for, these programs. This CUWA project is intended to fill part of that technical gap by producing a state-of-the-art procedures manual on the Evaluation of Urban Water Conservation Programs. The manual is necessarily highly technical and is intended to be used by experienced professionals.

CUWA was pleased to obtain the services of Planning and Management Consultants, Ltd., a leading water resource planning consulting firm, to conduct this work. We were also pleased to invite several project participants and reviewers from public interest groups and other organizations with strong interests in urban water conservation. While our reviewers represent a range of views on some basic water resource management issues, all are highly supportive of this project and its product. Invited reviewers also include representatives from the Water Conservation Committee of the American Water Works Association, to whom CUWA has offered the results of this project so that they might be disseminated for national and international use.

California Urban Water Agencies

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INTRODUCTION

THE ROLE OF CONSERVATION ALTERNATIVES

In recent years the arena of water resources planning has been broadened to include a number of unconventional solutions to water supply problems. Water conservation has captured the attention of water planners as a promising alternative to the development of new water supplies.

This broadening of planning perspectives has been brought about by a number of new challenges that must be faced by water supply agencies today and in the future. First, the untapped sources of water are becoming less available. Many urban areas, especially in the West, have begun to experience water allocation problems as regional surface supplies have become fully appropriated. The depletion and contamination of groundwater sources further limit water availability. Also, there are laws and regulations that limit the development of large-scale water transfers between river basins or across political boundaries. Second, the increased frequency of droughts during this decade may increase the competition for water between urban and agricultural interests. In order to adjust to frequent droughts, farmers can shift from irrigated agriculture to dry farming in many parts of the country including the state of California. Third, environmental concerns have intensified during the last two decades to the point where the development of new supplies is often socially unacceptable. Environmental interest groups and new environmental legislation make it very difficult to build new dams or water transmission facilities. Fourth, the prospects for financing major construction programs are discouraging for many water agencies. The cost of development of supplies has risen in some cases to prohibitively high levels, while the possibilities for obtaining federal assistance have become constrained because of new cost-sharing requirements (e.g., up-front financing). Finally, the Safe Drinking Water Act of 1974 and its recent amendments have forced many communities to comply with increasingly stringent limits on a large number of contaminants in drinking water. This has led to a significant increase in the cost of water treatment.

These new considerations have forced water planners to extend their perspective beyond the traditional water resource development projects. Alternative ways of increasing water supply are explored and evaluated. These new alternatives may include:

(1) More efficient utilization of existing water supplies (e.g., pumped storage or reduction of losses through lining of reservoirs and canals or evaporation suppression and reallocation of storage for flood protection to water supply)

(2) Protecting existing supplies by cleaning up the waste sources contaminating the water, building barriers against the intrusion of salt water, and developing new technologies for large-scale treatment of contaminated aquifers

(3) Conjunctive use of groundwater and surface water including the use of groundwater aquifers for storage of excess supply of surface water

(4) Upgrading marginal quality supply sources such as seawater or brackish groundwater

(5) Wastewater reclamation including the construction of dual pipe distribution systems

(6) Regionwide management of the existing and new sources of supply through water transfers and exchanges to improve the distribution of water among water surplus and water shortage areas within a region

However, an important change in water supply planning involves the use of water demand management (or water conservation alternatives). Water conservation programs may allow some water agencies to balance future supply and demand at a cost that is below the economic, social, and environmental cost of new supply development. Examples of such programs include:

(1) Public campaigns to educate the consumers on how to modify water use habits to reduce water consumption

(2) Promotion of, or mandatory requirements for, the use of water-saving technologies

(3) Promotion of, or mandatory requirements for, low water-using urban landscaping

(4) Adoption of marketplace pricing strategies to discourage inefficient uses of water

(5) Adoption of economic incentive programs to encourage efficient use of water

Despite the acceptance of water conservation as at least a partial solution to water supply problems, its role in water supply planning and the full implications of conservation in an engineering, economic, social, and environmental sense are not fully understood.

An underlying shortfall involving the implementation of water conservation as an effective demand management tool is the <u>lack of reliable knowledge</u> of actual water savings, market penetration, and interaction effects between conservation measures. For many conservation measures, data on these parameters are practically nonexistent. For other measures, data are not reliable and have to be very carefully examined before they are used to formulate the assumptions about the effects of implementing conservation measures. Although empirical studies have been conducted to estimate the water savings from conservation programs, these studies oftentimes produce widely divergent results for the same type of conservation measure or program.

Because water planners and administrators must have reliable estimates on water savings, as well as potential benefits and costs, from implementing a conservation program, there is a need for greater focus and standardization in procedures for estimating water savings. The major purpose of this manual is to address these needs. With reliable estimates of water savings, the potential benefits and costs of implementing conservation programs can be more accurately assessed. However, in order to best understand the factors that affect the estimation of water savings as well as benefits and costs, these issues are placed in the overall context of water planning and management.

DEFINITION OF WATER CONSERVATION

In order to make water conservation an integral part of water resources planning, it is necessary to establish a precise and practical definition of water conservation measures. Such a definition should permit the planners to distinguish between supply-and-demand-oriented strategies and to define the criteria for selecting alternatives that meet economic, social, and environmental feasibility requirements.

Comprehensive water supply management requires the evaluation of two basic sets of alternatives: (1) those alternatives that reduce water use and/or loss and (2) those alternatives that augment supplies. Taken together, these alternatives provide the basis for efficient water management. In balancing current and future water supply and demands, the objective should be to determine which combination of supply-and-demand management alternatives is optimal from social, environmental, and economic perspectives. The distinction between alternatives is most helpful in defining the economic criteria for selecting the best water supply/conservation plan. Accordingly, various water management practices can be conveniently separated into supply management (augmentation) and demand management (conservation) measures given a precise definition of water supply with respect to its location in space and in the hydrologic cycle.

In general, water that is appropriated or physically segregated (withdrawn or diverted) from supply so that it is temporarily or permanently unavailable for other purposes or users can be viewed as a given water supply. For example, if water supply is measured as a reservoir storage for urban use, then any management practice that conserves this supply through reduction in water use or losses can be classified as a conservation measure. In addition to any measures that reduce so-called end uses of water by residential, commercial, and industrial customers of the water supply system, conservation measures also include the reduction of any losses in the storage, transmission, treatment, and distribution of the reservoir water. Therefore, evaporation suppression, reservoir lining to prevent seepage, and prevention of reservoir spills greater than the minimum-flow requirements would all be classified as conservation measures.

On the other hand, all water management practices which increase the supply would be defined as supply management measures. These would include any actions that increase water supply, such as additional impoundments to increase storage or watershed management measures to increase runoff. Table 1 gives examples of water management practices within each of the two categories: supply management and demand management (or conservation).

TABLE 1
A TYPOLOGY OF WATER MANAGEMENT PRACTICES

(A) Supply Management (Supply Augmentation)

(1) Development of new supplies
- Surface storage (dams, impoundments)
- Groundwater development (wells, wellfields)
- Interbasin importation (water transfers)

(2) Enhancement of existing supplies
- Recharge of groundwater aquifers
- Pumped reservoir storage
- Watershed management (to increase runoff)
- Cloud seeding
- Wastewater reclamation/reuse

(3) Conjunctive management of surface and groundwater supplies

(B) Demand Management (Conservation)

(1) Demand reduction measures

Education (training users to use water more efficiently)
- -Promotional campaigns/events
- -Mass media campaigns
- -Personal contact/water audits
- -School programs

Management measures:
- -Rate-making policies
- -Tax incentives, subsidies, rebates (aimed at achieving use of water conserving devices, fixtures and/or water conservation strategies)
- -Field programs resulting in installation of devices

Regulation:
- -Federal and state laws and policies
- -Local codes and ordinances requiring performance criteria and standards
- -Restrictions/bans

(2) Reduction of losses
- Water recirculation/recycling
- Leak detection and repair
- Evaporation suppression
- Reservoir lining (to reduce seepage)

Criteria for Selecting Water Management Practices

Having distinguished between water conservation and supply augmentation alternatives, the next critical step is to determine which practices should be included in the plan to balance future demand and supply. An approach proposed by Baumann et al. (1980) is to first define a traditional water supply plan in which a given demand (not influenced by conservation programs) is met using only supply augmentation alternatives and associated expansions of water transmission, treatment, and distribution facilities. Typically, a water supply plan includes projected requirements not only for the water supply facilities but also for wastewater collection, treatment, and disposal facilities. Theoretically, such a plan could be formulated by minimizing the present value of capital and operation costs, by selecting the optimal timing and size of supply increments, to meet the projected water demand.

Once such a plan has been developed and adopted for implementation by the community, one can proceed with the evaluation of specific water conservation measures to determine whether the reduction in water use or losses (during the planning period) achieved by each measure, is beneficial. The term "beneficial" implies that the implementation of a given conservation measure will result in a net increase in social welfare. For example, a conservation measure will increase social welfare if the reduction in supply costs plus any external benefits of reduced water use exceeds the cost of implementation plus any net external costs associated with the conservation measure. This reduced supply cost may include the monetary savings that result from the postponement of new supply augmentation projects, as well as the delayed construction of associated water and wastewater treatment and distribution facilities. If these cost savings are greater than the cost of the conservation measure, then a tangible beneficial effect of water conservation would be the reduced rate of water use. Although some monetary effects of conservation measures are unrelated to the water supply plan (e.g., savings in energy used to heat water), they are also included in the determination of the net beneficial effect. The specific categories of beneficial and adverse effects of water conservation will be discussed later.

Definition of Conservation

In summary, a practical definition of water conservation, as provided by Baumann et al. (1984), can be stated as follows:

"'Water conservation is any beneficial reduction in water use or in water losses,' where the following apply:

(1) A reduction in water use occurs when a water management practice results in less water use as compared to the level of water use expected in the absence of the practice (the with and without comparison).

(2) A reduction in water use is beneficial if the aggregate of all beneficial effects resulting from implementation of the water management practice exceeds the aggregate of all adverse effects occasioned by such implementation. The practice should result in a net increase in social welfare. If all beneficial and adverse effects are measurable in monetary terms, a beneficial reduction occurs when the present value of the stream of expected benefits exceeds the present value of the stream of expected costs.

(3) Water that is for some purpose withdrawn, diverted, or physically segregated from supply so that it is temporarily or permanently unavailable for other purposes is considered water used. Water uses are therefore competitive by definition. No use can be increased without reducing, in some way, the availability of water for other uses.

(4) A quantity of water that, having once been defined as a part of water supply, is no longer available for use is considered water lost. If water supply is measured as reservoir storage, for example, water losses include spills from storage and leakage from the transmission and distribution systems."

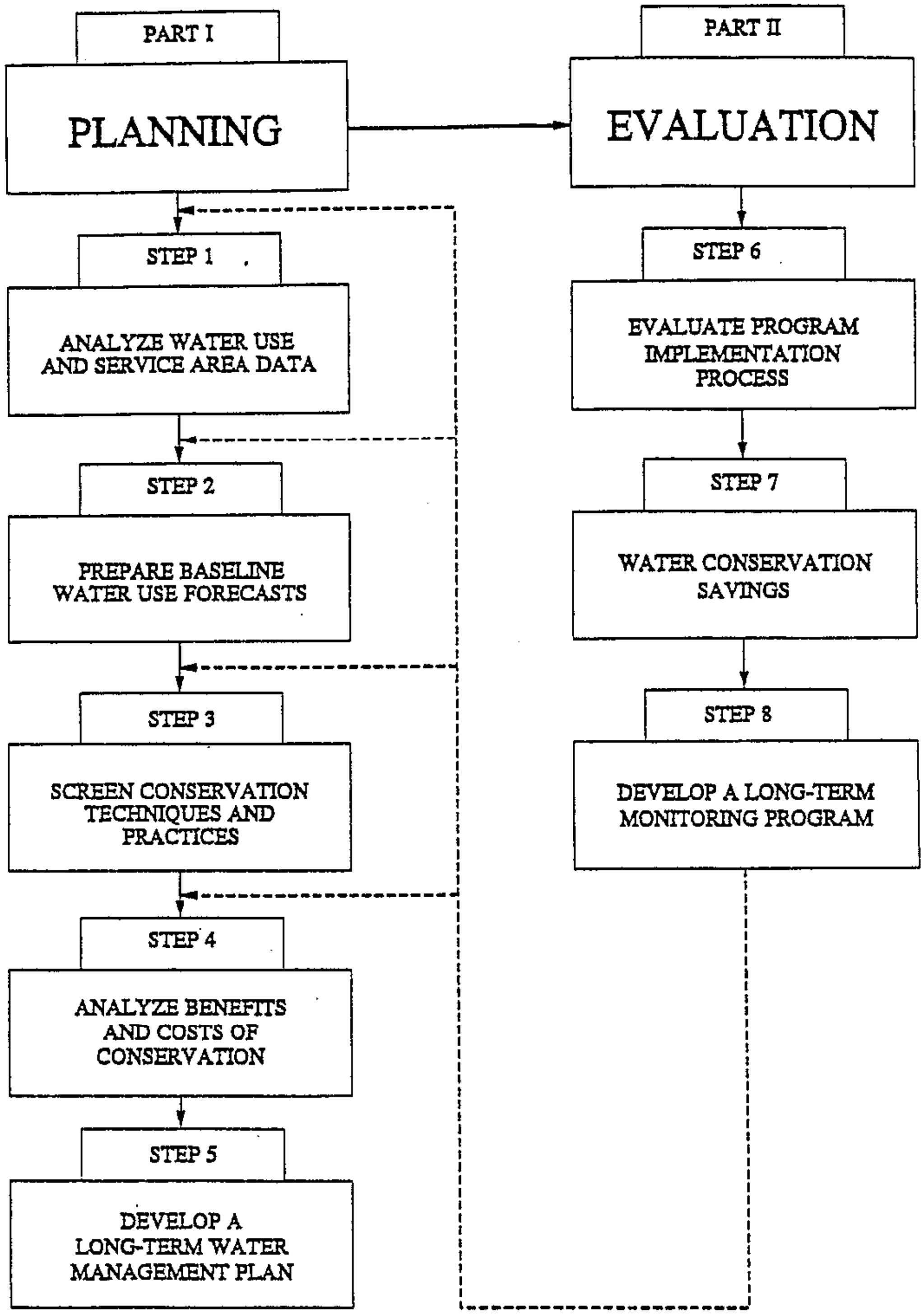
This definition of water conservation includes a subset of efficient water management techniques. The essence of conservation is a reduction in water use or water losses. Thus, conservation practices are those efforts that result in a level of water use at some future time, which is less that the level would have been at that time, had the practice not been implemented. However, not all practices that reduce water use should be considered desirable. The beneficial effects of the reduction in water use (loss) must be considered greater than the adverse effects associated with the commitment of other resources to the conservation effort.

THE PROCESS OF CONSERVATION PLANNING AND EVALUATION

The procedure for a systematic analysis of water conservation alternatives consists of eight analytical steps, as shown in Figure 1. The eight steps can be grouped into two parts: planning and evaluation. If carefully executed, these steps permit the conservation planner to formulate viable conservation alternatives and decide upon the optimal level of water conservation in the long term water management plan.

A brief description of the purposes of each part and each step is given below. The subsequent sections of this manual contain a detailed description of concepts, procedures, and measurement techniques for each step, with main emphasis on program evaluation.

FIGURE 1
CONSERVATION PLANNING AND EVALUATION PROCEDURES



Part I: Water Conservation Planning

The purpose of this part of the manual is (1) to determine conservation potential and conservation opportunities for a water service area and (2) to conduct a preliminary evaluation of conservation measures with respect to their potential water savings, costs, and benefits.

In **Step 1**, water use and service area data are analyzed in order to generate the necessary information for selecting and evaluating water conservation measures. The results of this step will include:

(1) Disaggregation of total urban water use by major user sectors
(2) Estimation of seasonal and outdoor components of water use in each sector
(3) Identification of significant end uses of water in each user sector
(4) Assessment of the existing conservation practices among various users
(5) Assessment of user motivations to implement conservation practices

The knowledge of current water use and its historical changes is required in order to identify customer groups or end uses of water that show the greatest potential for water use efficiency improvements. Also, knowledge of existing conservation practices brought about by passive programs (such as plumbing fixture codes) or market trends is very critical. Such practices may partially or completely preempt some conservation alternatives that might be considered for implementation and may enhance the attractiveness of other conservation opportunities.

The analysis of water use and existing conservation should be expanded to include the development of information on water users in the service area. Data on housing stock, household characteristics, business establishments, and other demographic statistics are required for proper design and implementation of water conservation programs.

Step 2 involves the development of a disaggregate forecast of future water use under some baseline (without active conservation) conditions. Reliable projections of future effects of water conservation programs cannot be made without first determining future water use without conservation. The rates of water use (e.g., daily per capita use) are a function of many factors. These rates may decrease, increase, or remain unchanged depending on the future values of these factors and their effects on water use.

The development of long-term forecasts of water use may require:

(1) The development of demographic and economic growth projections for the service area
(2) Selection and calibration of water use models
(3) Preparation of forecasts for alternative growth scenarios

In **Step 3**, an initial screening of potential conservation measures is conducted. The screening process begins by identifying all known conservation practices that (1) are applicable to water uses in the service area and (2) have not been already implemented or approved for implementation by local, state, or other authorities. The initial screening of each measure examines (1) technical feasibility--whether the measure will result in a significant reduction in water use and (2) social acceptability--whether the measure will be adopted by water customers. These tests will permit the conservation planner to reject some practices and rank the others. Using estimates from literature sources, pilot program results, or empirical studies from water agencies, the potential water savings of conservation measures can be estimated. After determining their applicability, feasibility, acceptability, and potential water savings, conservation measures are developed into fully implementable demand management alternatives (conservation programs).

The most likely candidates for program implementation can then be subjected to tests of economic efficiency as described in **Step 4**. With the development of the water use forecasts, the most likely future values of water use are compared to the projected (future) availability of water supply and capacities of transmission, treatment, and distribution facilities. Such a comparison allows the conservation planner to determine whether conservation programs might have long-term benefits that stem from the downsizing or postponement of future additions to existing capacities of water and wastewater facilities and/or the development of new sources of supply. The long-term benefits of implementing a conservation program can then be compared to the cost of implementation plus any net external costs that are associated with the conservation measure. Alternative methods of economic evaluation and consideration of different accounting perspectives are also presented in this step of the planning process.

The purpose of **Step 5**, the final step of the planning phase, is to select an optimal combination of water conservation alternatives. The optimal water management plan for a given community or water agency should be determined according to the same principles, standards, and criteria employed for other aspects of water resources development planning. All conservation alternatives that show net advantageous effects should be incorporated into the plan, provided that each conservation alternative retains its beneficial effect when implemented in combination with other measures.

Part II: Program Evaluation

The primary purpose of the program evaluation part of this manual is to provide concepts and procedures for generating estimates of reliable water savings, program costs, and other conservation parameters that are used in the formulation and evaluation of demand reduction alternatives in the conservation planning process. Program evaluation is an essential component of the water conservation planning process because the findings of the program evaluation can be used to support assumptions (i.e., market penetration, water savings estimates, etc.) that are used in each of the five steps described above (see Figure 1). Because of its importance to the planning process, program evaluation is detailed as a separate component of this manual. The analytical steps of program evaluation are (1) the design of a plan for evaluating the implementation process of a conservation program; (2) the design of an evaluation plan for determining the impacts of a water conservation program (i.e, the water savings); and (3) the development of a long-term program for monitoring water use and conservation.

Step 6 is the initial step of the program evaluation phase. Its purpose is to evaluate the process of program implementation. All relevant aspects of the program, except its effects on water use, may be included in process evaluation. The components of process evaluation may consist of (1) a survey of baseline (initial) conditions; (2) field tracking and program administration procedures including cost accounting; (3) surveys of water customers after the completion of the program; and (4) other evaluation elements and procedures. These process evaluation procedures will allow the conservation planner to obtain information on the rates of adoption and retention of conservation measures by the targeted populations of water users. Rates of adoption and retention are required to extrapolate water savings from pilot scale to full scale and to calculate cost-effectiveness of the program or its alternative designs (e.g., alternative modes of distributing water conservation kits).

The purpose of **Step 7** is to provide procedures for the measurement of the impacts of conservation programs on water use. Because water planners and administrators must have estimates of reliable water savings, as well as potential benefits and costs of implementing a conservation program, there is a need for greater focus and standardization in procedures for estimating water savings. With estimates of reliable water savings, the potential benefits and costs of implementing conservation programs can be more accurately assessed. Decisions to implement a certain water conservation program are often made based upon assumptions of the expected water savings that would result from that program. More reliable estimates of water savings can be obtained from empirical studies of implemented programs. In order to measure the actual water savings from a water conservation program, it may often be necessary to design a water use modeling study before initiating the program. Such a study will often include (1) selection of representative samples of water users; (2) building of databases with water use observations and other customer characteristics; and (3) statistical estimation or calibration of water use models for estimating water savings. These data collection and analysis techniques are presented in this step.

Finally, **Step 8** discusses the need for the development of a long-term water use and conservation monitoring program. One of the most important benefits of a long-term monitoring program is the ability to assess the progress toward reaching the goals of the implemented water conservation program. The results of a monitoring program can also be used as feedback to the conservation planning process. This allows planners and administrators to enhance or discontinue the ongoing programs or to design and implement new programs. The concepts and procedures for developing a long-term water use monitoring program are discussed in this final step.

FORMAT OF THE MANUAL

The manual is organized into two parts:

I. **Conservation Planning**
II. **Program Evaluation**

If the primary objective is to prepare an evaluation plan for a conservation program that has already been developed and is ready for implementation, the reader may wish to move directly to **Part II**.

Within **Part I** and **Part II**, the aforementioned steps are presented as separate chapters. At the beginning of each step, the objectives of the step are outlined.

The appendices provide additional, more comprehensive, examples of some of the methods and procedures described in this manual. A single list of the bibliographic references made throughout the manual follow the appendices.

PART I

WATER CONSERVATION PLANNING

PART I. WATER CONSERVATION PLANNING

ANALYSIS OBJECTIVES

The analytical steps included in **Part I** of this manual are designed to assist the water resource or conservation planner in:

(1) Examining conservation opportunities in their water service area by analyzing water use and service area data
(2) Preparing water use forecasts (exclusive of potential conservation activities)
(3) Assessing the applicability, technical feasibility, and social acceptability of water conservation measures
(4) Estimating the water savings, benefits, and costs of potential water conservation programs
(5) Incorporating water conservation into long-term water supply plans

If the primary objective is to prepare an evaluation plan for a conservation program that has already been developed and is ready for implementation, the analyst can move directly to **Part II: Program Evaluation.**

There are many possible ways to conserve water. New conservation techniques are periodically being added to the lists of known alternatives. Within the entire universe of possibilities, one can find measures at various stages of development. However, there are only a small number of practices for which water savings and economic, environmental, and social effects have been reliably documented in actual field applications. The potential outcomes of the remaining measures are uncertain. Such measures require the development of technical, economic, and social acceptability data before a major commitment of resources for their implementation can be made. Furthermore, the effects of the few documented measures are sometimes surrounded by considerable controversy, thus leaving water suppliers with uncertain estimates of water savings from conservation programs.

One of the critical questions in water conservation planning is, Among the many water management tools available to the policymaker for providing water to customers (including supply enhancement and demand management), what level of conservation is optimum? From another perspective, How much investment in water conservation measures can be justified? The answer to these questions will depend on many factors, especially, on the degree to which reduction of water demands will lead to the alteration of the long-term plan for acquiring new supplies and expanding or improving the existing water supply system.

Therefore, a complete evaluation of water conservation (or demand management) alternatives cannot be performed without a reliable long-term forecast of water use in the service area and an explicit water supply/wastewater disposal plan for the planning period. These two pieces of information will determine the benefits of water conservation derived from the elimination of new supplies; the elimination, postponement, or downsizing of planned expansions of water transmission, treatment, and distribution facilities; and the elimination, postponement, or downsizing of planned expansions of wastewater collection and treatment facilities.

ANALYTICAL STEPS

The analytical steps of **Part I** of this manual provide for a systematic screening of the universe of conservation measures in order to identify the potentially most promising practices to be evaluated as part of pilot or full-scale programs. The steps also provide procedures for developing a reliable water use forecast and for performing an economic evaluation of water conservation alternatives.

The knowledge of water uses in the service area offers the most valuable guidance in the initial screening of conservation measures. In order to be effective, the specific conservation measures must first address water uses that take place in the service area. Second, the targeted uses must show the potential for improvements in efficiency of water use. Third, the share of the targeted use in total water consumption must be known. Such determinations can be made based on the results of **Step 1.**

Step 2 describes methods for preparing a disaggregate forecast of water use under some baseline conditions (with existing conservation measures, at current price levels, etc.). The baseline forecast of average-day and maximum-day water demands will determine the need for expanding supply sources and facilities and identify opportunities for conserving water.

Once measures are selected to address the various uses of water that exist in a specific service area (i.e., applicability), they must be screened using technical feasibility, social acceptability, and potential effectiveness (i.e., the ability to produce a water savings) as criteria. **Step 3** describes procedures for assessing the potential effects of each measure. It is important to emphasize that such an initial screening must be based on a broad range of assumptions. Some measures may be included in conservation programs not because they pass the criteria of preliminary analysis but because their effects are critically dependent on some assumptions that need to be tested in the field.

Step 4 presents procedures for the economic evaluation (benefit-cost analyses) of water conservation measures. The first component of this step is the formulation of feasible (i.e., implementable) conservation programs. Potential costs and benefits of implementing conservation programs are identified, and alternative economic methods of evaluating programs are presented. This step also addresses the economic evaluation of conservation alternatives from different accounting perspectives.

The purpose of **Step 5**, the final step in the planning phase, is to compare conservation alternatives with water supply projects in order to select an optimal combination of alternatives. The optimal water management plan for a given community or water agency should be determined according to the same principles, standards, and criteria employed for other aspects of water resources development planning.

As indicated for **Step 3**, much of the preliminary analyses are dependent upon assumptions regarding the potential effectiveness (i.e., water savings) of conservation measures. Each water conservation measure or program which is field tested (evaluated) according to procedures outlined in **Part II** of this manual can be reanalyzed through the planning procedures outlined in **Part I.** If a conservation measure or program evaluated in **Part II** was a pilot program, the program can be expanded and/or modified and then fully evaluated in **Part I** as a full-scale water conservation alternative.

STEP 1. ANALYZE WATER USE AND SERVICE AREA DATA

OBJECTIVES

(1) To obtain and analyze current and historical service area data on climate, population, housing stock, economic activities, and current conservation practices

(2) To disaggregate total water use (i.e., total production or delivery) into major user sectors

(3) To disaggregate water use in each sector into specific purposes of use (i.e., significant end uses)

(4) To characterize the weather induced variability of aggregate and sectoral demands throughout the year

In order to develop water conservation programs, a water conservation planner must be familiar with the types and patterns of water use that occur within the water service area. The knowledge of historical and current water use is required to identify customer groups or end uses of water that show the greatest potential for improvements in water use efficiency. Water use in the service area can be characterized with respect to the relative needs of various customer groups (e.g., single-family residential, hotels, food processing plants), the purposes for which water is used (i.e., end uses such as sanitary needs, lawn watering, cooling), and the seasonal variations in water use.

The analysis of water use should be expanded to also include the development of information on water users in the service area. Data on housing stock, household characteristics, business establishments, and other demographic and economic statistics are required for proper design and implementation of water conservation programs. These types of information are important because socioeconomic characteristics are major determinants of water use.

Also, the knowledge of the existing conservation measures brought about by passive programs (such as plumbing fixture codes) or market trends is very critical in water conservation planning. These passive conservation measures may partially or completely preempt some conservation alternatives and enhance the attractiveness of other conservation opportunities.

This type of information allows the development of conservation programs that best target the water use sectors and the end uses of water that occur in the area. This chapter discusses the types of information that are useful in water conservation planning and identifies potential sources of information.

SERVICE AREA DATA

Because water use is a function of demographic, economic, and climatic factors, an accurate description of the characteristics of the resident population, housing stock, economic activities, and weather patterns in the service area can serve as a basis for many conservation planning activities. The following sections discuss the types of information that can be used to characterize the service area and identify potential data sources.

Multilayer Service Area Maps

Accurate maps of the service area are indispensable. Oftentimes, water service areas do not follow political (i.e., city or county) boundaries. However, demographic and socioeconomic data are most readily available by political boundaries or by census-designated boundaries (i.e., census tracts). Therefore, in order to relate water service area data with demographic and socioeconomic characteristics for planning purposes, it is often necessary to determine the relationship between service area boundaries and political or census-designated boundaries. A service area map with overlays for census tract, zip code, or other political boundaries are most useful for this purpose.

Service area maps with geographic or land use overlays have usefulness in many other planning activities. For example, only parts of the service area may be targeted for specific activities (e.g., the service area might be spatially disaggregated into pressure zones or rate zones for the purpose of water use forecasting and/or facility planning). In some instances, only a part of the service area may be targeted for a particular water conservation program.

Usually, a set of maps can be obtained from the facility planning or engineering department of the water agency. These maps should indicate the historical growth of the service territory and potential future additions. Also, the maps should note areas within a given community that are partially served or are served by other water supply agencies. Maps denoting political boundaries and demographic characteristics can often be obtained from local and regional planning agencies.

Mapping work could be greatly simplified by GIS (Geographic Information Systems) technology, which is a computerized mapping technique. The GIS system may have the service area divided into separate units (e.g., census tracts, pressure zones) and have several information bases about each separate unit (e.g., water use characteristics, land use, socioeconomic characteristics).

Population and Housing Characteristics

Population and housing/household characteristics (i.e., household income, lot size, persons per household, home value) are determinants of residential water use. Therefore, it is important to obtain information on these characteristics as well as to understand their impact on water use. The effects of the major determinants of water use have been extensively researched and reported in water resource literature.

The conventional method of estimating "population served" by multiplying "total service connections" by "persons per connection" is not very accurate. Although this method may be acceptable to estimate the population served in the residential sector (assuming an accurate measurement of persons per connection), this is not an accurate method for total service area population served because of the confounding effect of commercial, institutional, governmental, and industrial accounts.

Knowledge of the number and type of housing units in the service area is very useful for water conservation planning. Conservation programs typically target single-family and multifamily housing groups separately. One reason for this is that water use patterns differ among housing types. On both a per housing unit and a per capita basis, water use in the multifamily sector tends to be lower than in the single-family sector. This is the result of different household composition and the fact that residents in multifamily housing, on a per unit basis, has less opportunity for outdoor water use practices. Another reason that conservation programs typically target housing types separately is that program implementation may differ among housing types.

The total number of residential accounts served by a water supply system is not a good indication of the number of housing units in the service area because of the varying number of units served by multifamily accounts. However, the number of single-family customer accounts is typically a good indication of the number of single-family housing units served by the water system. Unless the water agency maintains records on the number of multifamily living units per multifamily account, housing count data must be obtained from secondary sources.

More accurate estimates of population and housing units in the water service area can be obtained by using the demographic data developed and/or maintained by:

(1) U.S. Bureau of the Census
(2) California Department of Finance
(3) Regional associations of governments
(4) Local county and city planning agencies

Again, deviations of the water service boundaries from political boundaries must be considered when using these data. In addition to population and housing counts, some of the agencies listed above can also provide data on population characteristics (e.g., family size, age, income) and data on local housing (i.e., number of homes by type, new construction permits, vacancy rates, etc.). Table 1-1 gives examples of demographic and housing data that are included in the 1990 census files. Two primary questionnaires were used in the collection of census data: the short-form which included questions that were asked of all persons and housing units (i.e., the 100 percent component) and the long-form which targeted only about 20 percent of the population on additional subject items (i.e., the sample component). These data are presented by geographic and political subdivisions (i.e., states, counties, cities). For major urban areas, census data are further disaggregated into census tracts, city blocks, and block groups (but not for individual dwellings).

Commercial/Institutional and Industrial Activities

There is a great diversity of purposes for which water is used in the commercial/institutional and industrial (manufacturing) sectors of a water service area. The uses of water may include sanitary, cooling and condensing, boiler feed, landscape irrigation, and others. The type of business activity conducted in a commercial and industrial establishment can provide useful information regarding the purposes for which water is used and therefore the types of conservation measures that might be applicable. Furthermore, data on square feet of floor space, land acreage, number of employees, number of rooms (for hotels/schools), and financial performance can also be useful information in predicting commercial and industrial water use. However, some of this information is not readily available for individual establishments or aggregated into political/census-designated boundaries. Some of the previously listed agencies maintain data on local economic activities including the number of establishments, employment, and financial performance of businesses (e.g., sales) disaggregated by industry type as denoted by the Department of Commerce Standard Industrial Classification (SIC) codes.

Additional establishment or employment data can be obtained from local and regional planning commissions, local chambers of commerce, or purchased from private firms. Some private vendors (e.g., Dun's Marketing Services, Contacts Influential) can provide water agencies with customized computer databases containing information on large samples of businesses in their service area. Establishment and employment data can be analyzed to determine types of business establishments that represent a major portion of nonresidential water use either because of large employment or because of large water requirements for processing or other needs. Business types can be cross-checked with agency billing records and used for targeting conservation programs to specific groups of nonresidential users. As an additional resource, the California Department of Water Resources (1973, 1978, 1982) has published data on employment and water use in manufacturing industries. Furthermore, the California Urban Water Agencies recently completed a survey of manufacturing industries in California to determine industrial water use patterns and the extent of adopted conservation (Spectrum Economics, 1991).

TABLE 1-1
SELECTED EXAMPLES OF CENSUS DATA

Population	Housing
100 Percent Component	
Household relationship	Number of units in structure
Sex	Number of rooms in unit
Race	Tenure (owned or rented)
Age	Value of home or monthly rent paid
Ethnic/racial origin	Congregate housing (meals included in rent)
	Vacancy characteristics
Sample Component	
Social characteristics:	
Education	Year moved into residence
Ancestry	Number of bedrooms
Migration	Plumbing and kitchen facilities
Language spoken at home	Telephone in unit
	Heating fuel
Economic characteristics:	Source of water and method of sewage disposal
Labor force	Year structure built
Place of work and journey to work	Condominium status
Year last worked	Farm residence
Occupation, industry, and class of worker	Shelter costs, including utilities
Work experience in 1989	
Income in 1989	

Public and Government Facilities

Water used in parks, cemeteries, school playgrounds, and highway medians can account for a significant portion of total use and offer a potential for conservation. Data on public and government facilities can be obtained from city and regional planning departments, city park districts, street departments, and the Department of Transportation (for highway medians). Information that might be obtained include land use data for various purposes (in square feet or acres) as well as the number of employees in various facilities.

Population and Economic Growth Projections

Projections of demographic and socioeconomic characteristics for the service area together with service area expansion plans can influence the selection of conservation measures. Conservation planners may target those urban sectors, business types, or geographic areas that are expected to have the highest growth. Important projections for benchmark years of the planning horizon may include:

(1) Total population
(2) Number of occupied housing units by type
(3) Total employment
(4) Employment by major industry sector
(5) Median household income
(6) Land use
(7) Other growth parameters

These projections can be obtained from state and local governments or planning agencies.

Current Conservation Activities

When assessing the potential for water conservation in the water service area, it is necessary to have knowledge about conservation practices that are already occurring in the service area. Conservation practices already implemented in the service area may partially or completely preempt implementing new conservation alternatives and/or enhance the attractiveness of other conservation opportunities. Existing conservation practices may be the result of previously implemented programs or passive programs (such as plumbing fixture codes) and market trends (i.e., low-flow plumbing fixtures). Furthermore, it is also essential that water conservation planners understand the factors that may affect the adoption of conservation measures such as:

(1) Socioeconomic characteristics
(2) Perceived need for conservation
(3) Perceived effectiveness of conservation measures
(4) Perceived economic benefits of conservation measures
(5) Perceived efficacy of conservation measures (i.e., belief that individual efforts can produce the desired effects)
(6) Perceived inconvenience and cost of adjustments from conservation measures
(7) Perceived equity of conservation measures

Information on the current conservation efforts and attitudes of customers in the water service area can be obtained by various means including survey research (telephone, mail, or personal interviews) or by conducting public meetings or focus groups. In addition to survey methods for assessing the level of conservation current conservation practices, water audits can be conducted to verify the installation of conservation devices or appliances or the modification of existing water-using equipment. The water audits would involve site visits to a sample of customers in a given urban sector and the visual inspection of plumbing, appliances, or other water-using equipment. An alternate approach to randomly selecting a sample for the audits would be to conduct water audits during the resale (new sale) of property. Methods for assessing the market penetration of conservation measures will be addressed further in **Steps 2 and 6** of this manual.

SOURCES OF WATER USE DATA

A disaggregation of total urban water use into seasons, sectors, and into specific end-uses within each sector can serve as a basis for selection and evaluation of potential water conservation measures. Various types of water use data can be used as an information base for targeting water conservation programs and for conducting impact evaluations of implemented programs. The following sections describe the types of water use data that can be obtained from water supply agency records.

Water Production Records

Water utilities usually have one or more production meters that are generally read at least daily. These production meters are typically maintained for accuracy and therefore usually produce highly reliable measurements of water flows into the distribution system. The water treatment plants or pumping stations usually employ continuous metering of the flow of finished water to the distribution system. The data may be recorded on paper recording charts which can be used to generate a time series of total production (or production from various supply sources) at daily or hourly time intervals. These data can be used for deriving temporal characteristics of aggregate water use (e.g., peak-day, peak-hour, day-of-week). The usefulness of the production data for water conservation analysis may include, but is not limited to (1) the analysis of unaccounted water use (comparing production with water sales data), (2) the measurement of the aggregate effect of emergency conservation campaigns on water use, and (3) the analysis of the relationship between water production and weather variability.

Customer Billing Data

Typically, retail water agencies maintain individual computer records of monthly, bimonthly, quarterly (or, less often, semiannual or annual) water consumption records for all metered customers. Active computer files usually retain up to 12 or 15 past meter readings for each customer. Depending on the length of the billing cycle, the active file records can contain a 12-month to 36-month history of water use. This is a valuable source of water use data that is often not exploited to its full potential. However, billing data can suffer from the following problems:

(1) Unequal billing periods
(2) A lack of correspondence between billing periods and calendar months
(3) Estimated meter readings or incorrect meter readings due to meter misregistration
(4) Unusual usage levels
(5) Meter replacements and manual adjustments to meters
(6) Changes in customer occupancy

Because of these problems, sole reliance on customer billing records necessarily limits the usefulness of these data for various measurements. Although billing data are becoming more readily available on electronic media, this is still not routine with many utilities.

Special Metering

In recent years, water utilities have begun to experiment with new meter-reading technologies that greatly reduce the cost of monitoring water use of individual customers. However, the initial investment costs of adopting these new technologies can be prohibitively high. The new technologies include automatic meter-reading (AMR) devices and electronic remote meter-reading (ERMR) devices (see Schlenger, 1991). Automatic meter-reading devices are carried by meter readers on their routes and plug into the site meters for the automatic meter reading. The data from the automatic meter readings are stored in the AMR and then can be downloaded to central computer systems. The electronic remote meter-reading devices can be used to read site meters without actually visiting the meter location. Various methods of remote meter reading include:

(1) Telephone dial-outbound
(2) Telephone dial-inbound
(3) Telephone scanning

(4) Cable television
(5) Radio frequency
(6) Power-line carrier

These new technologies may permit water agencies to obtain daily or weekly meter readings from individual accounts. More frequent readings can improve the precision of water use measurements. However, the most useful measurements can be obtained by devices that monitor individual pulses of water use on the service line. These pulses can be correlated with water flows through individual fixtures and appliances on customer premises (toilet flushes, shower flows, etc.) thus permitting accurate measurements of all end uses of water.

Currently, these new technologies are used only by a few water agencies. However, as the technology becomes more frequently adopted, there is great potential for new information sources for water conservation planning. Unobtrusive metering technologies that permit accurate measurements of end uses of water would be particularly useful for water conservation planning.

Customer Class Data

It is usually very helpful to determine the distribution of total water use by major sectors of urban users. For example, a recent study (Dziegielewski et al., 1990a) found the following disaggregation of annual water use by urban sectors in Southern California:

Residential	59%
Single-family	34%
Multifamily	25%
Commercial	19%
Industrial	6%
Public and other (parks, highway medians)	7%
Unaccounted	9%
	100%

These distributions may vary from city to city depending on demographic and economic characteristics. Table 1-2 gives examples of sectoral disaggregation of total metered use for selected cities in California. Although the sectoral distribution of water use in this example varies from city to city, on average about 60 percent of total urban use (i.e., production) is residential and 30 percent is nonresidential (including commercial, industrial, public, fire protection, and other uses). Unaccounted use represents, on average, slightly less than 10 percent of total water production.

TABLE 1-2
EXAMPLES OF SECTORAL DISAGGREGATION OF MUNICIPAL AND INDUSTRIAL WATER USE IN SELECTED CITIES (PERCENT)

City	Single-Family Residential	Multi-Family Residential	Total Residential	Commercial	Industrial	Public/ Fire/ Irrigation	Total Non-Residential	Unaccounted and Others
Anaheim	35.0	19.4	54.4	11.1	25.7	8.8	40.3	5.3
Burbank	-	-	59.7	21.0	9.3	2.8	33.1	7.2
Chula Vista	49.8	23.7	73.5	13.0	1.3	6.7	21.0	5.5
Fullerton	40.9	14.1	55.0	16.1	19.2	3.1	38.4	6.6
Los Angeles	34.6	27.6	62.2	17.8	4.2	6.9	28.9	8.9
National City	38.7	27.2	65.9	20.9	1.2	6.5	28.6	5.5
Oakland	40.7	13.8	54.6	14.4	15.2	6.9	36.6	8.8
Orange	47.5	14.3	61.8	21.8	1.9	9.5	33.2	5.0
Santa Monica	20.7	46.8	67.5	15.0	3.2	3.6	21.8	10.7
South Gate	-	-	65.7	15.6	10.1	2.8	28.5	5.8

A disaggregation of total metered use into major user sectors (such as residential, commercial, industrial, and others) can be developed from customer billing records by using one of the following four methods:

(1) Analysis of available premise (user-type) categories
(2) Distribution of meter sizes
(3) Sampling of billing files
(4) Development of premise code data

A brief description of advantages and disadvantages of each method is given below.

Customer Premise Categories

If individual customer files contain codes identifying the type of customers, then a simple computer program may by used to produce annual billing summaries by customer type. Table 1-3 shows examples of premise codes used by the City of San Diego Water Utilities Department and the Phoenix Water and Wastewater Department. The table also illustrates how to assign each premise code to various homogeneous sectors of water users. For conservation planning, the major user sectors may be defined as:

(1) Single-family residential
(2) Multifamily complexes and apartment buildings
(3) Commercial sector
(4) Government and public sector
(5) Manufacturing (industrial) sector
(6) Unaccounted uses

These sectors can be further disaggregated depending on the design aspects of water conservation programs.

Distribution of Meter Sizes

In cases where the customer billing file does not contain premise code (or customer-type) information, an approximate separation of users by residential, commercial, and industrial categories can be performed based on meter size with a manual classification of the largest users. For example, single-family homes and small business are usually serviced by 5/8-inch or 3/4-inch meters. The problem with this method is that some meter sizes, particularly the larger meter sizes (e.g., 1-inch) may overlap several customer types thus decreasing the precision of possible disaggregation of water use into customer types.

TABLE 1-3
EXAMPLE OF CUSTOMER PREMISE CATEGORIES

San Diego Water Utilities Department User Type Code	San Diego Water Utilities Department Description	Phoenix Water and Wastewater Department User Type Code	Phoenix Water and Wastewater Department Description
Single-Family			
01	Single-family dwellings	01	1-family residence
Multifamily			
02	Other domestic	10	2-family residence
08	Trailer parks	11	1-family, 1 commercial
		20	2 1-family residences
		21	3-family residence
		22	2-family, 1 commercial
		23	1-family, 2 commercial
		26	Apartment
		30	3 1-family residences
		40	Trailer courts
Commercial			
03	Commercial	02	1 commercial unit
07	Motels/hotels	04	Schools
09	Combined business and domestic	05	Institutions
30-33	Colleges and universities	06	Churches
60-63	Elementary and high schools	12	2 commercial units
74	Community colleges	24	3 commercial units
71	San Diego Zoo	25	Offices, 4 stores
		31	Laundries/commercial
		32	Car washes
		33	Offices/banks
		37	Restaurants/bakeries
		38	Service stations/auto repair
		45	Hotels/motels
		46	Laundries, self-service
		47	Mortuaries

TABLE 1-3 (Continued)
EXAMPLE OF CUSTOMER PREMISE CATEGORIES

San Diego Water Utilities Department User Type Code	Description	Phoenix Water and Wastewater Department User Type Code	Description
	Government		
10-19	Naval facilities	03	Government
20	U.S. Marine Corps	50	City offices
21	U.S. Coast Guard	60	Federal buildings
22	U.S. Post Office	83	Sewer and sanitation
23	Other federal agencies		
40-49	San Diego Park Division		
50-58	City facilities		
	Manufacturing		
04	Industrial	07	Heavy industrial
		36	Platers
		77	Ice producers
		39	All others
	Other		
05	Outside city services		
06	Wholesale customers		
80	Irrigation		

Sampling of Customer Billing Files

In cases where water use data by customer class are not available and the distribution of water use by meter sizes produce unreliable estimates of water use by customer class, disaggregation can be accomplished by taking a random sample of customer accounts. The number of accounts in the sample (i.e., sample size) will depend on the desired accuracy of water use in different customer classes. Sampling efficiency (or precision) can be improved by taking a stratified random sample of users with complete enumeration of the large water-using customers. (See the Introduction to **Part II** of this manual for a discussion of sampling procedures and determination of sample sizes.) Possible stratified sampling procedures include:

(1) Taking a random sample of customer accounts from each meter-size category (sample size within each stratum can be proportional to the total water use within each stratum)

(2) Using the same approach as in (1) except excluding the upper strata (e.g., meter sizes greater than 2 inches) from the sampled population and performing complete enumeration of the largest users

(3) Separating all accounts into two categories based on meter size, with the smallest meter sizes representing the residential sector and the remaining meters representing the nonresidential sector, and then taking a random sample from each category

The samples of the customer accounts can then be manually assigned into customer classes by visual inspection of customer record (account name) and/or by telephone verification of customer accounts. Depending upon the sample sizes, this can be a time- and resource-intensive exercise.

Regardless of which sampling approach is selected, analysis of the sample should produce the following two estimates:

(1) Proportion (or percent) of total customers by customer class
(2) Proportion (or percent) of total metered water use by customer class

It is also desirable to calculate the precision of the estimates based on the sample variance.

Development of Premise Code Data

If sufficient time and resources are available, the classification of all customer accounts into appropriate user types is a worthwhile undertaking. The classification would require performing the following operations:

(1) Add a data field (or using existing unassigned fields) to the customer computer file.
(2) Develop a set of nonoverlapping customer classes and precisely define each class.
(3) Determine customer class for each existing customer.
   (a) Train meter readers on how to distinguish among various customer types and classify all customers during meter-reading cycles.
   (b) Survey (independently) all customers and request them to classify their premises on water bills.

(4) Add customer classification categories to the application forms for new connections.

SEASONAL COMPONENTS OF WATER USE

When developing conservation programs, it is important to have knowledge about the magnitude of seasonal fluctuations in water use within the service area. For example, if the goal of a conservation program is to reduce summer (or peak-day) water use, sectors and activities that strongly contribute to the increased summer use (or peaks) should be targeted. Knowledge about the components of seasonal water use (i.e., relative contribution from sectors as well as end uses) will permit better targeting of those activities that strongly contribute to seasonal variations and will aid in deriving preliminary estimates of water savings that might result from implementing a given conservation program.

Seasonal and Nonseasonal Uses

Within each user sector, water use can be separated into its seasonal and nonseasonal components. Seasonal use can be defined as an aggregate of end uses of water, such as lawn watering or cooling, that varies from month to month in response to changing weather conditions (or due to other influences that are seasonal in nature). Nonseasonal use, on the other hand, can be defined as an aggregate of end uses of water, such as toilet flushing or dishwasher use, that remain relatively constant from month to month because these uses are not sensitive to weather conditions or other seasonal influences. Knowledge of the seasonal variations in water use and the factors that affect these variations within a given service area are essential for targeting and then assessing the effectiveness of conservation programs.

Outdoor and Indoor Uses

Often, seasonal and nonseasonal components of water use are taken to represent the outdoor (or exterior) and indoor (or interior) water uses, respectively. Such an assumption is imprecise because some uses that occur inside the house can be seasonal (e.g., humidifier use or evaporative cooler), and some outdoor uses can be nonseasonal (e.g., car washing in warmer climates). The difficulties in classifying end uses into outdoor and indoor categories must be kept in mind when water use is divided into seasonal and nonseasonal components.

Estimation of Seasonal Components

Monthly billing records can be used to derive estimates of seasonal and nonseasonal water use in each major urban sector. The terms "seasonal" and "nonseasonal" relate to the method of characterizing a monthly time series of water use records. This method is sometimes referred to as the "minimum-month" method because it uses the month of lowest use to represent the nonseasonal component of water use in a given user sector. With the minimum-month method, the percent of annual use in a given year that is considered seasonal is calculated from the formula

$$S_P = 100 - (M_P * 12) \tag{1.1}$$

where

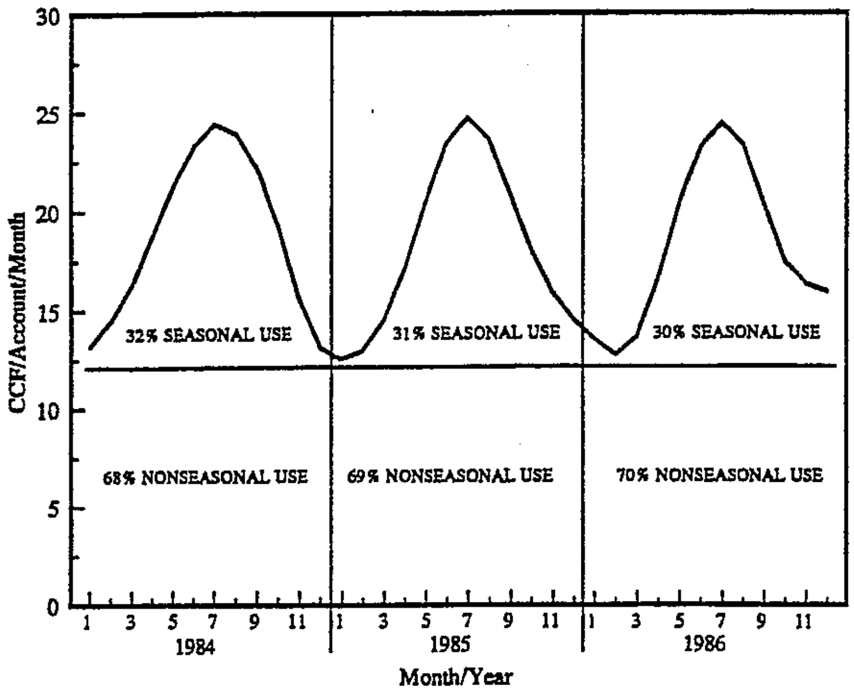
S_P = percent of annual use that is seasonal
M_P = percent of annual use during the minimum-month

It should be noted that this method, without modification, will be inappropriate for agencies that use bimonthly or quarterly billing cycles. Bimonthly or quarterly billing data can be used to estimate monthly water use; however, the accuracy of the seasonal component will be reduced.

Figure 1-1 shows an example of the seasonal and nonseasonal components of residential use obtained using the minimum-month method. For a given year, the nonseasonal use is assumed to be constant during all months and is represented by the area under the horizontal line. The seasonal use is zero (by definition) during the month of minimum use, and it varies with weather conditions during the remaining months. Seasonal water use typically peaks during the months when temperatures are at maximum levels and rainfall is at minimum levels. The relative components of seasonal/nonseasonal water use may vary substantially by geographic area considering variation in demographic/economic characteristics and weather conditions.

As noted previously, there are differences between seasonal and outdoor uses of water. There are three problems associated with translating estimates of seasonal/nonseasonal components into indoor/outdoor components. The first problem may lead to overestimation of outdoor use because indoor uses, such as evaporative cooling, are seasonal and will be included in the seasonal use estimates that are derived if the minimum-month method is used. Furthermore, it has been found that some indoor uses such as bathing and clothes washing may increase during the hotter summer months.

FIGURE 1-1
SEASONAL AND NONSEASONAL WATER USE



The second problem is more serious and it may lead to underestimation of seasonal use. By definition, the minimum-month method uses the month of lowest use to represent the nonseasonal component of use in a given user sector. However, since seasonal uses of water can occur during any month of the year, the minimum-month method of calculating seasonal use may underestimate outdoor use and therefore, overestimate the indoor use. The third problem arises when aggregate monthly consumption records are used to identify the minimum-month use. These "monthly" records do not necessarily represent water consumption that occurs in any given calendar month; rather, they tend to represent the amount of water billed for during any given calendar month. The billing records must be adjusted prior to the analysis of seasonal effects.

Seasonality of Sectoral Uses

Based upon water use data from urban areas in Southern California, Table 1-4 shows an example of seasonal disaggregation of urban water use together with the major components of outdoor use. Residential water use is highly seasonal (i.e., it changes from month to month) because it includes some end uses that are sensitive to changes in weather. The major portion of seasonal use in this sector is attributed to landscape irrigation. Other seasonal uses include water use for swimming pools and car washing. Another activity that may potentially cause

TABLE 1-4
EXAMPLE OF SEASONAL DISAGGREGATION OF URBAN WATER USE IN SOUTHERN CALIFORNIA

	PERCENT RANGE OF TOTAL ANNUAL USE						
					Approximate Components of Outdoor Use		
User Sector/Subsector	Nonseasonal (Base Use)	Seasonal (Peak Use)	Indoor Use	Outdoor Use	Irrigation	Cooling (AC)	Other
Residential Sector							
Single-family	65-75	25-35	60-70	30-40	25-35	0.0	0-5
Multifamily	80-90	10-20	75-85	15-25	10-20	0-1	1-2
Total residential	70-80	20-30	65-75	25-35	25-30	0-1	1-5
Nonresidential Sector							
Commercial	70-80	20-30	70-75	25-30	15-20	5-10	0.0[a]
Industrial	75-90	10-25	75-90	10-25	10-15	5-10	0.0[a]
Public	30-50	50-70	30-50	50-70	50-60	0.0[b]	0.0[b]
Other	30-60	40-70	30-60	40-70	40-50	0.0[b]	0.0[b]
Irrigation	10-50	50-90	0.0	100.0	100.0	0.0	0.0
Total nonresidential	65-75	25-35	65-70	30-35	27-30	5-10	0.0
Estimates Of Total Urban Use	75	25	72	28	25	2	1

Source: Adapted from Dziegielewski et al. (1990).

[a] Other uses in these sectors are included under landscape irrigation.

[b] Cooling and other uses are included under landscape irrigation.

seasonal variations is the increased frequency of bathing (mainly showering) during the hot summer months.

The seasonal variability of nonresidential uses (commercial, industrial, institutional) results not only from the effects of weather on landscape watering but also from changes in water requirements for space cooling and process cooling. Also, some variability will stem from increased water demands from businesses that are seasonal (e.g., processing of agricultural products, tourism). However, the major component of seasonal nonresidential use is water used by water-cooled air conditioning (AC) systems.

ESTIMATION OF END USES OF WATER

The separation of water use into its outdoor and indoor components can assist the conservation planner in assessing the overall potential for improvements in water use efficiency. For example, it is commonly believed that outdoor use is more discretionary and therefore has a greater conservation potential than indoor use. However, a meaningful assessment of the current efficiency of water use cannot be made without separating indoor and outdoor uses into their various end uses. Furthermore, knowledge about the end uses of water and their relative contributions to water use in the service area would allow conservation planners to more effectively target conservation programs to particular end uses and to make more accurate estimates of potential water savings. Unfortunately, up to now, very few measurements of actual water use for various indoor and outdoor activities have been made. With few exceptions, studies that have aimed at quantifying end uses of water have relied on the infrequent readings of customer meters. Therefore, the separation of total use by residential or commercial customers into indoor and outdoor components had to rely on such estimation techniques as the minimum-month method or was based on customer-reported information about the presence or absence of outdoor water-using activities. Even when a reliable estimate of indoor (or outdoor) use was derived, its further disaggregation into specific end uses had to rely on engineering estimates.

The lack of precise measurements of the quantities of water used for showering, toilet flushing, and other purposes (as well as the substantial variance in water use) are obstacles to the development of reliable estimates of water conservation savings. Engineering estimates of end uses are of limited validity because they tend to rely on a broad range of assumptions, and often ignore the physical and behavioral settings in which water use takes place. The potential error in estimating end uses can often exceed the magnitude of the expected conservation effect.

Improvements in quantifying the significant end uses of water can be achieved in two ways: (1) the actual end uses can be directly measured; and (2) a conditional demand analysis used by electric utilities can be developed to estimate end uses. The following is a description of each approach.

Direct Measurement Methods

In order to measure end uses directly, it would be necessary to install flow-recording devices on each water outlet found on customer premises (see previous discussion on special metering technologies, p. 24). For example, for residential customers it would be necessary to install water meters with automatic recording devices on waterlines connected to all indoor water appliances and fixtures, as well as on outdoor faucets and facilities. A sample of customers in this type of study should be randomly selected and sufficiently large to (1) ensure adequate representation of all customers in the studied user sector (e.g., single-family residential) and (2) achieve an acceptable margin of error in the results. The measurements should be taken for a period of one year in order to adequately characterize seasonal effects as well as the variability of use over time. Obviously, high costs would be incurred with such a research effort.

A less costly (but also less precise) alternative to the direct metering of all uses is to install one metering/recording device on the customer line that would record the pulses of flow (i.e., flow rate and duration). The analysis of such pulses can be calibrated to reveal the flows of water through various fixtures and appliances.

Statistical End-Use Analysis

Electric utilities use a form of econometric analysis, called conditional demand analysis (CDA), for estimating residential unit energy consumption (UEC) coefficients. In the electric utility industry, the method has been documented by Parti and Parti (1980), EPRI (1984), and EPRI (1991). The CDA method uses individual billing consumption data and survey data to derive estimates of consumption by end use.

The CDA theoretical model specification is based on two straightforward assumptions. The first is that the observed customer use in any given month is a summation of uses by all appliances and fixtures. This assumption may be represented by the following identity

$$Q_t = q_{0,t} + \sum_{i=1}^{N} q_{i,t} \tag{1.2}$$

where

Q_t	=	total customer water use in period t
$q_{0,t}$	=	water consumed through a set of unspecified appliances during period t
$q_{i,t}$	=	water consumed through the ith specified appliance during period t

The second assumption of CDA is that water use by each appliance (or fixture) depends upon a set of external factors (e.g., number of persons, price, weather, and others) if the appliance is owned by a household. Water use from the appliance is (obviously) zero if the household does not own the appliance. Hence, we can write the following conditional demand function

$$q_i = f_i\,(X) \tag{1.3}$$

if the *i*th appliance is owned by the household, 0 otherwise

where

X = a vector of external explanatory factors

Equation (1.3) can be written more compactly if we define a dummy variable A_i, that is equal to one for households possessing the *i*th appliance, and zero otherwise. Then

$$q_i = f_i\,(X)A_i; \;\; i = 1...N \tag{1.4}$$

If we assume that water use through the unspecified appliances (q_0) also depends on X, and that this relationship and equation (1.4) are linear, equation (1.2) can be rewritten as

$$Q = \sum_{i=0}^{N} \sum_{j=0}^{M} b_{ij}\,(X_j\,A_i) \tag{1.5}$$

where b_{ij} is the coefficient of the *j*th exogenous variable in the *i*th conditional demand function, and X_0 and A_0 are unity.

A useful feature of the CDA technique is that it can be used to provide econometric estimates of the average water usage levels of individual appliances without the necessity of directly metering end use (which could be costly and quite unrealistic for any large sample or population). The <u>average</u> water use through the ith appliance in a sample of households can be computed as

$$\bar{q}_i = b_{i0} + \sum_{j=1}^{M} b_{ij}\,(\bar{X}_{ij}); \;\; i = 0..N \tag{1.6}$$

where $\bar{X}_{ij}$ are the average values of the M exogenous variables in the households that possess the *i*th appliance. If one assumes that total water use is equal to the sum of average water use of each appliance and the deviations away from this average use, equation (1.5) can be written as

$$Q = \sum_{i=1}^{N} b_{io} A_i + \sum_{i=0}^{N} \sum_{j=1}^{M} b_{ij} \bar{X}_{ij} A_i + \sum_{i=0}^{N} \sum_{j=1}^{M} b_{ij} (X_j - \bar{X}_{ij}) A_i \tag{1.7}$$

or, using equation (1.6)

$$Q = \sum_{i=1}^{N} \bar{q}_i [(A_i)] + \sum_{i=0}^{N} \sum_{j=1}^{M} b_{ij} [(X_j - \bar{X}_{ij}) A_i] \tag{1.8}$$

An ordinary least-squares (OLS) regression method can be used to regress *Q* on the terms in brackets. The estimated coefficients for the appliance dummy variables can be taken to represent average water use through those appliances by households possessing the appliances.

The number of end uses modeled by this technique can vary. However, costs of data collection typically rise with the number of end uses modeled. It may be appropriate to model household water use as the sum of a set of unspecified appliances (indoor water use) and a set of specified outdoor appliances or fixtures such as garden hoses and swimming pools. Water use through the unspecified appliances would depend on explanatory variables such as price, weather, a variety of household socioeconomic characteristics that could be obtained from a household survey. Outdoor water uses would depend on variables such as price, weather, type of landscape, and landscape area. Landscape information could be obtained through either a household survey or a "driveby" type of survey where trained personnel observe and rate the landscapes of sample households.

Besides estimating average appliance end use, the CDA techniques can also be used for estimating water savings resulting from the implementation of a conservation program. This type of CDA application is described in **Step 7** of this report.

RESIDENTIAL END USES OF WATER

As previously mentioned, about 55 to 65 percent of total urban water use in California is for residential purposes. In a recent study of aggregate residential water use data from 28 retail water suppliers in Southern California, it was estimated that about 65 to 75 percent of residential water is used indoors and 25 to 35 percent is used outdoors (Dziegielewski et al., 1990a). Table 1-5 lists a number of residential end uses of water and provides estimates of the most likely end-use shares of total residential use. Toilet flushing accounts for the largest share

TABLE 1-5
RESIDENTIAL END USES OF WATER (SINGLE-FAMILY)

End Use	Percent of Total Use (Likely Range)	Gallons per Person per Day (Likely Range)
Indoor Uses		
Toilet flushing	20-25	15-25
Showering/bathing	15-20	10-20
Washing machine	10-15	10-20
Dishwasher	2-5	0-5
Faucet	5-10	5-20
Evaporative cooler	0-2	0-5
Humidifier	0-2	0-5
Leaks and drips	0-5	0-10
Outdoor Uses		
Lawn and garden watering	25-30	25-35
Swimming pool	0-5	0-5
Car washing	0-5	0-5
Driveway cleaning	0-2	0-2

Sources: Brown and Caldwell (1984), Maddaus (1987), Dziegielewski (1990a).

of indoor residential water use, followed by showering/bathing and washing machine use. In California, lawn and garden irrigation accounts for a significant portion of residential water demand, representing about 25 to 30 percent of total residential use.

The distribution of water use presented in Table 1-5 is likely to vary by housing type. For example, the relative share of total multifamily use for outdoor purposes is expected to be smaller than in the single-family sector because there is typically less landscapable area per multifamily housing unit.

Actual measurements of residential end uses of water are sparse. A study conducted by Brown and Caldwell (1984) for the U.S. Department of Housing and Urban Development (HUD) actually measured end uses such as showering frequency and duration, toilet flushing, and washing machine use. This study collected data on end uses from 200 households around the country. The East Bay Municipal Utility District in Northern California has also conducted some end-use monitoring studies. Table 1-6 provides likely ranges of engineering parameters for estimating residential end uses of water.

TABLE 1-6
ENGINEERING PARAMETERS FOR ESTIMATING RESIDENTIAL END USES OF WATER

Parameter Definition	Units	Likely Range of Average Values
Indoor Uses		
Average household size	Persons	2.0 - 3.0
Frequency of toilet flushing	Flushes/person/day	4.0 - 6.0
Flushing volumes	Gallons/flush	1.6 - 8.0
Fraction of leaking toilets	Percent	0 - 30
Showering frequency	Showers/person/day	0 - 1.0
Duration of average shower	Minutes	5 - 15
Shower flow rates	Gallons/minute	1.5 - 5.0
Bathing frequency	Baths/person/day	0 - 0.2
Volume of water	Gallons/bath	30 - 50
Washing machine use	Loads/person/day	0.2 - 0.5
Volume of water	Gallons/cycle	45 - 50
Dishwasher use	Loads/person/day	0.1 - 0.3
Volume of water	Gallons/cycle	10 - 15
Kitchen faucet use	Minutes/person/day	0.5 - 5.0
Faucet flow rates	Gallons/minute	2.0 - 3.0
Bathroom faucet use	Minutes/person/day	0.5 - 3.0
Faucet flow rates	Gallons/minute	2.0 - 3.0
Outdoor Uses		
Average lot size*	Square feet	5,000 - 8,000
Average house size*	Square feet	1,200 - 2,500
Landscape area*	Square feet	4,000 - 5,000
Fraction of lot size in turf*	Percent	30 - 50
Water application rates*	Feet/year	1-5

TABLE 1-6 (Continued)
ENGINEERING PARAMETERS FOR ESTIMATING RESIDENTIAL
END USES OF WATER

Parameter Definition	Units	Likely Range of Average Values
Percent of homes with pools	Percent	10 - 25
Pool evaporation losses	Feet/year	3 - 7
Frequency of refilling pools	Five years	1 - 2
Frequency of car washing	Times/month	1 - 2

Sources: Brown and Caldwell (1984), Boland et al. (1990), Dziegielewski (1990a).

* Reflects single-family averages.

NONRESIDENTIAL END USES OF WATER

It is estimated that about 30 percent of total urban use in California is for nonresidential purposes (i.e., commercial, industrial, public, and other) and that about 10 percent is attributable to unaccounted losses. Table 1-7 provides examples of nonresidential end uses of water. It is apparent that the shares of nonresidential end uses will vary considerably by business type and among communities. In targeting the nonresidential sector for conservation measures, it is necessary to determine the relative share of the major end uses of water. It is for this reason that many conservation measures targeting the nonresidential sector are implemented on an establishment by establishment basis (e.g., nonresidential water audits).

TABLE 1-7
EXAMPLES OF NONRESIDENTIAL USES OF WATER

Sector	End-Use Category
Commercial/Institutional	
	Sanitary use by patrons, general public
	Sanitary use by employees
	Food preparation (kitchen use)
	Cleaning indoor
	Cleaning of driveways and parking lots
	Indoor swimming pools
	Boiler feed
	Air conditioning (cooling towers)
	Process water (inputs to goods and services)
	Landscape irrigation
	Fountain and water features
Industrial	
	Sanitary use by employees
	Process water
	Cooling and condensing
	Cleaning indoor
	Cleaning of driveways and parking lots (dust control)
	Boiler feed
	Landscape irrigation
Public	
	Irrigation of public parks and medians
	Public fountains
	Public swimming pools filling and make up
	Air conditioning (cooling towers) for public facilities
Unaccounted	
	Leakage
	Meter slippage
	Hydrant flushing
	Major breaks
	Fire fighting
	Unmetered customers
	Illegal connections
	Street washing
	Water theft

STEP 2. PREPARE BASELINE WATER USE FORECASTS

OBJECTIVE

(1) To prepare a disaggregate long-term forecast of water use

CHOOSING A FORECASTING METHOD

The level and pattern of municipal water use (both spatial and temporal) are determined by demographic, socioeconomic, and climatic characteristics of the water service area. These may include:

(1) Resident and seasonal population
(2) Number, market value, and types of housing units
(3) Employment in service industries
(4) Manufacturing employment and output
(5) Water and wastewater prices and rate structures
(6) Irrigated acreage in residential and commercial/institutional use
(7) Personal income
(8) Climate (i.e., arid or humid)
(9) Weather conditions
(10) Water-using appliances
(11) Conservation activities

The forecasts of future water requirements and use are linked to the future values of these water use determinants.

Future water use may be projected by any number of methods, depending on the availability of data. These methods include the use of judgment, consensus, simple extrapolation, shift-share analyses, multiple regression methods, simulation models, and other techniques. In general, water use forecasting methods translate changes in projected values of one or more of the above explanatory variables into changes in future water use. Available forecasting methods make various assumptions regarding the number and type of explanatory variables, the nature of the relationship between explanatory variables and water use, and the way in which the relationship may change over time. Several methods of water use forecasting are discussed in the following sections.

Time Extrapolation

Time extrapolation of water use data is based on the assumption that future water use is determined by water use trends in the past; no other data or information need be considered. Usually, the change in water use over time is extrapolated into the future. The extrapolation may be accomplished by graphical or mathematical means, and the change over time may be assumed to follow a linear, logarithmic, exponential, or other function.

Single Coefficient Requirements Methods

The per capita requirements approach estimates future water use as the product of projected service area population and a projected value of per capita water use. The per capita water use coefficient may be assumed to be fixed over time or may itself be dependent on a projection of how per capita water use is expected to change. Its value and, when applicable, rate of change may be determined from past water use patterns in the study area, from data for other areas, or from national data. The per capita water use coefficient may also be obtained from reference works, or it may simply be assumed.

A variant of the per capita requirements approach is the per customer (or per connection) requirements method, which substitutes the number of customers for the resident population. This reflects the empirical fact that water use is better correlated with number of customers than with population served. Per customer methods are most frequently used in conjunction with sectorally disaggregate forecasts, where they may be applied to nonresidential sectors.

Other single coefficient methods are based on a range of parameters. Industrial water use is commonly forecast on a per employee basis, for example, while specific categories of commercial and industrial water use are frequently expressed as a (single coefficient) function of other variables, such as number of hospital beds, hotel rooms, etc. A study of water use at military installations used single coefficient methods to express water use for each of a number of use categories as a function of the floor area of buildings in that category (Langowski, 1984).

Multiple Coefficient Requirements Models

Future water use, either aggregate or by sector, can be expressed as a mathematical function of two or more explanatory variables. The functional form of the model is chosen to provide an acceptable fit to historic data, and the coefficients are estimated statistically, usually by multiple regression analysis. Models that do <u>not</u> include the price of water, or other economic factors, as an explanatory variable are known as requirements models (since they imply that water use is an absolute requirement, unaffected by economic choice). The variables are chosen because of past <u>correlation</u> (or relation) with water use, and any number may be included, although more than five or six is unusual. Multiple coefficient models used in forecasting are typically estimated from historic data for the same study area, or based on data for one or more other study areas, a larger region, or the nation.

Multiple Coefficient Demand Models

Multiple coefficient demand models differ from multiple coefficient requirements models in one key respect: demand models include the price of water to the user as an explanatory variable, as well as related economic variables such as income. Also, demand models are usually constructed according to econometric methods, where the structure of the model and the list of potential explanatory variables reflect assumptions regarding causality, rather than simply arising from observed correlation. The possibility of misspecified variables is, therefore, reduced. Attention is usually given to specifying an exhaustive set of all possible explanatory variables, thus minimizing the unexplained variance in the dependent variable (i.e., water use).

Disaggregate Water Use Forecasts

Disaggregate water use forecasting separately specifies water use for each sector (residential, commercial, etc.), season (e.g., summer, winter, and annual), or region, utilizing the best available model for each type of water use. This method permits the use of explanatory variables unique to a given type of water use and generally yields a more accurate forecast of total water use.

FORECASTING RESIDENTIAL WATER USE

Among the factors that have been found to influence the demand for water, it is possible to distinguish those that determine long-run influences on water demand and those that affect the responsiveness of short-run demand. Table 2-1 shows factors that are known to affect urban residential demand. Water use in a residential building will depend upon the number of residents and the presence of water-using appliances, fixtures, and facilities. However, for a given set of water-using fixtures and/or activities, water use in the short run will increase with increasing income and decrease with increasing conservation activity and price. Income (or as a surrogate, home value) measures the consumer's ability to pay for water. Conservation behavior reflects the consumer's willingness to substitute inconvenience or technological innovations for water. Finally, price of water (including the price charged for wastewater disposal) determines the amount of water the consumer is willing to purchase.

TABLE 2-1
TYPICAL DETERMINANTS OF RESIDENTIAL WATER USE

Long-Run Demand Response Variables	Short-Run Demand Response Variables
Standard of living	Household income
Persons per household	Water price
Housing type	Rate structure
Irrigable landscape area	Conservation practices
Water-using appliances	Precipitation
Plumbing fixtures	Air temperature
Swimming pools	Evapotranspiration rate
Evaporative coolers	

In water use modeling, the relationship between each determinant (independent variable) and water use (dependent variable) can be expressed as an elasticity, which indicates the percent change in water consumption expected as a result of a 1 percent change in the independent variable. For example, if the demand elasticity for the price of water is -0.25, then a 1 percent increase in the price of water would cause water consumption to fall by 0.25 percent. The relationship is said to be inelastic if the elasticity is less than one (in absolute value) and elastic if the elasticity is greater than one. The effects of the major determinants of residential water use are discussed below.

Income and Standard of Living

The importance of income in residential water use models goes beyond its effects on the consumer's ability to pay for water. It also measures the standard of living as expressed by the presence of convenience products in the house (e.g., washing machine, dishwasher, garbage disposal, multiple bathrooms, evaporative cooler, humidifier); decorative or convenience outdoor features and facilities (e.g., lawn, flower beds, decorative shrubs, swimming pool, sauna, water-mist systems, fountains, automatic sprinklers with timers); and perceived health-related fixtures such as home water treatment systems. All these features can be considered as representing a standard of living. The importance of this long-run demand responsiveness can be represented by household income or the market value of the house (or assessed valuation). Market value of the house is strongly related to the homeowner's income as well as to the presence of water-using appliances, fixtures, and facilities (or features).

It should be noted that the values of residential homes in some areas of the country include a substantial locational premium that has little bearing on water use, except for measuring the ability of residents to pay for water. If home value is taken to represent the stock of water-using fixtures, appliances, and architectural features of the residential landscape, then a four-bedroom single-family house with a replacement value of $75,000 is expected to have a similar capital water-using stock regardless of its location. However, the presence of a substantial location premium will bias the estimates of water use.

The effects of income or home value can be evaluated for various locations over time (especially among empirical studies) using the concept of elasticity. Income elasticity of water demand is defined as the percent change in water use divided by the percent change in income when all other factors affecting water demand are held constant. Income elasticity of 0.3 indicates that a 1 percent increase in real income will result in a 0.3 percent increase in water use. Standard economic theory and empirical evidence suggests that, for most goods and services, income elasticity will be positive (i.e., greater than zero). If the elasticity is between 0 and 1, it can be said that water demand is inelastic with respect to income. If it is greater than 1 then water demand is said to be elastic (with respect to income).

Literature estimates of income or home value elasticities range from 0.038 as obtained by Moncur (1987) to 1.45 as reported for residential sprinkling demand in the eastern U.S. by Howe and Linaweaver (1967). The best estimates of income (or home value) elasticities are those obtained using time series data, because they are not likely to include some specific (or unique) characteristics of cities or households that are incorrectly captured by the income variable when cross-sectional data are used (i.e., a locational premium). The estimates observed in the water demand literature suggest that the most likely range of income elasticity is between 0.3 and 0.6. Elasticities in this range are likely to be the best approximations of the response of water use to income over time when income is used to measure both the standard of living and the customer's ability to pay for water.

Retail Price of Water and Wastewater Services

Whereas income measures the consumer's ability to pay for water, the price of water influences the amount of water the consumer is willing to purchase. The price of water and wastewater explains relatively little variance in water use but is prone to large fluctuations that have often been responsible for significant shifts in water use levels. Unlike most other factors, price can both increase or decrease and is capable of causing large and abrupt changes in water use. Also, of all the factors that explain water use, price is frequently the only one within the power of the water supply agency to change (the only decision variable). These characteristics give price an importance that extends beyond its explanatory power in water use models.

There have been numerous empirical studies conducted on the price elasticity of residential water demand. Boland et al. (1984) presented a discussion of the impact of price and rate structures on water use based on a review of nearly 50 studies. However, many of the reviewed studies lacked the sophistication of study design and appropriate databases to produce reliable estimates of price elasticity. Most frequently, the questionable reliability of estimated price elasticity coefficients is a result of poor-quality data (e.g., sample selection), choice of explanatory variables (e.g., marginal price vs. average price), and other elements of study design.

Boland et al. (1990) recently conducted a study on the effects of price (and other factors) on water use with household level data from a random sample of 500 single-family residences in Southern California. The results of this study indicate that elasticity with respect to changes in marginal price alone (all other elements of rate structure held constant) was measured in the range of -0.004 to -0.015 for winter water use (November to April) and -0.132 to -0.175 for summer use (April to October). The elasticity with respect to changes in service charge (or other nonmarginal charges) was measured in the range of -0.027 to -0.182 for summer use.

A review of the empirical studies reported in the literature suggests that for the single-family sector, the most likely ranges of price elasticities of "across-the-board" water rate increases (approximated by response to changes in average price) may range from -0.10 to -0.20 for winter season use and from -0.20 to -0.40 for summer season use. The price elasticity of water use from the multifamily sector should range from -0.05 to -0.10.

Persons per Household

As might be expected, the number of persons per household is an important determinant of household water use. Individual households usually exhibit a declining trend in per capita water use and per capita conservation savings as the household sizes increases. This increased "efficiency of use," because of shared water uses, is often termed "economies of size." Morgan (1973) reported household-size elasticities of 0.45 and 0.57 derived, respectively, from linear and log-linear water use models. Elasticities of indoor water use ranging from 0.44 and 0.69 were obtained by Howe and Linaweaver (1967), Dziegielewski (1986), and Danielson (1979). In addition to the effects of economies of size, the decreasing per capita water use as the household size increases also can be explained by family composition. Hanke and de Mare (1982) showed that children under 18 were responsible for less water use than adults, and Billings and Day (1989) reported that persons in the 55-64 age group use less water at their residences than persons in the 65-and-older group. Based upon literature reviews of empirical studies, the most likely range of elasticities of indoor water use with respect to household size is between 0.30 to 0.60.

Weather and Climate

Another important predictor of water use, particularly outdoor use, is weather. The major component of outdoor use in the residential sector is lawn and garden irrigation. A recent study of Southern California water agencies found that 30 percent of total residential water use was for outdoor purposes (Dziegielewski et al., 1990a).

Based upon literature reviews of empirical studies, the most likely range of elasticities for maximum daily temperature is 0.5 to 1.5, whereas for annual rainfall, the range is -0.01 to -0.07. Therefore, as temperature increases, water use is expected to increase. Alternately, as annual rainfall increases, water use is expected to decrease, especially if the rainfall occurs during the normally dry season.

FORECASTING NONRESIDENTIAL WATER USE

The difficulty in quantifying the nonresidential demand for publicly supplied water is caused primarily by the great variability of water use rates among individual establishments. This variability is mainly a result of the great diversity of purposes for which manufacturing plants and commercial businesses use water. Often the only common purpose of use is that which is related to the sanitary needs of employees. The presence of other purposes, such as cooling or condensing, boiler feed, or processing depends primarily on the type of business activity. These factors contribute to a general lack of specific information on nonresidential uses of water, especially regarding the typical water requirements of identifiable classes of users.

When forecasting nonresidential water requirements, it is appropriate to correlate nonresidential water use with the number of employees, since the data for this parameter are easily obtained. From a sample of water agencies in Southern California, aggregate commercial water use and aggregate industrial water use was found to be highly correlated with total nonmanufacturing employment ($r = 0.98$) and total manufacturing employment ($r = 0.96$), respectively (Dziegielewski et al., 1990a).

Water use in individual establishments has also been found to be correlated with the number of employees. For example, a survey of water use in commercial and industrial (manufacturing) establishments in Southern California was conducted in 1988. Analysis of survey data found correlations between establishment-level water use and employment of 0.67 and 0.69 for the commercial and manufacturing sectors, respectively. Employee-use rates for different Standard Industrial Classification (SIC) groups can be estimated from data on establishment employment and establishment water use. An example of the data collection procedures and analysis of the survey results can be found in a report entitled Commercial and Industrial Water Use in Southern California (Dziegielewski et al., 1990b).

Table 2-2 gives ranges of average employee use rates for 19 commercial and institutional categories obtained from the survey of individual establishments in Southern California. The ranges are those from the survey database that were considered to be relatively stable. Table 2-3 contains similar data for manufacturing establishments from the same survey. Assuming geographic similarity, these water use rates can be used to prepare disaggregate forecasts of nonresidential water use. However, they should be used with caution because these rates are highly variable. The principal findings of the study conducted in Southern California are presented below as an example of the potential problems in forecasting commercial and industrial water use.

First, the population of nonresidential users of water from public systems usually contains a small fraction of manufacturing and business establishments that account for a major share of nonresidential water use and display much greater variability in water use rates than the remainder. As an example, in one of the water supply agencies sampled, 80 percent of nonresidential water use was accounted for by less than 10 percent of nonresidential customers. The remaining 20 percent of water use was primarily for sanitary purposes in a large number of small establishments with only a few employees. Exceptions included car washes, laundromats, ice-making firms, and other establishments using water for their business activity.

Second, the study found the following types of commercial establishments and institutions to account for a major portion of nonresidential water use:

(1) Restaurants
(2) Hotels and motels
(3) Hospitals and health service establishments
(4) Nursing and personal care facilities
(5) Urban construction sites
(6) Recreational facilities including golf courses, swimming pools, health clubs, and parks
(7) Car washes
(8) Commercial laundries

These eight categories, together with public administration offices, schools, and some accounts held by real estate lessors and operators, accounted for approximately 75 percent of commercial water use.

Third, seven categories of manufacturing activities (represented by two-digit Standard Industrial Classifications) were found to account for a major portion of water sales to industrial customers. These were:

(1) Chemicals and allied products
(2) Primary metal industries
(3) Paper and allied products

TABLE 2-2
ESTIMATES OF PER EMPLOYEE WATER USE IN SELECTED COMMERCIAL/INSTITUTIONAL CATEGORIES

SIC	Composition	No. of Establishments	Possible Range of Average per Employee Use (ged)
421	Trucking/warehousing	13	60.2 - 65.5
508	Machinery equipment	35	17.9 - 64.6
514	Wholesale groceries	12	134.0 - 149.3
53	General merchandise stores	6	35.5 - 36.0
54	Food stores	26	110.6 - 131.3
58	Eating & drinking places	153	121.0 - 204.2
60	Banking	20	44.9 - 58.8
61	Credit agencies	19	104.2 - 116.5
653	Real estate agents	17	119.1 - 166.9
70	Hotels/motels	69	186.0 - 286.4
739	Misc. business services	54	106.0 - 122.4
79	Amusement/recreation	16	451.7 - 487.6
801	Offices of physicians	33	237.3 - 356.2
805	Nursing & personal care	28	178.3 - 380.6
806	Hospitals	46	66.0 - 71.1
821	Schools	159	195.7 - 239.3
822	Colleges/universities	14	126.2 - 137.2
829	Schools/educational services	22	162.7 - 180.3
90	Public administration	5	82.7 - 138.8

Source: Dziegielewski et al. (1990b).
Range of estimates is based on weighted average estimate and significant estimates from the regression model(s).

(4) Petroleum and coal products
(5) Food and kindred products
(6) Electric and electronic equipment
(7) Transportation equipment

Manufacturing firms with these SIC designations are likely to purchase large quantities of water from local water supply agencies, especially in areas where groundwater is not available for developing self-supplied sources of water.

Fourth, there was great variability of water use rates (i.e., average daily use per employee or per unit of business volume) among individual establishments. In the survey sample, the ratio of the standard deviation to the sample mean (coefficient of variation) was about 3.0. This variability is mainly a result of the high diversity of purposes for which manufacturing plants and commercial businesses use water. It is likely that the presence of these

TABLE 2-3
ESTIMATES OF PER EMPLOYEE WATER USE IN MANUFACTURING CATEGORIES

SIC	Composition	No. of Establishments	Possible Range of Average per Employee Use (ged)
202	Dairy products	10	382.7 - 514.9
205	Bakery products	28	71.8 - 104.1
209	Misc. foods & kindred products	32	125.6 - 242.5
232	Mens' and boys' furnishings	16	16.1 - 34.2
233	Womens' and misses' outwear	29	12.7 - 13.5
239	Misc. fabricated textile products	17	24.9 - 41.0
243	Millwork, plywood & structural members	15	17.0 - 18.3
251	Household furniture	23	25.6 - 33.3
252	Office furniture	11	25.2 - 27.9
262	Paper mills, except building paper	5	1,364.3 - 1,589.6
264	Misc., converted paper products	30	90.8 - 190.9
265	Paperboard containers & boxes	22	76.7 - 134.0
271	Newspapers	17	47.2 - 49.7
275	Commercial printing	44	34.5 - 47.2
283	Drugs	31	91.6 - 190.5
285	Paints and allied products	17	34.3 - 51.3
289	Misc. chemical products	28	113.9 - 180.8
30	Rubber & misc. plastic products	76	56.0 - 91.7
335	Nonferrous rolling and drawing	12	78.7 - 107.4
336	Nonferrous foundries	15	49.2 - 97.7
344	Fabricated structural metal products	118	63.2 - 94.6
345	Screw machine products, bolts, etc.	14	98.8 - 118.5
346	Metal forgings and stampings	14	115.6 - 209.1
347	Metal services	58	219.9 - 318.3
349	Misc. fabricated metal products	14	52.3 - 55.4
354	Metalworking machinery	21	51.9 - 54.6
355	Special industry machinery	11	27.7 - 33.2
356	General industrial machinery	16	41.8 - 50.4
357	Office and computing machines	49	30.6 - 39.0
359	Misc. machinery, except electrical	30	33.2 - 41.5
362	Electrical industrial apparatus	19	27.1 - 30.1
366	Communication equipment	54	39.9 - 55.8
372	Aircraft and parts	75	48.6 - 54.0
376	Guided missiles, space vehicles, etc.	10	73.6 - 75.2
382	Measuring & controlling devices	38	33.2 - 45.6
399	Misc. manufactures	16	34.5 - 35.1

Source: Dziegielewski et al. (1990b).

Range of estimates is based on weighted average estimate and significant estimates from the regression model(s).

purposes relates to the type of business activity. However, individual establishments that belong to the same industrial category often differ in terms of water use rates because of differences in the production process for the same final product or service. In addition, when large quantities of water are required, especially for manufacturing processes, some firms tend to develop their own supplies and purchase only small quantities of water from public systems. The cost and quality of municipal water and the cost of wastewater disposal also influence the amounts of nonresidential water use in different urban areas.

Finally, water use in individual establishments was found to be correlated with the number of employees. The correlation coefficients from the total survey sample were 0.5 and 0.7 in linear and log-linear relationships, respectively. The correlations were substantially greater within specific categories of nonresidential users. Since employment data are accessible even for highly disaggregate categories of industries, these correlations are very useful in forecasting nonresidential water requirements. However, because of the substantial variability of water use among individual establishments, the maximum precision in predicting nonresidential use is achieved when (a) establishments are grouped into significant categories of users with similar mix of purposes (i.e., SIC classes), and (b) water use within each category is estimated using a log-linear relationship between water use and employment. For some categories of users, additional precision can be gained by geographical disaggregation.

EXAMPLES OF FORECASTING METHODS

As described above, there are a number of forecasting methods available. The following sections describe two forecasting methods that can be used for preparing a highly disaggregate long-term forecast of urban water use. The first method employs a computerized forecasting model, named the IWR-MAIN (Institute for Water Resources - Municipal And Industrial Needs) Water Use Forecasting System. The second method represents a simplified method, referred to as the Disaggregate Factor Forecast (DFF), which can be implemented using a hand calculator or a computer spreadsheet, and it is derived from the disaggregate approach used by the IWR-MAIN System.

IWR-MAIN System

The original version of the model was developed by Hittman Associates, Inc. (1970). The Institute for Water Resources (IWR) of the U.S. Army Corps of Engineers selected this approach as a way to improve water use forecasting practices within the Corps. Under the sponsorship of IWR, a substantial research effort was undertaken to update the model and modify it for easy access on personal computers. The final product of this effort is a public-domain software package called "IWR-MAIN Water Use Forecasting System, Version 5.1." The model and complete user's manual for the program is currently available (Davis et al., 1988) from the U.S. Army Corps of Engineers' Institute for Water Resources.

The general water use relationship of the IWR-MAIN System is

$$Q_{t,d,s,i} = f\ (P,V,H,W,C,N,E) \tag{2.1}$$

where

$Q_{t,d,s,i}$	=	average daily water use in year *t* and use dimension *d* (e.g., summer season use) in user sector *s* (e.g., single-family residential) by user category *i* (e.g., homes within a specific market value range)
P	=	price of water and sewer service
V	=	market value of housing units (in residential categories)
H	=	number of persons per housing unit (in residential categories)
W	=	weather conditions or climate (in residential categories)
C	=	conservation programs
N	=	number of users
E	=	number of employees (in nonresidential categories)

Different subsets of explanatory variables listed in Equation (2.1) are used to predict water use in various user sectors, categories, and dimensions. Once estimates of water use in individual categories have been computed, the total municipal water use is obtained from the following summation

$$Q_{t,d} = \sum_{s=1}^{k} \sum_{i=1}^{n} Q_{t,d,s,i} \tag{2.2}$$

where *n* and *k* represent the number of categories and user sectors in the forecast, respectively.

Figure 2-1 outlines the data requirements and the general procedure for deriving disaggregate water use estimates. The data required can be obtained from the U.S. Census of Population and Housing, County Business Patterns, and other publications containing information on population, housing, and employment in the study area (Table 2-4).

Residential water use is estimated using equations that utilize a combination of price, housing unit value (a surrogate for income and the stock of water-using appliances), household size, and weather conditions as explanatory (independent) variables. The estimating equations were selected after reviewing more than 50 empirical studies of residential water demand (Boland et al., 1984). All residential water use equations ultimately chosen were originally published by Howe and Linaweaver (1967) and Howe (1982).

FIGURE 2-1
IWR-MAIN PROCEDURE AND DATA REQUIREMENTS FOR ESTIMATING WATER USE

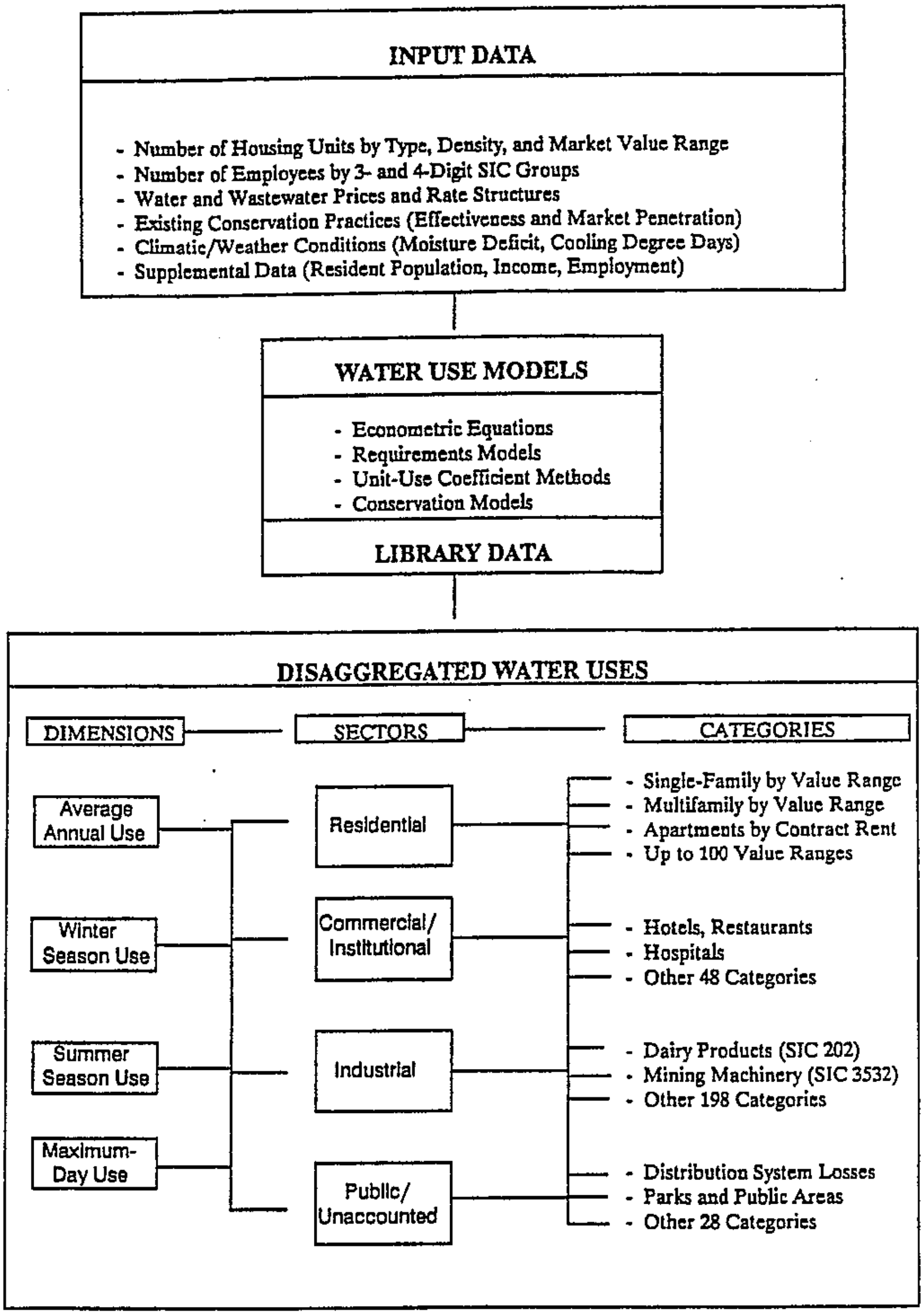


TABLE 2-4
DATA TYPES AND POSSIBLE SOURCES

Data Category	Specific Data Items	Possible Data Sources
A. Population	1. Population; household size 2. Population projections	U.S. Census of Population, housing; local and state planning agencies; city and county data books; state demographer; local and state economic development agencies; econometric firms; state and national statistical abstracts; OBERS regional projection
B. Housing	1. Number of housing units by type and by market value; housing density; average lot sizes; assessed valuations 2. Housing unit projections by type	U.S. Census of Population, housing; U.S. Census Metropolitan Housing Characteristics; local and state planning agencies; real estate assessment agencies; state demographer; state financial agencies; local and state economic development agencies; local zoning commission; econometric firms; OBERS regional projections
C. Employment	1. Total employment by major industry sectors: employment disaggregated by 3- and 4-digit SIC categories; local historical employment growth rates	U.S. Census of Population: Detailed Socioeconomic Characteristics; U.S. Census: County Business Patterns; U.S. Census of Manufacturers, Services, Wholesale Trade, etc.; local and state planning agencies; U.S. Bureau of Labor Statistics; U.S. Department of Commerce: Monthly Labor Review; employment security divisions; local and state economic development agencies; state financial agencies; econometric firms; localmanufacturing directory; local services directory; Chambers of Commerce employment listings; OBERS regional projections
D. Other economic variables	1. Consumer Price Index; construction costs index; personal and household income 2. Income projections	U.S. Census of Population: Detailed Socioeconomic Characteristics; local and state planning agencies; state financial agencies; Department of Commerce: Monthly Labor Review; state and national statistical abstracts; U.S. Bureau of Labor Statistics; econometric firms; OBERS regional projections

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TABLE 2-4 (Continued)
DATA TYPES AND POSSIBLE SOURCES

Data Category	Specific Data Items	Possible Data Sources
E. Climate	Local weather patterns: rainfall, temperature, evapotranspiration rates, moisture deficit (normal and temporal conditions)	National Oceanic and Atmospheric Administration (NOAA); National Weather Service, university experiment stations; soil and water conservation districts; local airports
F. Land use	Land use patterns; zoning ordinances	U.S. Census of Agriculture; local and state planning agencies; city zoning commissions; city directories; U.S. Census: Block Statistics Reports
G. Water statistics	Water/wastewater prices and rate structures; historical monthly water use by customer class; historical monthly number of accounts by customer class; historical data on unaccounted losses; scope of self-supplied users	Local water supply agency; engineering reports; state water surveys; customer surveys; state regulatory agency; local government ordinances
H. Conservation	Implemented conservation measures; future conservation alternatives; measurements of reduction, coverage or effectiveness of measures; social acceptability; institutional framework; water-using appliances	Local water supply agencies; state regulatory agency; local ordinances and regulatory statistics; local and state planning agencies; interviews of government officials and general public; consumer (satisfaction evaluation) reports; manufacturer (water-using appliance) specifications; literature studies

Nonresidential uses are disaggregated into as many as 280 categories within the three major sectors: industrial (manufacturing); commercial/institutional; and public/unaccounted. Most categories are defined as three- and four-digit subsets of Standard Industrial Classifications (U.S. Department of Commerce, 1978). Average water requirements in each category are determined on the basis of water use per employee per day. These coefficients are modified to reflect the intensity of water use as affected by changes in price of water and sewer service using the following relationship

$$q_2 = q_1 (P_2 / P_1)^e \qquad (2.3)$$

where

q_1 = employee use coefficient at price level P_1
q_2 = modified employee use coefficient representing use at price level P_2
e = price elasticity of nonresidential water demand

Different values of price elasticities derived from the literature (Boland et al., 1984) are applied to manufacturing and commercial/institutional sectors. Water use coefficients representing average use rates were derived from a nationwide survey of 3,448 commercial and institutional establishments in 60 cities (Boland et al., 1985) and from the surveys of manufacturing establishments conducted by the U.S. Bureau of the Census (1986) and the California Department of Water Resources (1982).

Since the intensity of water use in all sectors and categories can be affected by water conservation, the model contains a procedure for estimating the effectiveness of up to 18 different conservation measures. Conservation parameters obtained from the literature (Boland et al., 1982; Weston, Inc., 1984; Brown and Caldwell, Inc., 1984) are provided for 14 measures:

(1) Public information/education program
(2) Metering of customer connections
(3) Reduction of system pressure
(4) Water rate policy changes
(5) Rationing program (per capita basis)
(6) Sprinkling restrictions
(7) Industrial reuse/recycle
(8) Commercial/institutional reuse/recycle
(9) Leak detection and repair
(10) Retrofit of showers and toilets
(11) Moderate plumbing code
(12) Advanced plumbing code
(13) Low water use landscaping (new construction)
(14) Low water use landscaping (retrofit)

The impacts of one or more conservation measures already implemented (or planned for implementation) in the water service area are calculated based on (1) the estimates of the expected reduction in the uses of water affected by conservation; (2) the market penetration (coverage) of conservation practices; and (3) the expected interactions among measures that are implemented together. A conservation adjustment is calculated according to the formula derived from a relationship first presented in Baumann et al. (1979)

$$P_{s,d} = \sum_{m=1}^{n} \left[(R_{m,s,d} * C_{m,s,t}) * \prod_{g=1}^{m-1} (I_{m,g,d}) \right] \tag{2.4}$$

where

$P_{s,d}$	=	adjustment factor for the effect of all conservation measures affecting sector *s* and use dimension *d*
$R_{m,s,d}$	=	fraction reduction in the use of water by sector *s* in use dimension *d* expected as a result of implementing measure *m*
$C_{m,s,t}$	=	coverage of measure *m* in use sector *s* at time *t* expressed as a fraction of sectoral water use
$I_{m,g,d}$	=	interaction factor for the combinations of individual pairs of measures, *m* and *g* for dimension *d*
n	=	total number of measures implemented

The forecast of restricted water use for each use sector and dimension is calculated as

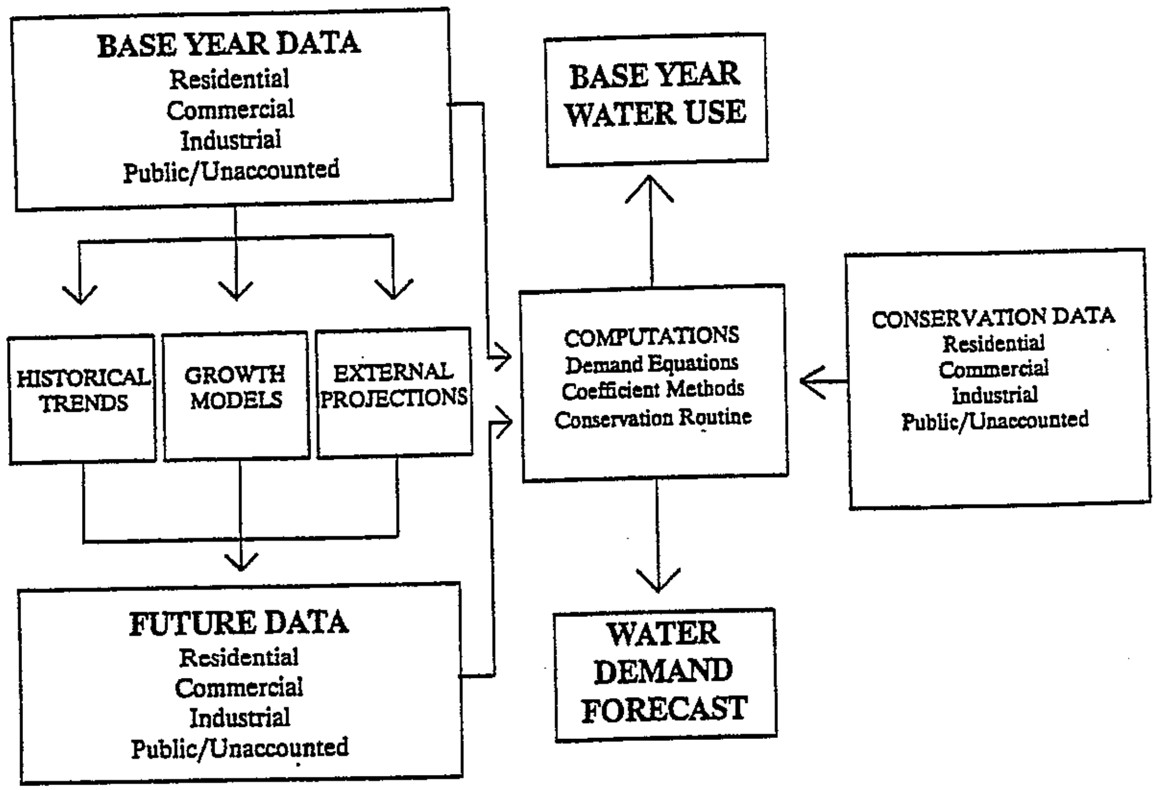
$$Q_{c,s,d} = Q_{u,s,d} (1 - P_{s,d}) \tag{2.5}$$

where

$Q_{c,s,d}$	=	restricted water use (with conservation) for sector *s* and dimension *d*
$Q_{u,s,d}$	=	unrestricted water use (without conservation) for sectors *s* and dimension *d*

Preparation of an IWR-MAIN water use forecast for a given urban area requires (1) verification of the empirical equations and coefficients for estimating water use and (2) projection of the future values of determinants of water use. Figure 2-2 shows the major components of the forecasting procedure. Model verification is accomplished by preparing independent estimates of water use for one or more historical years and comparing these estimates with actual water use conditions. The comparisons may indicate that calibrations to the water models are necessary. Methods of calibration are discussed in the IWR-MAIN User's Manual (Davis et al., 1988). The year from which values of explanatory variables are projected is the base year. Typically a calendar year that coincides with the U.S. Census of Population

FIGURE 2-2
MAJOR COMPONENTS OF THE IWR-MAIN FORECASTING PROCEDURE



and Housing is selected as the base year (e.g., 1980 or 1990). All years that follow are forecast years.

Future values of water use determinants can be developed externally or can be generated by growth equations built into the program. However, not all future parameters can be generated by the internal growth models. Total population, total employment, and median household income in each forecast year must be provided by the user. The growth models for the residential sector can produce default projections of total number of housing units and their distribution by market value from (1) base year housing data; (2) the projected median household income; and (3) population growth rate. Similarly, the distribution of employment among eight major SIC divisions is projected for each forecast year, using base year values and past employment trends in each category.

The DFF Method

The Disaggregate Factor Forecast (DFF) method is derived from the approach used by the IWR-MAIN System. The DFF method forecasts water use for the major urban sectors using a computer spreadsheet or a hand-held calculator. Although the DFF may have less data requirements than the IWR-MAIN System, and therefore would be easier to apply, some accuracy in the water use forecasts may be sacrificed. In the DFF method, total municipal water use is disaggregated into the following five sectors:

(1) Single-family residential
(2) Multifamily residential
(3) Commercial/institutional
(4) Industrial (manufacturing)
(5) Public/unaccounted

Total annual water use forecasts are obtained by preparing separate forecasts for each specified sector for a six-month summer season (May-October) and six-month winter season (November-April). Water use factors of the DFF method are coefficients representing unit water use. The total number of these coefficients depends on the number of sectors, seasons, and forecast years.

Table 2-5 shows all base year and forecast year coefficients for a hypothetical city. Each coefficient represents water use per unit (or end user) comprising the sector. For example, a single-family home is a unit for single-family residential water use. A person employed in the commercial sector is a unit for commercial water use. A resident of the water service area is a unit of the public/unaccounted sector. The factors may change over time (as discussed in sections that follow) because of changes in income, average number of persons per household, and other forces that influence water use.

The disaggregated forecast of future water use is obtained by:

(1) Multiplying the future number of single-family housing units by the forecast year factors for winter and summer

(2) Multiplying the future number of multifamily homes, commercial employees, industrial employees, and resident population by their respective factors for winter and summer

(3) Summing up the results over seasons and sectors to obtain total municipal water use for each forecast year

TABLE 2-5
THE DISAGGREGATE FACTOR FORECAST COEFFICIENTS (EXAMPLE)
(gal/unit/day)

Water Use Season and Sector	Unit	Base Year 1990	Forecast Year 2010
Winter Use			
Single-family	Housing unit	462.1	472.9
Multifamily	Housing unit	223.7	228.5
Commercial	Employee	156.1	173.3
Industrial	Employee	224.7	234.9
Public/unaccounted	Resident	29.6	30.4
Summer Use			
Single-family	Housing unit	730.5	743.1
Multifamily	Housing unit	278.0	284.6
Commercial	Employee	156.1	173.3
Industrial	Employee	224.7	234.9
Public/unaccounted	Resident	29.6	30.4

Table 2-6 and 2-7 demonstrate the above steps. Values in Table 2-6 are multiplied by the factors in Table 2-5 in order to obtain forecasts of water use in Table 2-7. The following sections show how to obtain base year and forecast year factor coefficients.

TABLE 2-6
PROJECTION OF SOCIOECONOMIC CHARACTERISTICS (EXAMPLE)

Sector	Base Year 1990	Forecast Year 2010
Single-family homes	22,228	23,580
Multifamily homes	19,286	24,546
Commercial employment	45,905	60,963
Industrial employment	28,311	23,555
Resident population	113,352	129,250
Median household income (80$)	27,006	29,310
Persons per household	2.73	2.64

TABLE 2-7
DISAGGREGATE FORECAST (EXAMPLE)
(MGD)

Season and Sector	Base Year 1990	Forecast Year 2010
Winter		
Single-family	10.272	11.151
Multifamily	4.314	5.926
Commercial	7.165	10.563
Industrial	6.362	5.533
Public/unaccounted	3.358	3.936
Summer		
Single-family	16.238	17.523
Multifamily	5.361	7.381
Commercial	7.165	10.563
Industrial	6.362	5.533
Public/unaccounted	3.358	3.936
Total Annual		
Single-family	13.255	14.337
Multifamily	4.837	6.654
Commercial	7.165	10.563
Industrial	6.362	5.533
Public/unaccounted	3.358	3.936
Total Municipal	34.978	41.023

Base Year Factors

The base year factors (i.e., gallons per single-family housing unit per day or gallons per commercial employee per day) can be obtained from municipal water use data that have been disaggregated by sectors and seasons and from socioeconomic data (population, housing, and employment). For example, if summer water use by the single-family sector is 21.915 million gallons per day (MGD) and there are 30,000 single-family customers, the single-family summer factor is

21,915,000 gallons per day / 30,000 units = 730.5 gallons per unit per day

Forecast Year Factors

The water use factors for individual sectors and seasons may change over time. In order to derive the forecast year factors, the base year factors have to be modified to reflect the influences of household income or other variables on water use. Table 2-8 provides recommended elasticities for income, price, and household size. These elasticities and the potential impacts of changes in income and persons per household are discussed below.

<u>*Income*</u>. Empirical studies clearly show that increasing income (in real terms) will cause an increase in water use in the residential sector. The elasticity of income in single-family sectors varies from 0.3 to 0.6. This means that a 10 percent increase in income may cause a 3 to 6 percent increase in water use.

For example, if the median household income in a city is expected to increase from $27,000 in 1990 to $29,310 in 2010 (in real terms), the effect of income growth on unit water use in the single-family sector can be obtained from the following formula

$$F_{SF,W,2010} = F_{SF,W,1990} * (I_{2010} / I_{1990})^{e} \qquad (2.6)$$

where

$F_{SF,W,2010}$	=	the unknown factor for single-family winter season use in 2010, gallons per day (gpd)
$F_{SF,W,1990}$	=	the base year factor for single-family winter season use, gpd (see Table 2-5)
I_{2010}	=	projected household income for 2010 (see Table 2-6)
I_{1990}	=	base year household income (see Table 2-6)
e	=	income elasticity (see Table 2-8)

TABLE 2-8
RECOMMENDED ELASTICITIES FOR DFF METHOD

Season and Sector	Recommended Ranges: Income	Price	Household Size
Summer			
Single-family	+0.3 to +0.5	-0.2 to -0.4	+0.2 to +0.5
Multifamily	+0.4 to +0.6	0.0 to -0.2	+0.3 to +0.5
Commercial	--	-0.1 to -0.3	--
Industrial	--	-0.1 to -0.3	--
Winter			
Single-family	+0.3 to +0.5	-0.1 to -0.2	+0.2 to +0.5
Multifamily	+0.4 to +0.6	-0.05 to -0.2	+0.3 to +0.5
Commercial	--	-0.1 to -0.3	--
Industrial	--	-0.1 to -0.3	--

Assuming an income elasticity of 0.4 and substituting the values into equation (2.6), we obtain

$$F_{SF,W,2010} = 462.1 * ((29{,}310 / 27{,}006)^{0.40}) = 462.1 * 1.033 = 477.5\text{gpd}$$

The 2010 factor will increase from the base year factor by 3.3 percent (or by 15.4 gpd) because of the change in household income.

Persons per Household. For the hypothetical city, persons per household is expected to decrease from 2.73 to 2.64 by 2010. Assuming that the elasticity of household size for winter water use in single-family residences is 0.3, the 2010 winter use factor is

$$F_{SF,W,2010} = 462.1 * ((2.64 / 2.73)^{0.30}) = 462.1 * 0.990 = 457.5\text{gpd}$$

The 2010 winter use factor will decrease from the base year factor by 1.0 percent (or 4.6 gpd) because of the projected change in average household size.

Summary

The effects of two or more variables can be incorporated into a forecast year for a given sector and season by summing up the changes in gallons per day attributed to each variable. For example:

462.1 gpd	Base year factor for single-family winter use
+15.4	Change due to income
-4.6	Change due to household size
472.9 gpd	Forecast year factor for single-family winter use

The DFF method is merely an approach that can be used in the preparation of water use forecasts. The method will require assumptions regarding expected changes in the service area under consideration. For example, consideration should be given to expected changes over the forecast period in:

(1) The number of housing units (residential accounts)
(2) The housing mix (single-family vs. multifamily units)
(3) Household income
(4) Persons per household
(5) The level of employment
(6) The mix of the types of establishments in the commercial/institutional and industrial water use sectors
(7) Retail prices

To obtain water use forecasts with conservation, estimates of the percent savings from conservation measures can be subtracted from the base water use forecasts (this will be discussed in greater detail in subsequent chapters).

STEP 3. SCREEN CONSERVATION TECHNIQUES AND PRACTICES

OBJECTIVES

(1) To assess the applicability, technical feasibility, and social acceptability of potential conservation measures

(2) To assess (or roughly estimate) the potential water savings of possible measures

(3) To formulate implementable conservation programs

ESTABLISHING PROGRAM GOALS

In developing a water conservation program, the first issue that must be considered is the overall purpose of the conservation program. By clearly defining the purpose of the program, a water conservation program can be designed with specific goals. Assuming that there is a problem in the balance of water supply and demand or in the water/wastewater distribution or treatment system, several questions can be posed to assist in the development of the water conservation program goals:

(1) Is there a short-term (e.g., drought-related, source contamination, or other emergency condition) or long-term (e.g., inadequacy of long-term supplies or storage capacity) water supply problem?

(2) Is there a distribution system problem (e.g., excessive sewer flows, water/wastewater treatment plant capacities)?

(3) Is the problem localized (e.g., capacity problems of a single water or wastewater treatment plant) or systemwide?

(4) Is the problem a seasonal issue (e.g., summer demands, maximum daily demands, or average annual demands)?

Even if the water utility is not facing a supply, treatment, or distribution system problem, there may be utility standards or state/local mandates for conservation. By assessing the need for, and objectives of, a water conservation program, goals can be set and water conservation measures can be screened with respect to meeting those goals.

POTENTIAL CONSERVATION PRACTICES

The overall purpose of this step is to present methods for screening specific water conservation measures (i.e., practices, techniques, devices) for potential implementation and further evaluation in **Step 4**. The initial screening of a large number of conservation practices will ensure that the most promising conservation measures for a given water service area are not overlooked, thus enhancing the overall efficiency of a conservation program. At the present time, the accumulated experience of water agencies in this country and elsewhere can provide a conservation planner with over 100 conservation measures (or variants thereof). Therefore, the initial screening of such a large number of conservation measures will assist the planner in selecting and evaluating only those measures that are feasible, acceptable by water agency customers, and effective in reducing water use. Typically, the screening process must necessarily rely on information about the effects of various measures that are found in the literature or derived from the experience of other water supply agencies. For most measures, such information will be adequate only for the purpose of the initial screening. Empirical analyses of pilot programs (see **Part II** of manual) as well as economic analyses of conservation alternatives (**Step 4**) will provide more reliable and complete data for making final decisions about whether various conservation programs should be implemented.

A Library of Conservation Measures

There are a large number of potential water conservation measures that may be used to reduce the use or loss of water in a particular water service area. An extensive listing of such measures should be obtained or developed and used as a starting point in selecting and evaluating conservation measures.

Tables 3-1 and 3-2 present two alternate typologies of long-term water conservation measures. The discussion in this step focuses on long-term water conservation measures rather than short-term (or drought management measures). Table 3-1 groups conservation measures by types of water use in urban areas. Table 3-2 categorizes various measures according to the method of their implementation.

Screening Tests of Applicability and Feasibility

An initial screening of conservation measures can be conducted by assessing their applicability and technical feasibility. Screening for applicability defines those conservation measures applicable to water uses that take place in the water service area. For example, a conservation measure targeting landscaping practices may not applicable if there is not a

TABLE 3-1
TYPICAL LONG-TERM WATER CONSERVATION MEASURES BY WATER USE TYPE

Area of Application	Conservation Measure
General	Public information In-school education Metering Pressure reduction Pricing policies (1) Uniform commodity rates (2) Increasing block rate (3) Seasonal rates Leak detection and repair System rehabilitation
Interior residential use	Low-flow showerheads Shower-flow restrictors Toilet-tank inserts Pipe insulation Faucet aerators Water-efficient appliances Low-flush toilets and ultra-low-flush toilets
Power generation	Recirculation of cooling water Reuse of treated wastewater In-system treatment
Industrial use	Recirculation of cooling water Reuse of cooling and process water Reuse of treated wastewater Efficient landscape irrigation Low-water-using fixtures Process modification
Landscape irrigation/design	Efficient landscape design Low-water-use plant material Scheduled irrigation Efficient irrigation systems Tensiometers Reduction or limitation of high water use plant materials such as turf

Source: Maddaus, W.O., 1987. Water Conservation. American Water Works Association. Denver, CO.

TABLE 3-2
TYPICAL LONG-TERM CONSERVATION MEASURES
BY MODE OF IMPLEMENTATION

EDUCATION	REGULATIONS	MANAGEMENT
(A) Direct mail • Pamphlets, bill inserts, newsletters (B) Mass media • Radio, TV, newspaper (C) Personal contact • speaker programs, customer assistance hotlines (D) Special events • School programs, exhibits	(A) State and local codes and ordinances • Plumbing codes for new structures • Landscape ordinances (B) Restrictions • Rationing (1) Fixed allocation (2) Variable percent plan (3) Per capita use (4) Prior use basis	• Leak detection and repair • Metering • Pressure reduction • Water reuse/recycling/recirculation • Pricing policies (1) Marginal cost pricing (2) Increasing block rate (3) Seasonal rates (4) Summer surcharge (5) Excess use charge • Tax incentives, subsidies, and rebates • Voluntary implementation of water-saving devices (1) Toilet inserts (2) Faucet aerators (3) Low-flow showerheads (4) Sprinkler timers (5) Water-efficient appliances (6) Pool covers (7) Ultra-low-flush toilets • On-site water audits (1) Residential indoor/outdoor (2) Large landscape (3) Commercial/industrial

measurable seasonal (or outdoor) water use component. The conservation measure should also address the water supply problem that was the impetus of the conservation program. If the objective for the water conservation program is to reduce demands on an overburdened wastewater treatment plant, implementing lawn-sprinkling restrictions would have little or no effect on this goal.

The test of applicability should also define conservation practices that have been implemented in the water service area. If a measure is already implemented for a portion of the water service area, or for some (but not all) water uses in the area, an applicable measure is one that would apply to that portion of the water service area or to those water uses not already affected.

Measures are deemed technically feasible if, upon implementation, they result in a measurable reduction in the quantity of water used at some time. Engineering analysis and reports of field studies may be used to establish apparent technical feasibility. In some cases, preliminary field tests of specific measures may be used to establish technical feasibility. For example, field tests of devices for reducing toilet-flushing volumes (plastic dams) may reveal that, for some types of toilets, flushing efficiency is so reduced that double-flushing occurs. If this leads to the determination that the devices would not achieve any measurable reduction in water use, the measure would be deemed technically infeasible.

Conservation measures that pass the tests of applicability to the water service area and technical feasibility should be further evaluated through the screening process.

ASSESSMENT OF SOCIAL ACCEPTABILITY

Social acceptability is essential for the successful implementation of a water conservation measure. Therefore, an assessment of social acceptability is necessary in the evaluation of any water conservation measure, since it determines the probable response of the community to the proposed measure. (This, in turn, provides practical information for the calculation of the expected level of coverage [or market penetration] of a conservation measure.) Measures are socially acceptable if they would be adopted by the community in which they are proposed. Unlike technical feasibility or economic feasibility, however, only rarely can the social acceptability of a given water conservation measure be predicted with a high level of certainty. The goal of this assessment is to increase the quality of the judgment regarding the probable response of various sectors of the community to a proposed measure.

Oftentimes, the social acceptability of conservation measures is determined based upon the intuitive considerations of water conservation planners or utility managers. This determination may be founded upon the successful application of the conservation measure in other communities. However, the successful application of a conservation measure in other communities does not ensure its success in all communities. Alternately, the failure of a specific conservation measure in one community does not ensure failure in all locations. Differences in socioeconomic characteristics, attitudes, and water use behaviors may preclude the same level of public acceptance as observed elsewhere.

The judgment of social acceptability can be assessed by initiating a public involvement program that addresses two sectors of the community: (1) community leaders and interest groups and (2) the general public. Input to the water conservation process can be elicited through workshops, personal interviews with community leaders and interest groups, or surveys of the general public. An example survey instrument used to assess the potential for water conservation for a community in Illinois, is presented in Appendix A. The results of the survey were used to assess the acceptability of conservation measures and were also used to estimate potential market penetration. Such surveys can also be used to identify target groups and to refine the design of conservation measures to be more publicly acceptable.

ESTIMATING POTENTIAL WATER SAVINGS

The screening tests of applicability, technical feasibility, and social acceptability should reduce the number of measures that are to be fully evaluated. The next step in the screening process is to assess the potential water savings that might be expected from implementing a conservation measure. The potential water savings resulting from a conservation measure is a function of (1) the fraction reduction in water use, (2) the market penetration (or coverage), and (3) baseline water use. Because water conservation measures typically address a particular user sector (e.g., single-family residential, industrial establishments) and a specific water use dimension (e.g., indoor, outdoor, or peak use), the estimation of potential water savings is disaggregated on this basis. The water savings from a conservation measure (or the effectiveness of the measure) can be calculated as

$$E_{ijdt} = R_{ijd} * C_{ijt} * Q_{jdt} \tag{3.1}$$

where

E_{ijdt} = effectiveness, or expected reduction in water use resulting from the implementation of measure *i* (e.g., low-flow showerheads) in use sector *j* (single-family sector) and water use dimension *d* (winter/summer use or indoor/outdoor use) at time *t* (e.g., 1990) in million gallons per day or acre-feet per year

R_{ijd} = fraction reduction in water use from sector *j* and dimension *d* expected as the result of implementing measure *i*

C_{ijt} = coverage of measure *i* in sector *j* and time *t*

Q_{jdt} = unrestricted water use in sector *j* and dimension *d* and time *t* in quantity per unit time (million gallons per day or acre-feet per year)

Each of the parameters for estimating the potential water savings of conservation measures is discussed below.

Unit Water Savings (Reduction)

The reduction factor measures the percent reduction in water use for a given user sector and dimension that is expected to result from a given conservation measure. For many conservation measures, empirical data on percent savings resulting from its implementation are unknown. The percent reduction can often be estimated based upon the calculation of unit water savings using device ratings and other engineering parameters. The water use and service area data presented previously in **Step 1** will be useful in these engineering-type estimates. Given unit water savings in gallons per capita day (gpcd) or gallons per household per day (gphd), the following formula can be used to calculate the reduction factor

$$R_{id} = (S_{id}/Q_d) \tag{3.2}$$

where

- R_{id} = fraction reduction in water use from dimension *d* expected as the result of implementing measure *i*
- S_{id} = water savings in gallons per household per day in water use dimension *d* (e.g., winter/summer water use or indoor/outdoor water use) resulting from measure *i* (e.g., showerhead retrofit)
- Q_d = average household water use in dimension *d* without implementing the conservation measure in gallons per household per day

Table 3-3 presents generally accepted engineering parameters for selected conservation measures. Table 1-6 of **Step 1** provides related information (e.g., toilet-flushing frequency, shower durations) for the estimation of water savings using engineering parameters. It should be noted that actual savings rates can vary considerably from the engineering estimates. Several factors can influence the actual savings of, for example, a low-flow showerhead program. The obvious variables include (1) water pressure at the plumbing outlets, (2) the model of the retrofitted (old) showerhead, (3) the degree to which shower valves are open during showering, and (4) the degree to which consumers change their habitual use of the fixture after it has been retrofitted. Somewhat less obvious variables that could influence water savings achieved in various communities are the demographic characteristics of the residential sector of water users, such as average household size and family composition as well as some socioeconomic variables such as income and education. It is for this reason that empirical studies are necessary for deriving reliable estimates of water savings for given study areas. However, when considering a conservation measure for potential implementation, it is necessary for screening purposes to obtain preliminary approximations of the potential water savings. When no empirical data exist, it may be necessary to rely on engineering estimates or the results of empirical studies conducted by other agencies (see Example 3-1).

TABLE 3-3
ENGINEERING PARAMETERS FOR ESTIMATING UNIT WATER SAVINGS FOR SELECTED CONSERVATION MEASURES

Appliance/Fixture	Typical Flow Rates	Water Savings
Standard toilet	5.5 gal/flush	--
Low-flush toilet	3.5 gal/flush	2 gal/flush[2]
Ultra-low-flush toilet	1.6 gal/flush	3.9 gal/flush[2]
Toilet dam	--	1 gal/flush
Toilet tank bag	--	0.7 gal/flush
Toilet tank replacement bottles (2)	--	0.5 gal/flush
Standard showerhead	3.4 gal/minute	--
Low-flow showerhead	1.9 gal/minute[1]	1.5 gal/minute[2]
Standard washing machine	55 gal/load	--
Water-efficient washing machine	42 gal/load	13 gal/load[2]
Standard dishwasher	14 gal/load	--
Water-efficient dishwasher	8.5 gal/load	5.5 gal/load[2]

Sources: Maddaus (1987), Brown and Caldwell (1984).
Note: See related parameters on Table 1-6.
[1] This is the rate after typical throttling. The current low-flow showerhead permitted under California law is 2.7 gpm.
[2] Unit savings are relative to standard appliance and/or fixture.

Table 3-4 provides estimates of the potential water savings of selected conservation programs known as "Best Management Practices" (BMPs). (These BMPs were developed for a Memorandum of Understanding among water agencies in California coordinated by the California Urban Water Conservation Council and are intended to provide a statewide standard for the evaluation of urban water conservation programs). The estimates of water savings present the best available estimates of what can be achieved by the adoption of the BMPs. For more information on the implementation conditions of these BMPs, see Brown and Caldwell (1991).

EXAMPLE 3-1
CALCULATION OF REDUCTION FACTOR USING ENGINEERING PARAMETERS

The following calculations represent the water savings expected as the result of a showerhead retrofit program. The savings rate represents a difference in average winter water use between homes with low-flow showerheads and homes without low-flow showerheads.

Nonconserving showerhead flow rate = 3.4 gallons/minute
Low-flow showerhead flow rate = 1.9 gallons/minute
Estimated showering time = 4.8 minutes/person/day
Average winter household water use = 200 gallons per household per day
Average household size = 2.5 persons
Water use with nonconserving showerhead
= 3.4 gal/min * 4.8 min/person/day = 16.3 gpcd
Water use with low-flow showerhead = 1.9 gal/min * 4.8 min/person/day = 9.1 gpcd
Water savings = 16.3 gpcd - 9.1 gpcd = 7.2 gpcd

At an average household size of 2.5 persons, the savings rate would be 18.0 gallons per household per day (2.5 persons * 7.2 gpcd). The formula for calculating the reduction factors representing the fraction of, for example, single-family winter water use is

R = (18.7 gphd) / (200 gphd during winter) = 0.09 (or 9 percent)

TABLE 3-4
POTENTIAL WATER SAVINGS FOR SELECTED CONSERVATION PRACTICES IN CALIFORNIA

	Estimated Water Savings		
Measure Description	**gpcd**	**gphd**	**Percent**
Single-family retrofit (pre-1980 homes)			
Toilet retrofit	1.3	4	1% of annual use
Low-flow showerhead	7.2	22	4% of annual use
Multifamily retrofit (pre-1980 homes)			
Toilet retrofit	1.3	3	1% of annual use
Low-flow showerhead	7.2	17	6% of annual use
Home water audits (pre-1980 single-family homes)			
Toilet retrofit	1.3	4	1% of annual use
Low-flow showerhead	7.2	22	5% of annual use
Leak repair	0.5	2	<1% of annual use
Outdoor use	--	--	5-10% of outdoor use*
Home water audits (post-1980 single-family homes)			
Low-flow showerhead	2.9	9	2% of annual use
Leak repair	0.5	2	<1% of annual use
Outdoor use	--	--	5-10% of outdoor use*
Large landscape water audits	--	--	10-20% of irrigation use in affected sectors

TABLE 3-4 (Continued)
POTENTIAL WATER SAVINGS FOR SELECTED CONSERVATION PRACTICES IN CALIFORNIA

Measure Description	Estimated Water Savings		
	gpcd	gphd	Percent
Landscape requirements for new commercial, industrial, multifamily complexes	--	--	10-20% of irrigation use in affected sectors
Governmental plumbing retrofit	--	--	5% of indoor use in governmental sectors
Distribution system water audits and leak detection	--	--	<10% of total production
1992 California Plumbing Code			
Residential use (relative to pre-1980 housing units)			
Toilets	16	50	10% of annual use
Showerheads	7.2	22	4% of annual use
Nonresidential use (relative to pre-1980 housing units)			
Toilets			3% of annual use
Public facilities	--	--	<1% of annual use

Source: Brown and Caldwell Consultants (1991) and Planning and Management Consultants (1991).

Notes:

(1) gpcd= gallons per capita per day; gphd= gallons per household per day.

(2) Assumes 3.1 persons per household in single-family units and 1.9 persons per housing in multifamily units.

(3) California Plumbing Code became effective in 1978 and was revised in 1980; therefore water savings will vary between pre- and post-1980 homes.

(4) *Provides best available estimates, but not substantiated with empirical data.

Market Penetration (Coverage)

The aggregate water savings in a given water use sector will depend on the proportion of the sector actually affected by the conservation measure. The market penetration (or coverage) is an indication of the percent of water use within a given sector affected by a given measure at a given point in time. Coverage factors may be approximated by the percent of water users who are in compliance with, or who have adopted, a given measure.

The coverage factor is an unknown quantity for most measures. Typically, the estimation of coverage is based upon the expected compliance rates (e.g., plumbing codes) or rates of installations (e.g., voluntary low-flow showerhead programs). For screening purposes, the results of surveys of the general public (see previous discussion on social acceptability on p. 71) may provide indications of the potential initial market penetration. Alternately, market penetration can be deemed as a policy goal for a given conservation measure (e.g., a goal to achieve a target of 80 percent of single-family units for a retrofit program). Consideration must be given to the difference between consumers who are exposed to a conservation measure (or who receive conservation devices) and those consumers who actually implement the conservation measure. The value of the coverage factor may be expected to either increase over time as more users comply with a given measure or decrease as the water-saving devices wear out with time or as customers remove the devices (e.g., toilet dams).

Unrestricted Water Use

The product of the reduction and coverage factors (R_{ijd} * C_{ijt}) of a given conservation measure will provide an estimate of the percent savings from the implementation of a conservation measure. In order to estimate aggregate sector water savings over time, it is necessary to apply this estimate of percent savings to baseline water use forecasts for a given sector for each given point in time. It should be noted that the product of reduction and coverage may vary over time due to changing compliance rates and consumer behavior and the attrition of devices. Therefore, in order to evaluate the effectiveness of water conservation measures in future years, it is necessary to prepare a baseline water use forecast by user sector. The baseline water use forecasts (**Step 2**) from either the IWR-MAIN System or the DFF Method can be applied here.

CANDIDATE MEASURES

Once the conservation measures have been tested for applicability, technical feasibility, social acceptability, and potential water savings, a list of candidate conservation practices, devices, and regulations can be prepared. The candidate measures can thereby be included as components of water conservation programs. Such a list should also include information on expected water savings and the degree to which each practice or device is expected to be acceptable to water users. The estimates of potential water savings of conservation measures can be rank-ordered with the least likely candidates excluded from further evaluation.

DEFINITION OF IMPLEMENTATION CONDITIONS

The screening tests should have reduced the number of measures that are to be fully evaluated. In order to provide a basis for further evaluation of each conservation practice, it is necessary to formulate each measure as a fully developed conservation alternative or program. It is helpful to distinguish between a conservation measure (method, practice, or technique) and a conservation program or alternative. A conservation measure is broadly defined to include any activity, practice, technological device, law, or policy that can potentially reduce water use. The definition of a conservation measure should be sufficiently narrow to permit the evaluation of its applicability, technical feasibility, social acceptability, and measurement of water savings. However, a conservation program or alternative is designed to facilitate implementation of one or more conservation measures.

Therefore, the following sections discuss the types of implementation conditions that must be specified before the conservation alternatives can continue to be evaluated. The implementation plan of each program should include the following elements:

(1) Program contents
(2) Definition of the target population and program participants
(3) Program incentives
(4) Customer contact mode(s)
(5) Schedule of program implementation and duration
(6) Specification of responsible agencies
(7) Program evaluation plan

Program Contents

The contents of the potential water conservation alternatives must be clearly defined. Some programs may be designed to accomplish the adoption of only one conservation measure, while others may be designed to promote several conservation measures. For example, the Ultra-low-flush (ULF) Toilet Replacement Program listed in Table 3-5 covers only the installation of the ULF toilet. Other programs may include or promote packages of individual conservation devices and practices. For example, the High Use Home Water Audit Program may include several conservation devices, educational literature, oral instructions, and even

TABLE 3-5
EXAMPLES OF WATER CONSERVATION PROGRAMS

Type of Program/Program Name
Educational Programs
Elementary School Conservation Education Program
High School Conservation Education Program
Mass-Media Public Information Program
Xeriscaping Garden Demonstration Program
Plumbing Retrofit Campaigns
Residential Plumbing Fixture Retrofit Program
Governmental Plumbing Retrofit Program
ULF Toilet Replacement Program
Conservation Audits
High Use Home Water Audit Program
Commercial and Industrial Audit Program
Residential Leak Detection Program
Distribution System Audit and Leak Detection Program
Large Landscape Irrigation Audit Program
Conservation Ordinances
Indoor Plumbing Code for New Construction
Point-of-Sale Plumbing Fixture Ordinances
Residential Landscaping Ordinance
Commercial Landscaping Ordinance
Submetering Ordinance
Water Waste Ordinance
Landscape Replacement
Buy-Back Turf Program
Xeriscape Replacement Program
Irrigation Retrofit Program

simple plumbing services. Packaging of conservation measures will often enhance the cost-effectiveness of a conservation program. The following is an example of a package of devices and activities covered by a home water audit program (Brown and Caldwell, 1990):

Indoor Audit
-- Measure indoor water flow rates
-- Checks for leaks
-- Survey frequency of appliance/fixture use
-- Install low-flow showerheads, toilet dams, and faucet aerators

Outdoor Audit
-- Obtain soil probe core
-- Check root development
-- Determine moisture distribution
-- Test sprinkler flow rate
-- Determine turf type
-- Determine soil absorption rate
-- Make recommendations on watering times and frequencies based on above observations and calculated evapotranspiration rates

The potential costs of a conservation program will be affected by the advertising and/or public information component of the program. Therefore, in devising the program content, consideration must be given to program publicity. Various channels of communication can be used for program publicity. The channel of communication to be used for a particular program should be chosen with regard to the target population. For example, if a citywide water-rationing program is being implemented, the program announcements should be made through the mass media (i.e., television, radio, newspaper). Alternately, a plumbing retrofit program targeting only selected neighborhoods could mail notification letters only to the customers in targeted neighborhoods.

Definition of Target Population and Program Participants

The program design should clearly establish the target population for the program. For example, a home water audit program can be directed to:

(1) All residential dwellings within the service area
(2) All residential single-family homes built prior to the implementation of a plumbing code
(3) All homes occupied by households with annual income not exceeding a certain amount
(4) All single-family homes with annual water use exceeding 120,000 gallons

In addition to type and age of housing, household income, and water usage, the target population can be defined in terms of water use type, geographic location, meter size, or other characteristics.

Once the program contents and target population have been determined, it is necessary to determine the coverage of the conservation program (e.g., 2,000 single-family homes in a particular neighborhood; 25,000 multifamily units citywide; or top 20 percent of total industrial water use). When estimating the coverage of the program, the planner must consider that not all eligible consumers in the target population will participate in the program. For example, only 50 percent of eligible single-family residences contacted for a home water audit may actually participate. Although the entire target population may be initially contacted, thereby affecting notification costs, the actual number of participants will affect the field labor and equipment costs. As mentioned previously, the coverage of a conservation program can be deemed as a policy goal for a given conservation program (e.g., to achieve the retrofit of 80 percent of all single-family homes).

Program Incentives

Savings in water use alone may not be a sufficient incentive for program participation. Oftentimes, other incentives are added in order to increase the number of "willing and eligible" program participants. Typically, economic incentives for motivating consumers to conserve water include (1) rebates, (2) tax credits, or (3) subsidies. If the conservation program being screened uses economic incentives, the amount and conditions of the incentives should be specified in the tentative implementation plan. For example, ULF toilet programs typically utilize rebates to encourage the purchase and installation of the toilets. The maximum dollar amount of the rebate should be set at the difference between the price of a typical conserving toilet and the price of a typical ULF toilet, plus a reasonable margin.

Customer Contact Modes

Almost all conservation programs will require some level of contact with each eligible customer of the target population. Such contacts can be facilitated in several ways, including:

(1) Telephone solicitation and scheduling
(2) Call-in requests and scheduling
(3) Sign-up booths in malls or at public events
(4) Door-to-door canvassing
(5) Direct written contact
(6) Mass-media contacts

These contact modes (or distribution modes) differ in terms of cost and the potential rate of success in reaching the target population. The selection of a specific mode of customer contact will depend on the desired goals of program participation and the type of conservation program.

Schedule of Program Implementation and Duration

A realistic schedule for implementing all phases of the program should be developed. This should include both the estimated start date of the program as well as its duration. The duration of the program can be specified as a time frame (2-year program) or as an expected implementation rate (5,000 single-family homes to be retrofitted each year for the next 5 years).

Specification of Responsible Agencies

For each conservation program considered for implementation, there is likely to be various levels of involvement from different agencies, organizations, and individuals. Some conservation programs may be conducted with in-house personnel, and others may be contracted out to private companies. Some conservation programs may require the recruitment of field labor from temporary help agencies or community groups. The participation of various groups in the program implementation phase will affect program costs. Therefore, the specification of the responsible agencies in each conservation program must clearly be defined in the implementation plan.

Program Evaluation Plan

If the conservation program being considered is expected to be the subject of an empirical program evaluation (as outlined in **Part II** of this manual), this needs to be stated in the program implementation plan. The program evaluation plan should include a clear description of the programs' goals and data collection methods. The costs involved with conducting an empirical program evaluation may need to be considered in the benefit-cost analyses.

STEP 4. ANALYZE BENEFITS AND COSTS OF CONSERVATION ALTERNATIVES

OBJECTIVES

(1) To describe economic costs and benefits associated with implementing conservation programs

(2) To provide methodologies for the economic analysis of conservation programs

(3) To describe alternative perspectives or accounting stances for estimating economic effects

BACKGROUND

As stated in the **Introduction** to this manual, water conservation is any "beneficial" reduction in water use or water losses. More specifically, the total beneficial effects (benefits) of the reduction in water use and/or water losses resulting from implementation of a conservation measure should be greater than the adverse effects (costs).

Prior to the analysis of benefits and costs, implementation plans must be developed for conservation programs (see **Step 3**). Each conservation alternative must be carefully formulated because the implementation conditions will affect the determination of potential benefits and costs. A conservation alternative can be analyzed separately under varied implementation conditions.

The analysis of benefits and costs of conservation programs is essential for water supply planning. Before allocating resources to the implementation of conservation programs, planners and administrators must conduct analyses to determine whether the program can achieve "beneficial" reductions in water use. A benefit-cost analysis enables supply augmentation alternatives (e.g., the construction of a new reservoir) to be compared to demand management alternatives (e.g., conservation) using the same economic criteria. A benefit-cost analysis also enables planners to evaluate the effect of water use reductions resulting from water conservation on the sizing and timing of future water facilities. Benefit-cost analyses can also be used to compare the potential economic impacts of alternative conservation programs and therefore can provide guidance on which programs to implement.

TYPES OF BENEFITS AND COSTS

There are several types of benefits and costs typically associated with water conservation alternatives (Table 4-1). The following types of benefits and costs of water conservation are usually evaluated.

Costs

Certain costs of implementing water conservation alternatives result directly from reduction in water use and the consequent changes in the need for acquiring new supplies or in the scale and/or timing of planned water supply facilities. Other costs are related to conservation program implementation (to both the utility and the customers).

Each water conservation alternative is associated with a proposed implementation plan. The implementation plan indicates the agency or agencies responsible for implementation of the conservation program, the time of implementation, the coverage of the measure, and the specific actions that must be taken to implement and maintain the measure. These details are used to estimate implementation costs, including those occurring at the time of implementation and those required to maintain the program's full effectiveness in the future. Implementation costs are also estimated separately by the type of organization to which they accrue. Costs borne by a water utility (i.e., utility program costs) are stated separately from those borne by water users (i.e., customer program costs), by public interest groups, or by public agencies other than the water utility. Each water conservation alternative must also be reviewed to determine whether any additional costs can be expected to result from its implementation. When such effects can be found, their future levels should be estimated and evaluated.

If water use reductions are expected to alter the scale and/or timing of planned water use facilities, consideration must be given to the effect of such changes on other users of water resources. The water supply plan should be analyzed to determine (1) economic benefits expected to be realized from other purposes and (2) the sensitivity of those benefits to water use-related changes in scale or timing. The relationship between water use reduction, facility scale, and timing must be determined. Foregone economic benefits should be determined as a function of the appropriate dimensions of water use (average-day, maximum-month, etc.).

Each potential water conservation alternative should be reviewed to determine whether any costs to environmental quality are likely to occur. For example, if sprinkling restrictions are likely to result in brown lawns and damaged shrubbery, such consequences may be considered a cost to the community as a whole in addition to constituting a cost to the property owner. Whenever such effects are found, they must be quantified to the extent possible for each measure.

TABLE 4-1
EXAMPLES OF BENEFITS AND COSTS
FOR WATER CONSERVATION ALTERNATIVES

Benefit/Cost Category	Examples
(A) Costs	
(1) Utility program costs	Labor, materials, economic incentives, related to implementing conservation program
(2) Customer program costs	Materials, installation, operations and maintenance costs, related to implementing conservation measures
(3) Other economic costs	Increased energy costs for air conditioning due to reduced shading from trees (i.e., from converting from shade trees to xeriscape landscaping)
(4) Reduced aesthetic value	Decreased customer satisfaction due to the replacement of lush green lawns with xeriscaping
(5) Reduced revenues	Without rate adjustments, reduced water use leads to reduced revenues
(B) Benefits	
(1) Reduced short-run incremental costs	Lower costs of chemicals, energy, labor, and materials
(2) Reduced long-run incremental costs	Lower costs of capital facilities for water supply, wastewater disposal facilities
(3) Energy savings	Reduction in the use of heated water
(4) Other economic benefits effects	Reduced costs of lawn maintenance (fuel, labor) in efficient irrigation
(5) Environmental quality	Reduced damage to natural water sources
(6) External costs	Reduced pumping costs by farmers due to reduced drawdown of groundwater

Benefits

The benefits of water conservation alternatives arise from the reduction in water use and/or water losses. Some of the benefits are related to the reduction in water supply costs. These types of benefits require knowledge about existing water supply costs as well as information regarding planned future expansions in water supplies and/or facilities (i.e., a water supply plan). Other benefits are indirectly related to reductions in water use and do not require knowledge about the water supply plan (e.g., energy cost savings).

Implementing water conservation alternatives may reduce the short-run incremental costs of water supply and wastewater disposal. The water supply plan must be analyzed to determine expected short-run incremental costs associated with the last units of water to be produced or purchased in various years of the planning period. Short-run incremental costs are those costs that are immediately changed in response to changing use patterns, and are not associated with capital facilities. They include the costs of chemicals, energy, labor, materials, etc. These costs should be identified separately for existing and planned facilities, including wastewater collection, treatment, and disposal facilities as well as water supply facilities.

Long-run incremental costs of water supply and wastewater disposal may also be reduced. Therefore, the water supply plan must also be analyzed to determine the expected long-run incremental costs associated with the last increments of capacity that are to be provided in various years of the planning period. Long-run incremental costs are those costs associated with providing capital facilities for water supply and wastewater disposal. These costs vary as the design capacity of the facilities varies; design capacity varies as a consequence of changes in patterns and levels of water use. The foregone costs of new supply facilities may be a major benefit of the conservation program.

Water conservation alternatives that affect the use of heated water in residential, commercial, and industrial sectors should be examined for potential energy cost savings based on the average-day reduction in the use of heated water for each measure. Also, each water conservation alternative should be reviewed to determine if any additional advantageous economic effects can be expected. If such effects can be found, their future levels should be projected and evaluated.

Reduced costs to parties other than the water utility and the participant must also be considered as benefits. If water conservation reduces overall water use and therefore reduces the pumping costs for someone else drawing out of the same water source, the conservation measure has benefitted someone unrelated to the water utility and its customers.

In many cases, water conservation reduces extraction of water from rivers and groundwater, thereby increasing the amount of water available for environmental purposes. Increased environmental supplies can have significant benefits for fish, wildlife, and water quality.

COSTS OF CONSERVATION PROGRAMS

Water utilities incur costs to implement water conservation programs and, in some cases, customers also incur costs to perform specific recommended actions. Cost estimates are necessary so that benefit-cost analyses can be completed and used to justify utility budget requests. This section provides some guidelines on cost estimating.

Utility Program Costs

Costs for water conservation programs vary not only with the implementation method (contract out or in-house) but also with the size of the program and the extent of the evaluation planned. Listed below are cost equations describing the two types of programs:

Contracted program cost =
Administration cost +
(number of sites * Unit cost per site) +
publicity cost + survey cost + evaluation cost (4.1)

In-House program cost =
Administration cost +
(field labor hours * labor hourly rate (with overhead)) +
publicity cost + survey cost + evaluation cost (4.2)

Administration Costs

Administration of contracts and field labor forces requires staff time. Typically, the newer the program or the larger the contract, the higher the administration cost. Administration cost is usually in the range of one half-time staff for small programs, such as a low-key public relations program, to two full-time staff persons for very large programs (such as a citywide residential retrofit program of 50,000 dwellings or more per year). The preferred cost-estimating method is simply to plan the work and determine the staffing. As a rough guideline, the administration cost is about 10 to 15 percent of the total of other program costs.

Unit Costs

Most costs of retrofit kit distribution, rebate, or audit type programs can be estimated on a per participant basis, provided that the program is large enough so that the unit costs are constant. Small pilot or demonstration projects have high unit costs because of the small number of sites involved. Retrofit programs above 10,000 units, residential audit programs above 500 units, and commercial/industrial audit programs above 50 to 100 sites generally can be expected to have constant unit costs. Table 4-2 shows typical unit costs, exclusive of administration, survey, and evaluation components.

TABLE 4-2
TYPICAL UNIT COSTS

Program	Equipment Used	Cost Per Site[a]
Residential retrofit		
Canvass style	Showerheads (2) Dams (2)	$15
Mailed kits	Flow restrictors (2) Displacement bag (1)	$1
Home water audit	Same as canvass Retrofit plus hose Timers	$40
Commercial/industrial audit	None	$2-5,000
Large turf audit	None	$100[b]

Source: Brown and Caldwell, personal communication.
[a]Contract cost includes equipment and field labor, 1990 dollars.
[b]Per irrigated acre.

Field Labor Costs

Large-scale programs that are done in-house require temporary help. Home water audit programs have been done this way by North Marin Water District, Contra Costa Water District, and the city of Pasadena. By running these programs in the summer, students can be hired for about $7 to $9 per hour. Once the auditors are trained, they can audit 3 to 4 homes per day, if the auditor sets his/her own appointments, and 4 to 6 homes per day if a scheduler is employed.

Commercial/industrial audits are much more complex than home water audits and information is limited on the costs of such audits. Specialized training in process water use, cooling water use, and employee sanitary-use efficiencies is necessary for persons conducting commercial/industrial audits. Costs vary with the complexity of the sites and the goals of the audit. A single audit may require a few days to a week or more. The time required can be estimated by preparing a work plan for an audit of a typical site and estimating the number of hours to carry out the work. Labor rates are typically in the range of $15 to $20 per hour.

Large landscape water audits can involve two auditors for a half-day to several days, depending upon the size and type of irrigation system at the site. Labor rates for turf auditors are in the range of $12 to $15 per hour.

After base labor cost has been estimated for nonresidential audits, an allowance for the difficulty in completing the audit should be made. This allowance covers the cost of scheduling, missed appointments, equipment breakdowns, extra data processing, follow-up site visits, etc. In some cases, these factors have been found to double the original estimate of the amount of labor required.

Publicity Costs

All water conservation programs require publicity to achieve the targeted customer participation rate. Publicity can take one or more of the following forms:

(1) Radio and/or television spots
(2) Mailed flyers
(3) Water bill inserts
(4) Billboards
(5) Booths
(6) Announcement letters
(7) Invitational workshops

For large programs, such as communitywide retrofit or rebate programs, water utilities often consult public relations professionals to design and implement the public information program. Small programs, on the other hand, can usually be handled in-house. Costs are usually proportional to the number of customers contacted or exposed to the publicity. As a rough guideline a cost range of $0.50 to $1.00 per household or customer should be used for large-scale programs.

Evaluation Costs

Two types of evaluations can be performed:

(1) Process evaluation (of program implementation efficiency)
(2) Impact evaluation (of water savings)

An evaluation of program efficiency (process evaluation) includes an analysis of how the program was carried out by the utility and/or contractor. Some factors to be measured may include customer contact and installation rate, customer satisfaction, what problems occurred, and how any problems were overcome. (See **Step 6** for more detailed discussion of process evaluation.)

Surveys can be used to measure customer attitudes and program participation/installation rates. They can also be used to collect customer-specific data to assist in determining water savings. Surveys can be conducted either in person, by mail, or by telephone. Survey costs increase with the number of questions asked and the number of completed surveys needed to achieve a certain level of confidence in the results. Telephone water conservation surveys normally contain about 20 to 40 questions and cost about $3,000 to $10,000, depending upon the number of persons contacted and the extent of the data tabulations and reports required. For the same target population, mail surveys tend to be less expensive than telephone interviewing. The costs of mail surveys depend on printing/duplication of survey instruments, postage, and survey administering.

An evaluation of water billing and other data, according to the methods outlined in this manual, is essential to documenting the amount of water saved. Because this type of analysis is relatively new in the water industry, the costs for recently evaluated programs vary considerably. Thus far, this type of rigorous statistical analysis has typically been done by consultants. One of the important cost factors is the ease/difficulty of extracting data in a usable format from the utility's billing system. Most utilities store the most recent 12 to 15 prior meter readings on their computer system, and these data are becoming more readily available on electronic media. Obtaining older water consumption records is sometimes more difficult, because the data may have to be entered into a database by hand from hard copy (or microfiche).

Evaluation costs of large-scale residential audit or retrofit type programs have ranged from $35,000 to $70,000 (excluding survey costs). Evaluation of nonresidential audit programs is usually included in the audit package, at least on a site by site basis. In general, the amount of money to be spent on the program evaluation depends on many factors, including the relative importance of the conservation program in the long-term water management plan. It also depends on the agency budget and any pending decisions regarding the program. "Rules of thumb" are difficult to devise here. In the electric utilities industry, one such "rule of thumb" suggests that investments in program evaluation should range from 3 to 20 percent of program costs, depending on the type of program.

It should be noted that some agencies may not want to include survey and evaluation costs in a cost-benefit analysis. Although these costs are not necessary for implementation, they are necessary to evaluate the success of the program. See **Steps 6 and 7** in **Part II** of this manual.

Decreased Utility Revenue

As a result of reduced water use due to conservation, water utilities may experience reduced sales and, hence reduced revenue. Therefore, reduced revenues may be considered as a program cost. (It should be noted that although utility revenues may decrease due to conservation, the utility will also receive cost savings from the reduced variable costs from purchasing, treating, and pumping less water. These benefits are described in following sections.)

If the reduced revenues lead to budget shortfalls, the answer may be to raise water rates to cover the shortfall. Because the decrease in revenues due to long-term conservation is relatively small and tends to be gradual (over time), the impacts can be easily factored into future rate studies, and rates can be raised as needed.

Customer Program Costs

Most water conservation programs rely on the customer to install a device or modify a behavior based on educational information, products, or assistance provided by the utility. In nonresidential programs, the customer cost can be substantial. Audits may recommend an investment in new water-saving equipment. These audits should include an analysis of the economic consequences resulting from the recommended conservation actions. There are no general guidelines for customer costs; each site-specific program must be analyzed individually. Costs to residential customers must be considered; those customers who feel that the program will cost them too much will not participate. Following is a list of some of the costs to participating customers.

Equipment, Materials, and Installation Costs

If residential customers are required to purchase special fixtures or other equipment to participate in the program, these costs must be considered in a benefit-cost analysis. However, one way to promote customer cooperation and offset customer installation costs is to design a rebate program. In programs such as ULF toilet rebates, the rebate serves two purposes. First, it may help to promote participation by helping to offset the customer's cost of installation. Second, it rewards the customer for the avoided cost experienced by the utility. The level of cost reduction for the utility resulting from the conservation action must obviously be considered when setting the amount of the rebate.

Operations and Maintenance Costs

In the case of a nonresidential water audit, it may be recommended that businesses invest in water-saving equipment. If there are costs associated with the operation and maintenance of this equipment that the business did not previously incur, these costs must be considered.

BENEFITS OF CONSERVATION PROGRAMS

Benefits of water conservation programs accrue separately to water, energy, and wastewater utilities and to the utilities' customers. Careful accounting can allocate the benefits to the proper beneficiary. Not all benefits can be quantified, and nonquantifiable benefits must be dealt with outside of the quantitative economic analysis. The benefits of water conservation programs are based upon average annual water savings, and these benefits depend upon how the water savings develop over time. The easiest method to arrive at average annual savings is to determine the total aggregate water savings over the planning period and divide by the number of years for the analysis.

$$\text{Average annual water savings} = \left(\sum_{t=1}^{n} Q_t\right) / \, n \qquad (4.3)$$

where

Q_t = water savings in year *t*
n = number of years in analysis

Utility Cost Savings

Reduced water demand may save utilities money as a result of:

(1) Reduced water purchases
(2) Reduced operation and maintenance expenses
(3) Deferred, eliminated, or downsized capital facilities

By saving the utility money, all three of these result in freeing capital for alternative purposes. Reduced water demands may also increase the reliability of existing water supplies; however, quantifying this effect would be difficult.

Reduced Purchases of Raw or Finished Water

Average water savings to the utility can be valued at the variable cost of existing sources of water, such as the cost of water purchased from a water wholesaler. The variable cost should represent the utility's most expensive source or the source most likely to be cut back if water demand is reduced. The utility usually knows which source of supply would be cut back and what the unit cost savings would be from that particular source.

Sometimes, a water utility must contract to purchase a minimum volume of water regardless of actual needs. In this case, only water above this limit can be considered when calculating purchased water costs.

$$\text{Unit cost of purchased water} = \frac{[\text{Annual water purchase costs} - (12 * \text{monthly fixed charges})]}{\text{Units of water used}} \qquad (4.4)$$

Reduced Operation and Maintenance Costs

Energy and chemical costs are directly related to the amount of water processed. Similarly, energy and chemical costs associated with wastewater treatment and disposal are directly related to the volume of wastewater discharged. Energy costs associated with pumping can be reduced at the wellhead, water treatment plant, distribution system, wastewater collection system, and wastewater treatment and disposal facilities. The use of chemicals that are used in both water and wastewater treatment (such as chlorine and various coagulants) may be reduced as well.

Variable electric and/or natural gas costs can be determined by evaluating annual electrical or gas utility bills and subtracting those portions of the bills for such things as heating and lighting of buildings and process equipment energy use (e.g., a clarifier mechanism that operates continuously regardless of the production rate). Normally, an electric or gas utility bill will also have a fixed charge that must also be subtracted. Equation (4.5) illustrates how to calculate variable energy costs.

Cost of energy per unit of water =
[(Annual energy bill) - (12 * monthly fixed charges) -
(nonwater production-related energy cost)] /
[units of water used] (4.5)

Variable chemical costs are calculated by subtracting fixed chemical costs (those that are independent of the volume of water production) from total chemical costs. From a practical standpoint, most chemical costs can be considered variable. However, if fixed chemical costs exist, variable chemical costs can be calculated in a manner similar to variable electrical costs (using Equation 4.5) and expressed in dollars/1,000 gallons. Sometimes, energy, chemical, and purchased water unit costs are a function of the amount purchased (e.g., $1/100 lb up to 1 ton and $.85/100 lb over a ton), and this must be taken into account.

The combined energy and chemical cost savings should be converted to dollars saved per unit of water saved, as illustrated in Example 4-1, by dividing annual cost savings by annual water savings.

Summary of Variable Costs

As indicated above, it is important to determine the impact of reduced water use (resulting from conservation) on variable costs (energy, chemical, water purchases). To do this accurately, certain utility operating characteristics must be considered. For example, in the case of multiple treatment plants, it must be determined how water savings will be distributed between the plants in order to calculate cost savings accordingly. Other factors that must be considered include multiple water sources, multiple pressure zones, and contractual agreements regarding water purchases.

The variable water utility costs are calculated as follows:

Variable cost per unit volume of water =
Variable water energy costs +
variable water chemical costs +
variable water purchased water costs +
variable hydroelectric power costs (4.6)

EXAMPLE 4-1
EXAMPLE CALCULATION OF ENERGY COSTS

The following example illustrates how to determine electrical variable costs. These variable costs are expressed as the electrical costs to treat and distribute a certain volume of water. The same method can be used for gas costs.

Given: Annual energy bill is \$174,996
Annual water use is 500,000,000 gallons
Fixed energy charge per month is \$1,042
Annual energy cost that is not related to water production (estimate) is \$62,500

$$\text{Electrical variable cost} = \frac{\$174{,}996 - (12 \times \$1{,}042) - \$62{,}500}{500{,}000{,}000} = \$0.20/1{,}000 \text{ gallons}$$

The calculation of variable wastewater utility costs can be made in the same way. Variable electrical energy costs are evaluated by reviewing annual electrical and chemical bills. If wastewater treatment is contracted to another agency, the variable portion of the cost for this service must be included as well. Wastewater discharge reduction resulting from water conservation is approximately equal to the reduction in indoor water use (water use that is normally discharged as wastewater). Therefore, in order to calculate wastewater utility savings, it is necessary to separately determine the impact of conservation measures on both indoor and outdoor water use.

Variable cost per unit volume of wastewater discharged =
Variable cost of wastewater energy +
variable cost of wastewater chemicals +
variable cost of wastewater disposal (4.7)

Water cost savings are computed by multiplying the average annual reduction in total water use (Equation 4.3) by the appropriate unit variable costs (Equation 4.6). Wastewater cost savings are calculated by multiplying the average annual reduction in wastewater discharge (indoor water use) by the appropriate unit variable costs (Equation 4.7).

Deferred, Eliminated, or Downsized New Facilities

Studying the effect of water use reductions on the timing and need for additional water facilities necessitates the determination of the reduction in both average-day and peak-day demands. Peak-day water use occurs in the summer and is caused by landscape irrigation and, to a lesser extent, cooling. Although indoor conservation measures will also reduce peak-day demands, savings in landscape and cooling water use can have greater effects on reducing the peak. In cities with arid climates, peak to average day ratios of 2.0 to 3.0 are common. The peak-day ratio can be determined from analysis of the utility's water production records using the following formula

$$\text{Peak-day ratio} = \text{maximum-day production/average-day production} \qquad (4.8)$$

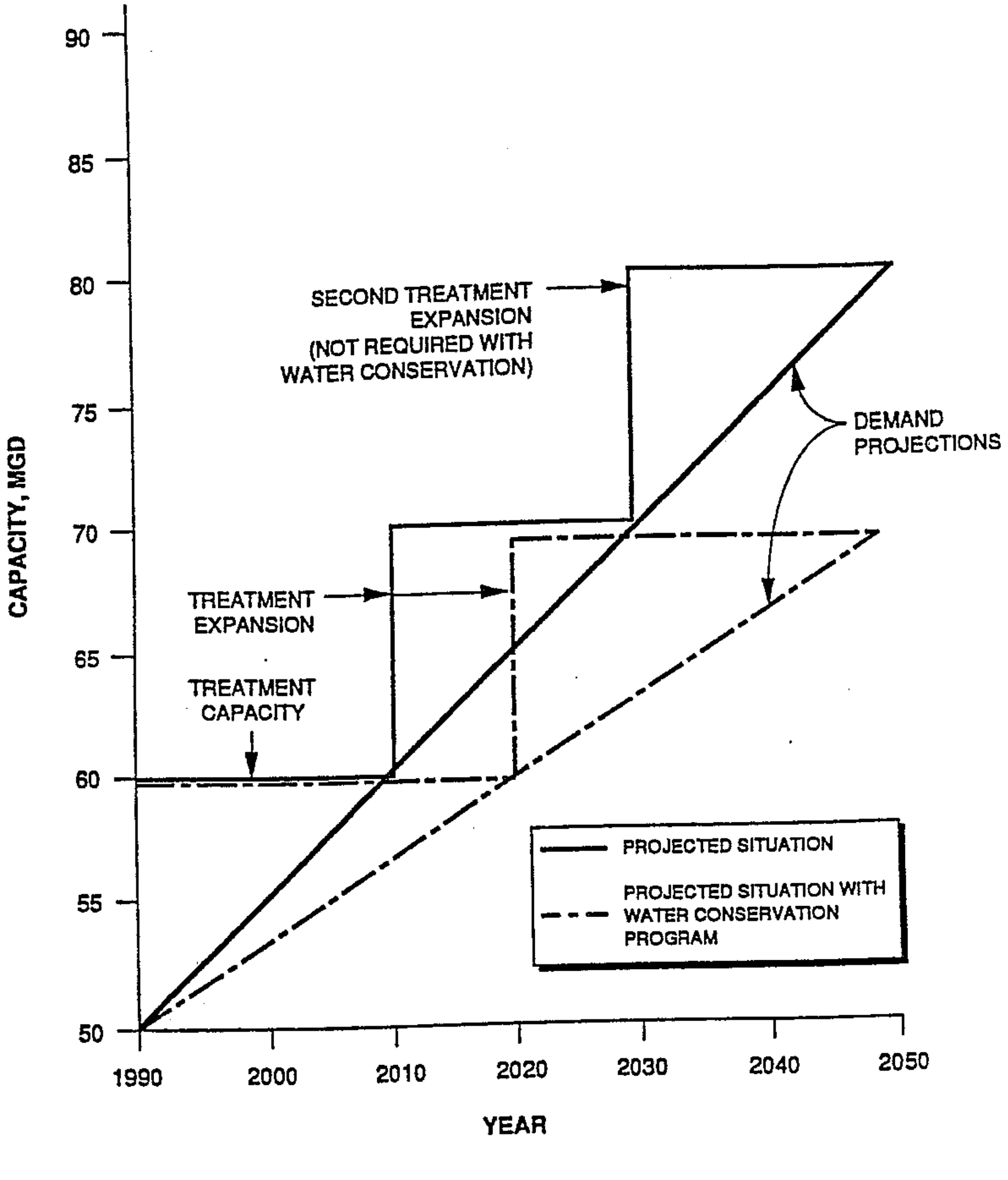
Reductions in seasonal water use may have a misleading effect on the peak day ratio. This results from the fact that reductions during high-usage seasons will have a greater effect on maximum-day water usage than on average water usage, providing an inappropriately low ratio.

The timing of capital facilities depends on the rate of growth in both peak and annual water demand and on the physical condition and capacity of existing facilities. If the planned facilities are dependent upon growth in water demand, then water conservation can have an important impact on the timing of the construction of these facilities. Figure 4-1 shows an example of how water conservation was able to affect the timing of water treatment plant expansions in Boulder, Colorado (Brown and Caldwell, 1990). In this case, a treatment plant expansion that would have been needed in the year 2010 could be delayed 10 years and the second expansion could be delayed 20 years. These delays were based on the estimate that the city's water conservation program would reduce peak-day demands by 10 to 15 percent. The resultant dollar savings to the utility is the difference in the present value of the relevant costs associated with building the plant in 2020 versus building the plant in 2010.

The sizing of capital facilities also depends on the rate of growth in peak-day and average-day water demand. When water demand begins to level off as growth slows down and the last facility expansion is being planned, a lowering of demand through conservation also implies that the last expansion can be downsized. The savings can be expressed as the reduction in the present value of relevant costs associated with a smaller facility as compared to those associated with a larger facility.

Identifying the cost savings to utilities resulting from deferring, eliminating, and/or downsizing facilities involves reviewing the plans for all new capital facilities in light of reduced water needs. The types of facilities most likely impacted and the principal design criteria (based on water demands) are:

FIGURE 4-1
PROJECTED DEMAND AND REQUIRED TREATMENT CAPACITY EXPANSION, BOULDER COLORADO



(1) Raw water storage reservoirs - average-day demand
(2) Raw water transmission lines - peak-day demand
(3) Water treatment plants - peak-day demand
(4) Distribution system storage and pumping stations - peak-day or peak hour demand
(5) Wastewater treatment plant hydraulic loading - peak wet weather flows

Modifying the sizing or timing of these facilities necessitates a review of the supporting engineering calculations usually found in the utility's master plan or predesign report. In most cases (e.g., water treatment plants and transmission mains) the size of the facility is directly related to the peak-day demand. In some cases, however, it may not be entirely related to customer demand, such as in the case of distribution system reservoirs that also provide storage for fire flow and emergencies. These facilities can be resized to meet peak demand that is not affected by water conservation.

In the case of wastewater treatment plants, it is necessary to separate those processes related to hydraulic loading from those related to solids loading. Hydraulic loading is dependent on peak-day wastewater flows. This is greatly affected by infiltration and inflow from the collection system and, to a lesser extent, by indoor water conservation. The reduction in peak wet weather wastewater flows can be used to determine how to downsize or postpone additions to processes that are sensitive to hydraulic loading.

For example, if planning studies initially call for the construction of a large storage reservoir to accommodate a growing future demand of 100 million gallons per day (mgd) in year 2010, and a water conservation program is designed to save an average of 10 mgd in the year 2010, then it is possible to delay or downsize this construction project. Most facilities that are downstream of raw water storage facilities are sized based on peak-day demands. Therefore, alternatives such as the need for another pump to accommodate 20 mgd of peak-day demand should be compared to a conservation program that reduces peak-day demands.

A delay, downsizing, or elimination of new facilities will result in economic benefits. The following calculations can be used to determine the benefits (in the year the benefit occurs) under various scenarios.

Scenario 1: Project is **downsized**

CC = cost at initial size - cost at downsize

where
CC = resultant cost savings in original year of construction

Scenario 2: Project is **delayed**

$$CC = (\text{cost in initial year}) - \frac{(\text{cost in delayed year})}{(1 + i)^n}$$

where

CC = resultant cost savings in original end year of construction
n = number of years project is delayed
i = project interest rate (i.e., rate of return that could be earned by project funds)

Scenario 3: Project is **eliminated**

CC = cost in year of construction

where

CC = resultant cost savings in original end year of construction

Program Participant Benefits

Incentives

If the tax incentives or rebates paid to participants exceed the cost for them to participate, this incentive must be counted as a net benefit.

Customer Cost Savings

Customers who save measurable amounts of water through conservation are likely to benefit from reductions in their utility bills - water, wastewater, and energy. This can be calculated for the entire service area by multiplying the total average annual water savings by the marginal commodity rate. Customers also save whatever costs would have been incurred by purchasing alternative equipment. Some guidelines are presented below.

***Reduced Water Bills*.** The cost savings to the customer are calculated as the product of water savings and the customer's marginal commodity rate, which may depend on the customer's usage. Most water utilities have adopted a uniform commodity schedule, but some also have a lifeline rate for minimal residential use and/or inclining or declining block commodity rates. Some utilities have different rates for different customer classes, so the value of the savings should be tabulated separately for each class. The commodity rate of water is usually expressed as dollars per one hundred cubic feet (CCF), which can be converted to dollars per thousand gallons by multiplying by 1.34.

For complicated commodity rate structures (inclining or declining block structures), savings can be estimated by evaluating a random sample of customer water bills to determine the average variable cost per customer. This is easier than determining how many customers use water in which billing rate commodity block and for how long each year.

$$C_{cw} = \sum_{i=1}^{n} \frac{1}{n} \left[\frac{(\$ \text{ total bill} - \$ \text{ fixed costs})}{(1{,}000 \text{ gallons usage})} \right]_i \qquad (4.9)$$

where

C_{cw} = the variable customer cost/1,000 gallons
n = the number of random observations to achieve the statistical accuracy desired

Reduced Wastewater Service Bills. The reduction in wastewater discharge is typically equal to indoor water savings from a conservation program. There are several methods used by utilities to bill for wastewater service.

Nonresidential customers usually pay a fixed monthly service charge plus a rate per unit of flow. The flow charge is usually expressed in dollars per thousand gallons of flow. In this case, the cost savings to the customer can be calculated as the product of water savings and the customer's commodity rate, which may depend on the customer's usage. It should be noted, however, that some wastewater agencies include an additional charge for industrial customers based on average suspended solids concentration. In this case, reduced sewer discharges could contain a more elevated suspended solids concentration, thereby actually increasing wastewater service bills.

There are several ways that residential customers are billed for wastewater service including:

(1) A fixed monthly charge plus a unit charge per unit of water use
(2) A fixed monthly charge that may be based on the customer level of water use in winter
(3) Annual property tax bill
(4) Ad valorem tax levies

In the first case, the interior water savings together with unit costs can be used to approximate customer cost savings. In the second case, there is no direct benefit to the customer from flow reductions unless the winter season use affects the fixed charge. In the third and fourth cases, there are no direct cost savings on wastewater service bills because the charges are unrelated to water use.

Reduced Energy Bills. Customers will save energy because of reduced hot water use. Energy savings can be significant when low-flow showerheads are installed in housing units, public facilities, and in certain types of commercial establishments (e.g., hotels, health spas). Reduced hot water use can also occur in industrial processes.

Variable electrical or gas energy unit costs are best calculated by evaluating a random sample of customer bills. Again, the fixed costs must be subtracted out. The following formula is used to determine average variable customer energy costs.

$$C_{ce} = \sum_{i=1}^{n} \frac{1}{n} \left[\frac{\text{(total bill - \$fixed cost)}}{\text{(energy usage for same period)}} \right]_i \qquad (4.10)$$

where

C_{ce}	=	the variable customer cost/energy unit
n	=	the number of sampling units in a random sample taken to achieve the statistical accuracy desired

The annual energy savings (AES) for a hot-water-saving device can be determined from the following formula:

$$AES = DHWS * 8.34 * 365 * (T_s - T_i) * (1/e) \qquad (4.11)$$

where

AES	=	annual energy savings for a water-saving device (BTU per capita per year)
DHWS	=	daily hot water savings of the device (gpcd)
8.34	=	energy required to raise 1 gallon of water 1°F (BTU)
365	=	number of days per year
T_s	=	temperature at device outlet (°F)
T_i	=	incoming water service temperature (°F)
e	=	water-heating efficiency as a decimal

Table 4-3 lists typical energy savings associated with certain residential conservation measures. Included in the footnotes to Table 4-3 are typical values for water-heating efficiency, *e*. Values in the table are computed from the water savings shown and the assumed water temperatures and other parameters detailed in the footnotes (Maddaus, 1987). Incoming service water temperatures have been found to average 62°F, and preferred shower water temperatures

TABLE 4-3
ENERGY SAVINGS ASSOCIATED WITH RESIDENTIAL WATER CONSERVATION

Device	Water Saved gal/day/person[1]	Annual Energy Saved per Person: Gas Water Heaters therm/year[2]	Annual Energy Saved per Person: Electric Water Heaters kWh/year[3]	Value of Energy Saved per Person $/year: Gas[4]	Value of Energy Saved per Person $/year: Electric[5]
Low-flow shower-heads, 2.75 gpm	7.2	11.6	275	8.3	33.0
Water-saving dishwashers	1.0	3.0	71	2.2	8.5
Water-saving clothes washers	1.7	5.1	121	3.7	14.5
Total	9.9	19.7	467	14.2	56.0

1. 104°(40°C) water for shower, 140°F(60°C) water for dishwasher and clothes washer.
2. 79% efficiency. Source: The California Appliance Efficiency Program-Revised Staff Rept. Calif Energy Conser. and Devel. Comm., Conser. Div. (Nov. 1977).
3. 98% efficiency. Source: ibid.
4. $0.72/therm.
5. $0.12/kWh.

Source: Maddaus, 1987.

are 104°F (Brown and Caldwell, 1984). Because using electricity to heat water is more expensive than using gas, the cost savings are larger for programs involving customers using electric hot water heating. Gas water heating, however, predominates in most areas of the country. It is necessary to know the relative ratio of gas to electric heating to accurately forecast the value of energy savings. Energy savings produce a significant rate of return on low-flow showerhead retrofit programs, commercial laundry recycling, and other hot water process changes.

BENEFIT-COST ANALYSES[1]

One of the primary goals of a water conservation program is to be economically efficient. The larger the savings and smaller the costs to implement, the more favorable the program. However, it is worth noting that in some cases, the costs of a conservation program may be too great to even be considered for implementation (due to budgetary constraints), regardless of the potential benefits. If this is the case, those programs that are outside budgetary limitations can be eliminated from further analysis.

Alternately, in some cases (i.e., water supply shortages), conservation programs must be implemented, although it is not beneficial in an economic sense (e.g., benefit-cost ratio not greater than one). In this case, benefit-cost analyses can be used to rank the most economically optimal and effective program.

This section describes various methods of evaluating water conservation programs using the notions of costs and benefits developed in the prior sections. All of these methods take into account the time value of money, that is, the fact that a dollar today is worth more than a dollar a year from now.

Six standard methods of economic analyses can be performed to evaluate relative costs and benefits. They are (1) net present value; (2) benefit-to-cost ratio; (3) internal rate of return; (4) discounted payback; (5) life-cycle revenue impact; and (6) levelized costs. These six methods follow the guidelines of the Standard Practice Manual for the Economic Analysis of Demand-Side Management Programs of the California Energy Commission (1987). While each analysis is correct and uses similar input, the output is expressed differently. All methods are valid analyses, but some agencies may have a preference as to which method is used. Having collected the background economic data (costs and benefits), it is possible to evaluate water conservation alternatives using one of the six economic analysis methods. These methods can be used to evaluate one particular conservation measure or a number of measures being implemented together.

Net Present Value

The net present value (NPV) method provides a comparison of costs and benefits throughout the life of the conservation project. The NPV of a project is calculated as the difference between the net present value of benefits and the net present value of costs. A project

[1]This section draws from the work of the California Public Utilities Commission (CPUC) and the California Energy Commission (CEC), 1987, Standard Practice Manual: Economic Analysis of Demand-Side Management Programs.

with a positive (>0) NPV is economically viable. The following equation is used to perform this analysis.

$$\text{Net Present Value} = \sum_{t=1}^{n} (B_t - C_t)/(1 + i)^t \qquad (4.12)$$

where

B_t	=	all applicable benefits in year *t*
C_t	=	all applicable costs in year *t*
i	=	selected interest (discount) rate (see discount rate selection discussion, p. 110)
n	=	number of years in the time period selected for analysis (see discussion of time period for analysis, p. 111)

Appendix B provides an example of the use of Equation (4.12).

Benefit-to-Cost Ratio

The benefit-to-cost ratio is another commonly used method of measuring economic efficiency. This method determines the ratio of the net present value of benefits to the net present value of costs. Those conservation measures with a benefit-to-cost ratio greater than 1.0 are economically efficient. The method of calculation is

$$\text{Benefit-cost Ratio} = \sum_{t=1}^{n} \frac{B_t}{(1+i)^t} \Big/ \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} \qquad (4.13)$$

Sometimes the ratio of net benefits to cost is used in the benefit-to-cost ratio. This ratio can be express as

$$\sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+i)^t} \Big/ \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} \qquad (4.14)$$

Using this form of the benefit-to-cost ratio, those conservation measures with a benefit-to-cost ratio greater than zero are economically viable. Appendix B provides an example of the use of the benefit-to-cost ratio method.

Internal Rate of Return

The discount rate used in the net present value and benefit-to-cost ratio methods for determining efficiency is subject to debate (see discussion on p. 110). A that which does not require the selection of a discount rate is the internal rate of return (IRR) method. The IRR is the discount rate that equates the present value of expected future benefits to the present value of costs. It is a calculated figure as opposed to a given discount rate. The equation for calculating this rate is

$$\sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+IRR)^t} = 0 \qquad (4.15)$$

In the above equation, we know the values of C_t and B_t, but we do not know the value of IRR. We have one equation with one unknown which can be solved for IRR. Because the equation is nonlinear, there may be more than one IRR that solves the equation. This is a problem which often limits the use of the IRR method.

As stated earlier, the discount rate to be used in analyses can be subject to considerable debate. If the internal rate of return (IRR) criterion is used and a unique solution to Equation (4.15) is found, an investment brings net benefits if the IRR exceeds either the cost of capital or the alternative investment rate for the agency. The IRR provides an indication of the sensitivity of the results to the interest rate chosen. For example, if the IRR is twice as high as the threshold interest rate for a particular conservation measure, the efficiency of the measure is not sensitive to a small change in the interest rate. Thus, it is not necessary to devote much time to examining the interest rate to be used in the analysis of that measure.

Discounted Payback

The discounted payback method is used to estimate the consumer's perception of future benefits and costs. The discounted payback is the number of years it takes until the cumulative discounted benefits equal the cumulative discounted costs. Participants will prefer a shorter discounted payback period.

DP = minimum *j* such that

$$\sum_{t=1}^{j} \frac{B_t}{(1+i)^t} > \sum_{t=1}^{j} \frac{C_t}{(1+i)^t} \qquad (4.16)$$

where

DP = discounted payback in years
j = first year in which cumulative benefits are > cumulative costs

Life-cycle Revenue Impact

The life-cycle revenue impact (LRI) measures the direction and magnitude of a one-time change in water rates resulting from implementation of a particular conservation program. LRI will be positive for conservation programs that over their lifetime will cause an increase in water rates. LRI will be negative for programs that decrease rates.

$$LRI = \frac{\sum_{t=1}^{N} \frac{(UC_t - UB_t)}{(1+i)^t}}{E} \tag{4.17}$$

where

UC_t = utility costs in year *t* from program
UB_t = utility benefits in year *t* from program
E = number of customers in first year or discounted water savings as defined with levelized costs

Instead of calculating one number representing the life-cycle revenue impact over the duration of the program, one can calculate the LRI for each year of the project. This gives a more detailed look at the year-to-year cash flow changes caused by the program (see the Standard Practice Manual: Economic Analysis of Demand-Side Management Programs by the California Energy Commission (CEC) and California Public Utilities Commission (CPUC), 1987).

Levelized Costs

Levelized cost is a measure of the total costs of utility-owned supply additions. It represents the total costs of the program to the utility and its ratepayers on a per unit basis levelized over the life of the program. (A more detailed description is provided in CEC and CPUC, 1987).

$$LC_{TRC} = LCRC/IMP \tag{4.18}$$

where

LCTRC = levelized cost per unit of the total cost of the resource
LCRC = total resource costs used for leveling
IMP = total discounted water savings of the program

$$LCRC = \sum_{t=1}^{N} \frac{UC_t + PC_t}{(1 + i)^t} \tag{4.19}$$

$$IMP = \frac{\sum_{t=1}^{N} \Delta Q_t}{(1 + i)^t} \tag{4.20}$$

where

UC = utility cost
PC = participant cost
TC = tax credit
ΔQ_t = reduction in net water use in year t

Selecting a Method

Different individuals and organizations will want to evaluate costs and benefits differently. For example, for mutually exclusive measures or in cases where the utility may consider reinvestment of its funds as an alternative, there are two basic conditions under which the NPV and IRR may make conflicting choices. The first condition is when the sizes of the potential conservation measures are different, meaning that the cost of one measure is larger than that of the other. The second condition is when timing differences exist; meaning the timing of savings from the two measures differs, with most of the savings from one measure coming in the early years and most of the savings from the other measures coming in the later years.

When the possibility of downsizing or delaying facility expansion exists, the utility will have different amounts of benefits and/or costs in various years, depending on which of the mutually exclusive measures it chooses. For example, if one measure costs more than the other, then the utility will have more money at time 0 to reinvest elsewhere if it selects the less costly measure. For measures of equal size, the one with the large early savings will provide more benefits for reinvestment. The NPV and IRR methods are based on different assumptions about how differential savings can be invested, this is called the reinvestment rate assumption, and it is a basic difference in their assumptions about the applicable reinvestment rate that gives rise to NPV/IRR conflicts.

Other Issues in Methodology

Selection of Discount Rate

Discounting future costs and benefits is an important part of the benefit-cost analysis. It allows the comparison of options with very different patterns of costs and benefits over time. If all else is equal, everyone would prefer to have their benefits earlier and costs later. Discounting to present worth is the method that enables recognition of this "time preference."

The discount rate to be used in this calculation can sometimes be quite controversial. Generally, it is based on an observable interest rate, which is another measure of time preference. Inflation is usually ignored in benefit-cost calculations by not escalating the real costs of implementation or benefits. Therefore, the interest rate chosen to represent the discount rate should be the real interest rate after removing the effects of inflation. There are three things that should be considered when selecting a discount rate.

(1) The analysis is forward looking. That is, it should reflect what is expected for interest rates over the lifetime of the project rather than current or past interest rates. However, these interest rates may be a good indicator of expected future rates. If current or recent interest rates are either unusually high or low, they should not be used in the analysis.

(2) The analysis is long-term. The projects being compared could have lifetimes of 5 to 50 years; the discount rate should reflect interest required for loans of similar maturities.

(3) The appropriate discount rate will vary according to the perspective being considered in the analysis.

Benefit-cost analysis that measures the impact on the utility or the utility's rates will have the same discount rate. In both cases, it should be tied to the utility's real, long-term bond rate. For a private utility, this should be the after-tax rate, because this is the true measure of the impact on the utility's cost structure and rates.

The choice of a discount rate to be used in benefit-cost analysis from a societal point of view is more problematic. It should be based on a pretax rate. Tax deductions do not decrease the societal interest rate but merely spread some of the payments from the ratepayer to the taxpayer. Second, it should be a long-term rate that is chargeable to society as a whole. There is no such blanket rate, but a composite might include mortgage loan and corporate bond rates.

Selection of Analysis Period

Selecting the appropriate analysis period is also subject to interpretation. There will be situations where the alternative conservation measures have useful lives different from the analysis period. Suppose that a retrofit measure was expected to have a 5-year useful life, or twice that of an irrigation workshop measure. In the evaluation (or comparison) of these two measures, the useful lives are different. For measuring costs and benefits, it is important to select a fixed analysis period and evaluate the efficiency of the conservation measures over this same period. A suitable analysis period should be based on an estimate of how long the particular water conservation measure is likely to be in place and performing its intended conservation role.

BENEFITS AND COSTS FROM DIFFERENT PERSPECTIVES[2]

Conservation programs affect several different groups including participants in the program, nonparticipating customers that pay water rates, water utility companies, and society as a whole. All are affected in different ways by each conservation measure. A condition resulting from conservation cannot simply be classified as a cost or benefit, for it may be a cost to one group and a benefit to another. Table 4-4 lists the respective costs and benefits that apply to each perspective.

Table 4-5 summarizes the primary and secondary methods of economic analysis considering each perspective. The CEC and CPUC (1987) defined the primary unit of measurement as "the most useful for summarizing and comparing demand-side management program cost-effectiveness." The NPV method is listed most often as the primary method of analysis. Secondary indicators were deemed to "represent supplemental means of expressing test results that are likely to be of particular value for certain types of proceedings, reports, or programs."

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[2]The techniques and methods of economic analysis by perspective are based on California Energy Commission (CEC) and California Public Utilities Commission (CPUC), 1987, Standard Practice Manual: Economic Analysis of Demand-Side Management Programs.

TABLE 4-4
BENEFITS AND COSTS BY PERSPECTIVES

Participant Perspective	Utility/Ratepayer Impact Perspective	Total Resource/ Societal Perspective
(A) Benefits		
(1) Incentives received from utility or tax credits (2) Reduced water bills (3) Reduced wastewater service bills (4) Avoided costs of other alternatives	(1) Avoided supply costs when water use is reduced: - Administrative - Labor - Equipment & materials - Operation & maintenance - Chemical processing - Pumping - Energy - Installation - Capital (2) Avoided long-run capital costs	(1) Avoided supply costs when water use is reduced as listed under "utility perspective" (2) All benefits listed under "participant perspective" (3) Environmental benefits—see section "Qualitative Evaluation"

TABLE 4-4 (Continued)
BENEFITS AND COSTS BY PERSPECTIVES

Participant Perspective	Utility/Ratepayer Impact Perspective	Total Resource/ Societal Perspective
(B) Costs		
(1) Equipment & materials (2) Installation (3) Operations & maintenance (4) Removal (5) Time required to participate (6) Increase in bills if reduced water use results in higher rates	(1) Program costs: - Incentives - Equipment & materials - Operations & maintenance - Installation - Labor - Removal - Program administration - Publicity - Surveys - Evaluation (2) Increased supply costs when water use increases: - Administration - Labor - Equipment & materials - Operations & maintenance - Chemical processing - Pumping - Energy - Installation - Capital (3) Decreased revenue when water use is decreased	(1) All utility costs (2) All participant costs (3) External costs such as environmental damage--see section "Qualitative Evaluation"

TABLE 4-5
ECONOMIC ANALYSIS METHODS BY PERSPECTIVE

Primary	Secondary
Participant	
Net present value (all participants)	Discounted payback (years) Benefit-cost ratio
	Net present value (average participant)
Ratepayer Impact Measure	
Life-cycle revenue impact per unit of water	Life-cycle revenue impact per customer
Net present value	Annual revenue impact (by year, per unit of water, per customer)
	First-year revenue impact
	Benefit-cost ratio
Total Resource Cost	
Net present value	Benefit-cost ratio
	Levelized cost ($ per unit of water)
	Societal (NPV, BCR)
Utility Cost	
Net present value	Benefit-cost ratio
	Levelized cost ($ per unit of water)

Source: California Energy Commission and California Public Utilities Commission, 1987.

Participant Perspective

The participant perspective considers the costs and benefits of a water conservation measure on customers who participate in the conservation program. Since many customers do not base their decision to participate in a program entirely on variables that can be quantified, a benefit-cost analysis may not always be a complete measure of the value of the program to the customer. It is difficult for any methodology to completely reflect the complex consumer decision-making process.

Estimating costs and benefits from the participants' perspective provides information about the desirability of a specific alternative to customers. It is especially useful as an indicator of how willing people are to participate in voluntary programs. For programs such as ULF toilet rebates, it is important to consider the costs and benefits from the customer's perspective to derive the minimum dollar value of rebate that would induce the necessary participation rate.

This perspective is also useful for comparing different water conservation alternatives. By comparing net present values of different alternatives over the lifetime of the program, a determination can be made as to which will be in the best interest of the customer in the long run.

Ratepayer Impact Perspective

The ratepayer impact perspective measures the effects that changes in water utility revenues and operating costs have on customer water rates. Water conservation measures that result in measurable reductions in water use should also result in both reduced operating costs and reduced revenues. This perspective examines the direction and magnitude of the expected change in customer water rates and bills.

In many water conservation programs, the revenues that the utility loses must be recaptured by the customers paying higher rates. This perspective is the only one that reflects this shift in the burden of cost. An additional strength is that the lifetime revenue impact per customer is the most useful method when comparing the merits of programs with highly variable scopes. This test is very sensitive to the difference between long-run projections of rates and long-term projections of marginal costs. However, both are difficult to estimate.

A major concern to utilities implementing conservation programs is that they will sell less water and earn less revenue. While this is true, the revenue shortfall can be predicted and water rates increased accordingly. The following factors need to be kept in mind while evaluating the impact on utility revenues:

(1) Few fully-implemented conservation programs provide water savings in excess of 10 to 15 percent.

(2) Water savings may develop slowly, since they are usually planned over a 5-to-10-year period.

(3) The utility will benefit from the reduced variable costs resulting from purchasing, treating, and pumping less water.

Utility Cost Perspective

The utility cost perspective measures the net costs of a water conservation program as incurred by the utility. Because this perspective treats revenue shifts as transfer payments, there is no uncertainty about long-term rate projections. The utility cost perspective includes only the portion of the participant equipment cost that is paid for by the utility-provided incentive. Therefore, this perspective reflects only a portion of total resource costs. Also, by treating revenue shifts as transfer payments, rate impacts are not reflected.

Total Resource Cost and Societal Perspective

The total resource cost perspective (TRC) combines the costs to the participants with the costs to the utility. A variant of the TRC is the societal perspective on benefits and costs. The societal perspective differs from the TRC perspective in that it includes the effects of externalities such as environmental impact and other external costs.

QUALITATIVE EVALUATION

Not all aspects of a water conservation program can be quantified as either a benefit or cost in dollar terms. A water conservation program may have nonquantifiable effects on:

(1) The environment
(2) Social/political/legal institutions
(3) Customer equity and acceptability

Other factors such as feasibility are critically important and must be balanced with the economic analysis.

An approach to evaluating these other effects is to make a comprehensive list, describe the impact concisely, and then evaluate whether the impact is positive, negative, or neutral. Table 4-6 shows an example of this approach, where conservation measures are listed in the left hand column and possible impacts across the top. A plus sign is assigned for a positive impact, a minus sign for a negative impact, and no entry indicates a neutral impact. This type of analysis allows the consideration of the negative social and environmental impacts of mandatory measures that may have a favorable benefit-cost analysis (because of large water savings due to high installation rates and relatively low utility costs).

If this type of qualitative evaluation is used in a benefit-cost analysis, the significance of the +'s and -'s assigned to each measure should be fully explained in the analysis report. Some negative ratings may be important enough to stop an economically attractive measure from being implemented because of large customer impacts or negative environmental externalities.

CANDIDATE PROGRAMS

At the end of **Step 4**, the evaluation should be concluded by preparing a list of candidate conservation programs that are rank-ordered by water savings and by a benefit-cost measurement (whichever method was used). This list of conservation programs can then be considered for integration into water management plans as discussed in **Step 5**.

TABLE 4-6
EXAMPLE COMMUNITY IMPACT OF WATER CONSERVATION PROGRAM

	Conservation Programs					
Impact	Plumbing Rebates	Retrofit Devices	Large Commercial Water Audit	Low Water Use Landscape Water Audits	Landscaping Required	Public Education
Environmental/technical						
New source development postponed or reduced	+	+	+	+	+	+
Reduced homeowner energy consumption	+	+	+			
Reduced utility energy consumption	+	+	+	+	+	
Increased life of water and wastewater treatment facilities	+	+	+	+	+	+
Increased streamflows	+	+	+	+	+	
Social/political						
Create new jobs locally	+	+	+	+	+	
User and special-interest group opposition to program			-		-	
Requires mandatory ordinance					+	
Cooperation of enforcement authority to implement program may be difficult					-	
Cooperation with school department and other community departments may be difficult		-		-		-
Fairness of measure					-	
Requires landscaping attitude change					-	
Customer costs not equally shared between existing and new customers				-	+	
Costs not equally shared between customer classes		-	-	-	-	
Users who conserve will have lower energy bills	+	+	+			+
Health and safety				+		+
Significant customer expense if mandatory	-			-	-	

Plus (+) = positive impact.
Minus (-) = negative impact.

STEP 5. DEVELOP A LONG-TERM WATER MANAGEMENT PLAN

OBJECTIVES

(1) To select an optimal combination of water supply and water conservation alternatives

INTEGRATION OF WATER CONSERVATION INTO WATER SUPPLY PLANS

Overview

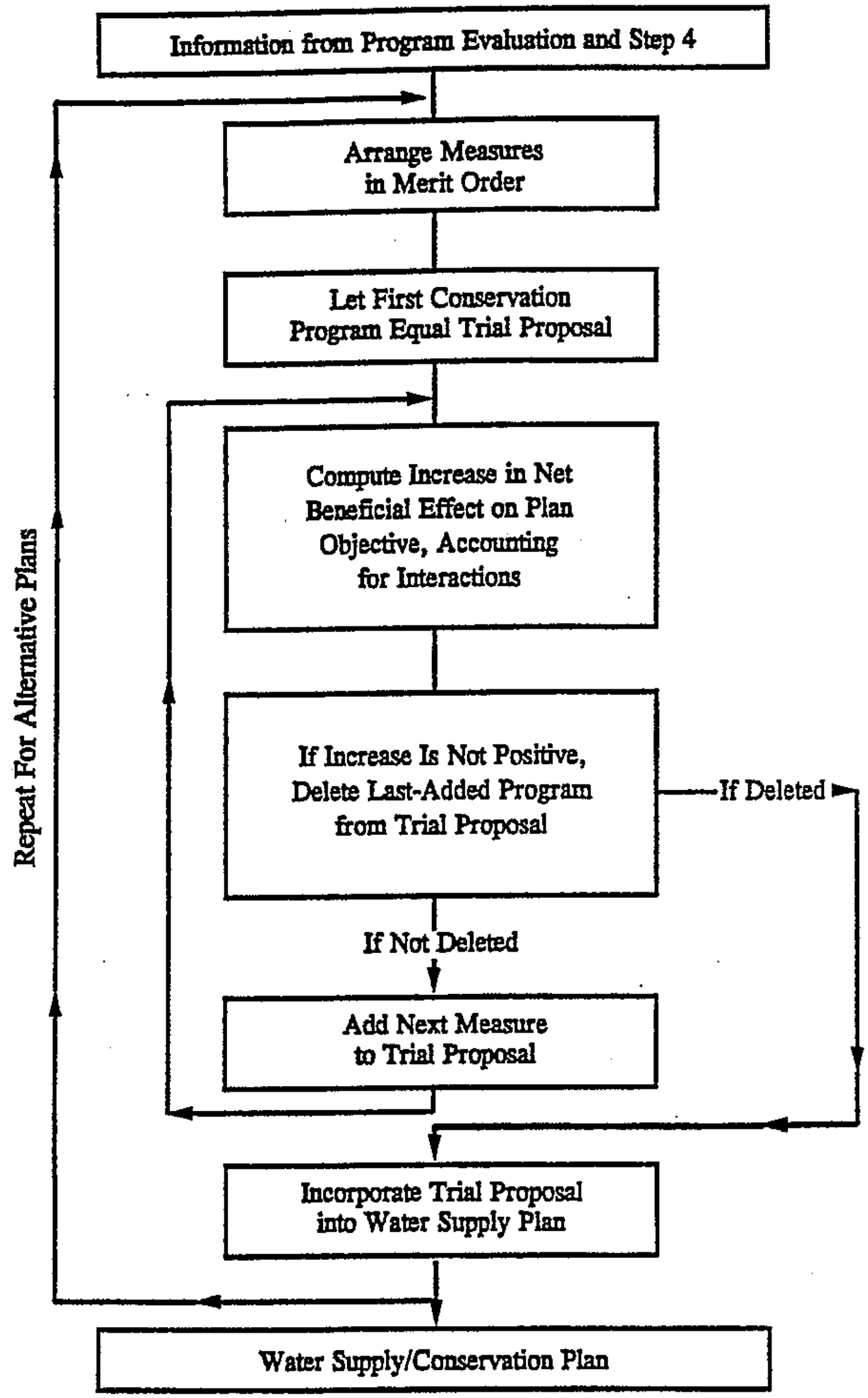
Evaluation of water conservation alternatives (as described in **Step 4**) results in a list of conservation programs with all advantageous and disadvantageous effects identified and measured or described for each measure. In order to integrate water conservation programs into water supply plans, individual programs must be combined to form water conservation proposals (or demand management plans); the proposals become the water conservation elements of the supply plans. Water conservation proposals can be developed in order to enhance desired features of the final water supply/conservation plan. The following sections describe the development of water conservation proposals suitable for integration into a water supply plan, illustrated by Figure 5-1.

Proposal Development Principles

Merit Order

Because of the possibility of interactions among individual water conservation measures and/or programs, it is helpful to introduce individual programs into each alternative water conservation proposal in merit order--the "best" program is included first, followed by the "next best," etc. The definition of "merit" depends upon the objective of the water conservation proposal. For example, a proposal intended to maximize net benefits implies a different notion of merit than does a proposal directed to other objectives, such as reducing wastewater outflows.

FIGURE 5-1
INTEGRATION OF WATER CONSERVATION INTO WATER SUPPLY PLANS



(1) Economic Objective. For purposes of developing a water conservation proposal that makes the maximum net contribution to the economic objective, water conservation programs can be arranged in order of decreasing net benefits. Net benefit is defined as the sum of all advantageous economic effects less the sum of all disadvantageous effects.

(2) Environmental Objective. For purposes of developing a water conservation proposal that makes the maximum contribution to the environmental objective of water conservation, programs can be arranged in order of decreasing net environmental benefit. Net environmental benefit is defined as the sum of all advantageous environmental effects less the sum of all disadvantageous effects. If environmental effects are diverse, considerable judgment may be required to achieve this ranking.

(3) Combined Objectives. Other plans may be proposed that affect significant tradeoffs between the economic and the environmental objectives. Such plans are judged according to a selected combination of the two objectives. Water conservation programs are arranged in decreasing order of their individual contributions to the same combination of objectives.

Interaction Effects

Water conservation measures and programs can be expected to exhibit interactions with respect to both effectiveness and implementation costs. In some cases, interactions may also appear for other advantageous and disadvantageous effects, including environmental effects.

Interactions with respect to effectiveness (or water savings) can result when two different conservation measures impact the same water use or water use behavior. In fact, whenever metering and pricing measures are implemented in conjunction with other water conservation measures, interactions can be expected. (**Step 7, p. 230** discusses methods for empirically estimating interaction effects.)

Interactions with respect to implementation costs can result when two measures share common implementation characteristics. Typically, the implementation of two measures at the same time results in costs borne by the water utility and/or public agencies that are less than the sum of costs of implementing the measures individually. In most cases, joint implementation can be expected to reduce aggregate implementation costs. This interaction is most striking in the case of educational efforts.

Net Beneficial Effects

As individual water conservation measures are added to trial water conservation proposals, the net beneficial effect of adding the additional measure must be determined. In every case, the net beneficial effect is defined with respect to the plan objective--economic, environmental, or combined. The net beneficial effect can be found by determining the excess of all advantageous effects of the plan objective over all disadvantageous effects of the plan objective before adding the additional measure, and then determining the same excess after adding the additional measure. Finally, it may be noted whether the second amount is greater (an increase in net beneficial effect) or less (a decrease in net beneficial effect) than the first.

Development of Alternative Conservation Proposals

Economic Objective

The proposal that makes the maximum net contribution to the economic objective is developed from the list of eligible water conservation programs, arranged in suitable merit order and evaluated on the basis of the water supply plan. Proposal development begins by choosing the first listed program. Then, the second program is added to the first. The advantageous effects of the second program are added to those of the first along with the disadvantageous effects. Interactions between the two plans are investigated, and the summed effects adjusted when necessary. For example, if the two programs interact with respect to water savings such that their combined effectiveness is less than the sum of their effectiveness, advantageous economic effects must also be adjusted downward.

If the water conservation proposal now formed (two programs) exhibits a net contribution to the economic objective (net beneficial effect) that is larger than that recorded for the immediately preceding plan (one program), the second program is retained and the development proceeds. If the proposal development proceeds, additional programs are tentatively added in the same way, effects are summed, interactions are investigated, summed effects are adjusted when necessary, the net beneficial effect is tested. Development stops when the next program in the merit order list fails to contribute to the net economic effect: this is when the contribution to the economic objective is maximized. The programs then included constitute the water conservation element of the water supply/conservation plan that maximizes economic benefits.

Environmental Objective

The proposal that makes the maximum contribution to the environmental objective is developed from the list of eligible water conservation measures, arranged in suitable merit order, and evaluated on the basis of the water supply plan. The second program is then added to the first. Tentatively, the advantageous effects of the second program are added to those of the first, and the disadvantageous effects are added. Interactions between the two programs are investigated, and the summed effects adjusted when necessary.

If the water conservation proposal now formed (two measures) exhibits net beneficial effects on the environmental objective that are judged to be not less than those observed before the first measure was added, the second measure is retained and the development proceeds. If not, the second measure is removed and the development stops. If proposal development proceeds, additional measures are tentatively added in the same way; effects are summed, interactions are investigated, summed effects are adjusted when necessary, and the results are tested. Development stops when the next measure in the merit ordered list reduces the cumulative net beneficial effect on environmental objective. The resulting conservation proposal constitute the water conservation element of the water supply/conservation plan that maximizes environmental benefits.

Combined Objectives

Combined objectives reflect tradeoffs between the planning objectives or between one of the planning objectives and other considerations.

Conservation programs can be merit-ordered, and the conservation proposal developed in a manner analogous to that described above for the basic plans. Effects of individual programs are estimated on the basis of the other water supply plan. The merit order should reflect the combined objectives. For example, if a compromise between economic and environmental objectives is sought, measures with net beneficial effects on both objectives would be listed first, followed by those considered less desirable in view of both objectives, etc. The proposal formulation then proceeds until the mix of environmental and economic effects desired in the plan cannot be enhanced by adding other measures.

Treatment of Potentially Feasible or Potentially Acceptable Measures

Some eligible water conservation measures may not be feasible or acceptable under existing physical or social conditions. These measures are categorized as "potentially feasible" or "potentially acceptable," and the conditions under which they would become feasible in the future are specified. Initially, such measures may be included in the list of eligible measures, and in the development of water conservation proposals. Whenever one of the final water supply/conservation plans includes potentially feasible or potentially acceptable measures, however, a second plan will be developed on the same criteria, except that potentially feasible and potentially acceptable measures will be excluded from the list of eligible measures. Both plans will be presented for comparison, so that the consequences of not implementing the potentially feasible or potentially acceptable measures can be contrasted to the difficulty of removing impediments.

A good example of treating potentially feasible and acceptable measures is the selection process of Best Management Conservation Practices by urban water districts in California. Two types of practices are distinguished: "present" and "potential." The present best management practices are conservation methods for which water savings, economic, environmental, and social effects are being documented in field applications. Documented savings from these practices will be incorporated into the overall water supply planning program of the agencies participating in the program. The potential best management practices are those with uncertain outcomes that require the development of technical, economic, and social acceptability data before a major commitment of resources for their implementation can be made.

If any potential conservation measures or programs are identified at this stage of the conservation planning process, then the procedure should be repeated by going back to **Step 2** and repeating the screening process.

Supply Reliability Considerations

The advantages of water conservation result largely from possible reductions in supply capability, when system reliability is held constant. If the overall reliability of the supply system is altered by the implementation of water conservation practices, additional disadvantageous or advantageous effects are created. The need to identify and measure these additional effects can be avoided by holding system reliability constant throughout the analysis. Following development of alternative water conservation proposals, this assumption should be tested by determining the performance of each alternative supply plan, with and without the water conservation element, for the last year in the planning period assuming design drought conditions. Supply plans with water conservation will differ from those without this element in having downsized or delayed construction schedules as well as lower levels of water use. When water deficits appear under design drought conditions, emergency water use reduction measures (not already incorporated in the water conservation proposals) are required. The extent and severity of measures required for supply plans that incorporate conservation should not exceed those for the corresponding supply plans without conservation.

Documentation of Water Management Plans

The procedures described in the previous sections will result in one or more water conservation proposals that can be integrated with water supply plans to form water supply/conservation plans. Whenever proposals include potentially feasible or potentially acceptable programs, alternative plans will be developed that exclude these measures. The documentation of each water supply/conservation plan must include:

(1) A full list of water conservation programs considered, showing conservation measures that were excluded from these programs as not technically feasible, those that were excluded as not socially acceptable, those that were excluded as not eligible because of negative impacts on the economic and environmental objectives, and those that were excluded in the process of plan formulation.

(2) A list of water conservation programs considered not applicable because they are already implemented, or because definite commitments have been made to implement them within the planning area.

(3) A list of each water conservation program included in the proposal, with a full description for each program, an indication of the agency or other entity responsible for its implementation, and a summary of the implementation plan including estimated coverage and duration.

(4) Aggregate implementation cost for the water conservation proposal, expressed as annualized cost; implementation cost for the proposal identified by responsible party (utility, residential water users, etc.).

(5) Aggregate water savings for the water conservation proposal, shown separately with respect to average-day water use, maximum-day water use, and average-day sewer contribution; shown for selected times throughout the planning period.

(6) A description of the water supply plan, without water conservation, including a summary of beneficial and adverse effects.

(7) A description of the water supply/conservation plan, incorporating the water conservation proposal, including a summary of beneficial and adverse effects.

(8) A summary of the performance of the water supply plan (without conservation) and the water supply/conservation plan for the last year of the planning period under design drought conditions. Data provided should include projected supply capability, projected water use (including maximum-day use), and the nature and assumed effectiveness of emergency water use reductions measures required, if any.

PART II

PROGRAM EVALUATION

PART II. PROGRAM EVALUATION

THE NEED FOR EVALUATION

During the last decade, water conservation has achieved national prominence as a promising water management alternative. The water supply industry is currently undergoing the same change that took place in the energy industry during the 1970s. The national enthusiasm for energy conservation at that time led to widely divergent claims of the efficacy and beneficial effects of energy conservation programs. The optimistic estimates of energy savings were used by conservation advocates during permit hearings for new generating sources to argue that utility money would be better spent on energy conservation rather than on new sources. Although the energy industry often took a cautious view of the potential conservation effects, a growing number of planning decisions and financial outcomes depended on whether the utilities were able to demonstrate successful conservation programs and conservation savings. The inability of utilities and regulators to reconcile the divergent claims of energy savings has focused more attention on the area of program evaluation.

The water supply industry turned its attention to the potential of water conservation measures after the experiences of droughts in Europe and in the United States during the mid-seventies. The experience of urban water agencies in California demonstrated that it was possible to temporarily reduce water use by as much as 50 to 70 percent and to sustain reductions of 25 to 35 percent over several months (Berk et al., 1981). These conservation outcomes brought about hopes among water conservation planners and water agencies that these extraordinary reductions in water use could be maintained during normal conditions of supply. Such hopes had to be quickly abandoned, however, as water agencies experienced a return of water use to near pre-drought levels shortly after the drought ended. Again, the ongoing multiyear drought in California is expected to bring about some permanent changes in the patterns of water use because of its severity and long duration. However, research studies show that the habitual and ingrained patterns of water use are inherently resistant to change. The necessity for change must be dramatic and convincing, and the continuance of conservation practices must rest on the continuation of concern over the availability of water (Dziegielewski and Opitz, 1988).

The cost of evaluating water conservation programs may be very high, and it has to be justified in terms of the payoff from the evaluation. The grounds for expending resources on evaluation include:

(1) The cost-effectiveness of water conservation programs has to be established in order to undertake only those investments that are beneficial; the most cost-effective programs should be implemented first. Decision makers are very reluctant to spend money on a large-scale conservation program with an uncertain outcome.

(2) The level of uncertainty surrounding program outcomes must be known in order to allow water planners to fully incorporate conservation alternatives into their long-term water supply plans. A careful examination of empirical evidence of achievable water savings, public acceptability of water conservation measures, and other conservation impacts will increase the level of confidence among planners and managers who are responsible for the provision of an adequate water supply to urban economies.

(3) An adequate evaluation will allow conservation planners to (a) formulate least-cost conservation programs for achieving various levels of water savings, (b) implement only those programs that are cost-effective (i.e., programs with long-term benefits exceeding costs), and (c) take into account conservation effects (i.e., reduction in water demand) in planning for water supply development. In many instances, the overall payoff from expenditures on program evaluation will be to reduce the cost of water supply and increase its reliability in the long run. Improvements in water use efficiency along with well-timed investments in water supply should result in lower water rates paid by the consumers as compared to rates without the benefits of water conservation.

EVALUATION OBJECTIVES

The overall purpose of **Part II** of this manual is to provide the conservation planner with evaluation procedures that are both practical and based on sound scientific principles of research. The recommended procedures draw heavily from the program evaluation experience of the energy industry. The experience of the energy industry shows that program evaluation must be viewed as an integral part of the design and implementation of water conservation programs.

Evaluation of a water conservation program usually has several very specific purposes, which typically include one or more of the following:

(1) To compare the effects of the program against its intended goals
(2) To determine whether an ongoing program is working as expected or if it needs to be modified
(3) To forecast the effect of the program on long-term needs for resources and facilities
(4) To document pilot program implementation and performance for designing and evaluating future full-scale programs

Although the purposes of program evaluation in most cases are related to decision support activities, it is important to recognize the other reasons for undertaking program evaluation. These reasons (or motives) can be:

(1) Rational; e.g., to meet the above-listed evaluation objectives or demonstrate the validity of the results

(2) Promotive; i.e., as a means for advancement of the program or generation of public or institutional support
(3) Financial; i.e., to obtain funding for a new program or to justify expenditures on existing programs
(4) Administrative; e.g., satisfaction of outside requirements for evaluation
(5) Political; e.g., as a means to delay (or accelerate) full-scale implementation of the program

The motivations for undertaking program evaluation may influence the design of the evaluation procedures. In cases where the motives are other than rational, it may be difficult to maintain scientific objectivity in performing the evaluation. However, evaluations that fail to achieve the standards of objectivity may have far-reaching adverse consequences on any future conservation efforts by undermining public confidence in an agency's decision making.

DESIRABLE CHARACTERISTICS OF EVALUATION DESIGNS

The most important consideration in developing an evaluation procedure is determining the validity of its design. In scientific language, the design of the evaluation procedure would generally be considered the design of the experiment. An appropriate evaluation design (i.e., experimental design) enhances the validity of results and provides the analyst with maximum information within the constraints of the budget of the evaluation project. Without a valid experimental design as a starting point, the results of evaluation may be questionable and may not provide definitive answers to the questions that need to be answered. If the evaluation design is flawed, it may be difficult or impossible to salvage any meaningful results from the data.

Agencies that regulate electric utilities often require that the evaluation program design meet two distinct requirements: internal and external validity. These two concepts are discussed below.

Internal Validity

Internal validity of the evaluation design enables researchers to formulate evaluation procedures that procure the desired measurements while excluding the confounding effects of factors that are external to the conservation program under consideration. For example, an evaluation design that compares water use before and after program implementation without controlling for the effects of weather, price changes, economic factors, and other confounding influences will fail the requirement of internal validity. Internal validity is important because the purpose of evaluating a conservation program is to measure the effects that are clearly attributable to the program. External factors that may affect the evaluation results must be controlled for by an appropriate design of the evaluation procedures. The designer of the procedures should take steps to ensure that they produce the correct measurements. Also, a correct specification and clear statement of the evaluation objectives is considered a part of the internal validity check. Although internal validity is a desirable characteristic of the evaluation procedure, it is difficult to formulate an actual check for internal validity. In practice, it is easier to focus on the process of validation of results by assessing the confounding effects of externalities.

External Validity

External validity of the evaluation design ensures that the findings of the evaluation process can be generalized (i.e., applied) to similar conservation programs within the service area. For a water utility undertaking a pilot conservation program, the major importance of external validity is that the results should be transferable to the major group of interest. For example, the results of a pilot low-flow showerhead distribution program conducted with a small sample of single-family homes in a city should be transferable to the entire single-family residential sector. In scientific terms, this aspect of research design is referred to as inference.

A secondary interest might be the transfer of program results to other utilities or other geographic locations. External validity also increases the ability of other researchers to replicate the methodology and results of the evaluation. In scientific terms, this aspect of research design is referred to as replication.

The replicability, or the ability to reproduce the procedures and results of a research project, is especially relevant to academic researchers, so that their research findings can be verified and documented by their academic peers. Replication is necessary in order to ascertain that the reported results are universal and not uniquely dependent on the evaluation design or the features of the evaluated program (e.g., location, time period, customer mix). Evaluation designs are often customized to particular programs rather than standardized to conform to current designs for similar programs. This complicates the comparison of results from one evaluation to another, even when the programs are almost identical.

The ability to generalize the findings of a particular evaluation to other programs and consumer groups depends on whether the evaluation design was capable of isolating and controlling for:

(1) The characteristics of the evaluated program that could significantly influence the results of the evaluation.
(2) The characteristics of the customer groups targeted by the program that could also influence the results.
(3) The characteristics that are external to both the program design and the targeted customer groups (e.g., weather, price, drought, and others).

Particularly difficult is ascertaining which characteristics of the conservation program (including characteristics of the program participants) will preclude generalization of the evaluation findings. If such characteristics are identified and included in the evaluation design, the analyst will be able to control for their effects and thus procure meaningful results. The knowledge of such effects will facilitate generalization of the evaluation results by adjusting them to fit the characteristics of different programs.

Factors That Affect the Validity of Evaluation Designs

A number of factors can affect the validity of the evaluation process. Such factors are often referred to as outside effects or externalities. Although some factors are beyond the control of the evaluation, in most cases the confounding factors are inherent to the methodologies employed by the analyst. Factors that can threaten the internal and external validity of evaluation designs include:

(1) History or changes in the environment surrounding the program
(2) Maturation caused by change in participant attitude over time
(3) Testing also known as "Hawthorne effect" of sensitizing program participants to behave differently
(4) Instrumentation or the effect of changing the calibration of the measuring instrument (e.g., "nonblind" data collectors).
(5) Regression-to-the-mean caused by choosing the participants on the basis of extreme measurements
(6) Self-selection bias when program participation is voluntary
(7) Experimental mortality when program participants drop out of the program

Although these factors are design-specific (e.g., history and maturation do not apply to designs which use cross-sectional data), they have the potential of biasing the results of the program evaluation unless some appropriate actions (to quantify their effects) are taken by the analyst.

The history problem often arises when the environment surrounding the conservation program changes during or after the implementation of the program. Without anticipating and controlling for these changes, it may be difficult (if not impossible) to distinguish between the causal effects of the program and changes in environment. For example, during the course of a low-flow showerhead retrofit program, water rationing might be imposed due to drought conditions. In a time series analysis of water-billing records, the impact of the rationing has the potential for distorting the impacts of the low-flow showerhead retrofit program, possibly leading the analyst to incorrect conclusions. To control for the effects of history, the evaluation procedure should be designed to monitor nonparticipants, as well as program participants, both before implementation and after completion of the program. This will permit the effects of the change in environment to be determined independently of program effects and incorporated into the results.

In the case of conservation programs that encompass several years, the program participants may undergo maturation, or change, in their attitudes and behavior. For example, some participants may grow cynical of the potential effectiveness of the water conservation program, leading them to lessen their conservation efforts. The overall results of the program would then be biased downward due to the effects of maturation even though the program itself may be highly successful if participation were as expected. Even for programs of shorter duration, changes over time may still affect the responses and characteristics of program participants. Again, time series data should be gathered on participants and nonparticipants in order to determine the degree of maturation effects. This information should be incorporated into the evaluation results to avoid any possible biases.

Validity problems that are due to the testing factor occur because participants who are aware that they are part of a program may change their behavior due to monitoring by an experimenter. This may be due to a desire to enhance their image, as in the case of monitoring worker efficiency or as part of the learning process, such as when skills tests are administered to program participants prior to the inception of a program that monitors learning ability; the participants are able to practice those skills being tested by the program and thereby enhance their skills before the program begins. In either case, the participants become alerted to the variables being studied by the program. Participants in a water conservation program may alter their water use due to their knowledge that they are being monitored, possibly in an attempt to show others that they are performing their civic duty. The effects of testing upon program results can be controlled by examining water use data for nonparticipants, as well as participants prior to the program, and possibly by informing the nonparticipants that they are monitored. In assessing the effects of the testing factor, it is important to distinguish between the effects of monitoring (sometimes referred to as the Hawthorne effect) and the unexpected responses to the program (sometimes referred to as "spillover" effects). For example, recipients of an indoor retrofit kit may also change their outdoor water use behavior. Evaluation designs should be capable of distinguishing between the effects of testing and spillover effects. Time and unobtrusive measurement will lessen the Hawthorne effect.

The instrumentation effect can take the form of changes in the specifications of the evaluation procedures after implementation of the program. A common cause of the instrumentation effect is employment turnover among the staff and administration of the program. This can be controlled for by carefully orienting incoming staff and administrators regarding the procedures and goals of the program. Some instrumentation problems can also be related to changes in the implementation procedures of the conservation program itself. For example, the hardware manufacturer, fieldwork contractor, or participant incentives could be changed at some point in time during the implementation period. Failure to note such changes would be extremely unwise and potentially very detrimental to the validity of program results. Careful monitoring of the program and careful training should help to control for, or reduce, the instrumentation effect.

The regression-to-the-mean effect is related to the fact that the conservation behavior of program participants will most likely vary over the life of the program. All measurements contain some degree of error, and there is the possibility that the study participants are chosen on the basis of their extreme behavior (i.e., measurements). If this is the case, then the participants most likely will tend to regress back toward their mean (or average) behavior regardless of the effects of the program. For example, a sample of water users in the highest rate block at any point in time will consist of at least two types of customers:

(1) Those customers whose water use consistently falls into the highest block, and
(2) Those customers whose water use just happened to fall into the highest block because they experienced circumstances (such as many out-of-town visitors or a leaking water fixture) which made their use higher than normal.

Water use of the second group is likely to drop during the program because the unusual circumstances will no longer exist. This change will incorrectly be attributed to the performance of the program. Depending on the proportion of the second type of participants in the sample, this effect may significantly bias the overall results. Because of this regression effect, any samples consisting of "the largest" or "the smallest" will result in biased estimates unless they are very carefully chosen. The most effective countermeasure for regression effects is to construct the participant group by random sample and avoid definitions of the sampling strata based on one-point-in-time observations. Also, it may be helpful to examine individual water use records for serious anomalies (e.g., high leaks, refilling of a swimming pool) and remove such cases from the sample.

Self-selection bias can occur when the participant and control groups do not have the same characteristics in terms of conservation behaviors and attitudes. If the members of the participant group volunteer for the program, and the control group consists of consumers who chose not to volunteer, then it is logical to assume that the members of the participant group have more favorable attitudes toward conservation, which will be manifested in their water use behaviors being different than those of the control group. Researchers have devised several stratagems for overcoming this difficulty. For example, the members of the control program may be "unawares," i.e., consumers who did not hear of the program prior to the selection of the participant group but would have volunteered if they had. Another method is to choose "geographic ineligibles," consumers with characteristics similar to members of the participation group but who live in areas with no such program. Each of these measures, however, raise further questions and problems. For instance, what characteristics of the "unawares" prevented them from having knowledge of the program? What will the effects be of location-specific characteristics of the different location on the results of the program? The latter should be approached with caution, for there exists a danger that utilities may offer services similar or identical to those of the conservation program in question after the inception of that program; this would make subsequent posttest comparisons questionable or completely meaningless. Sometimes, self-selection bias can be overcome by choosing both participant and control groups from program volunteers. In this case, if the volunteers are randomly assigned to each group, then the condition of similarity is fulfilled. However, neither group is representative of the entire population.

Finally, when some participants drop out of the program, they cause the problem of experimental mortality. This has the potential of biasing the results, since the participant and control groups are no longer, strictly speaking, random samples. Subjects who drop out tend to have the control characteristics necessary to make the groups random. That is, for conservation programs, dropouts tend to be less motivated to conserve than subjects who do not drop out. This would induce an upward bias in program results. A further source of experimental mortality occurs when the program staff decides to add participants to the program after implementation of the program. This may be because the staff desires to confer the benefits of the program to the largest possible group or to the neediest individuals. Participants added after the start of the program may not have the same characteristics as the experimental (participant) group and might thereby induce bias into the results. Program staff should be made aware of the necessity of maintaining the purity of the experimental and control groups. Close cooperation between the program and evaluation staffs should help prevent the problems of experimental mortality.

RESEARCH DESIGNS

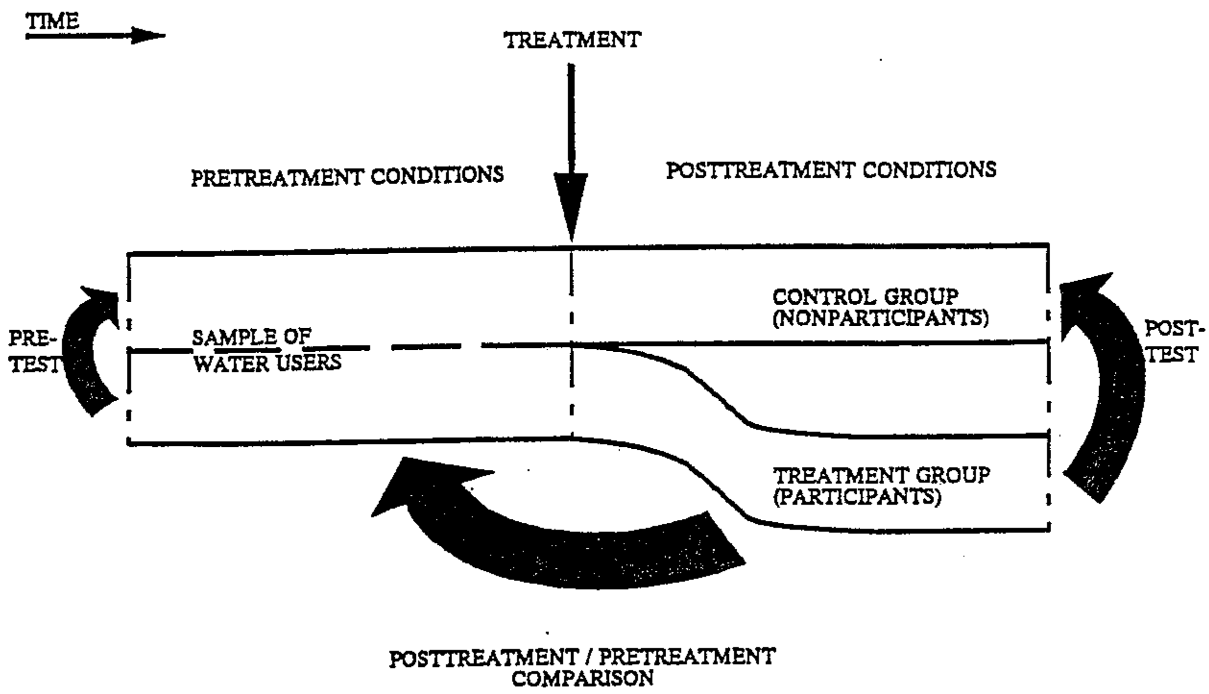
Several evaluation designs can be used to obtain measurements of the success of the conservation program and its impact. These designs range from vigorously controlled experiments, where only the variable in question (e.g., program participation) is allowed to change, to methods in which there is little control over extraneous variables (or external effects) in the evaluation process. Usually, the choice between alternative designs is made on the basis of feasibility, reliability of measurements, and costs.

Practically all evaluation designs employ comparisons of water use behavior and other population characteristics over time and/or between groups of customers. Possible types of such comparisons are illustrated by Figure II-1. The time continuum is divided into two periods by the implementation of the conservation program. The behavior and characteristics of water users before the program implementation (or pretreatment) are often referred to as <u>ex ante conditions</u>. After program implementation (or posttreatment), the observed behaviors and characteristics are called <u>ex post conditions</u>. The treatment, or implementation of the conservation program, also divides the water users into two groups: the control group of nonparticipants and the treatment group of program participants. As a result of program implementation, four categories of conditions are created:

(1) Pretreatment (ex ante) conditions of control group
(2) Posttreatment (ex post) conditions of control group
(3) Pretreatment (ex ante) conditions of treatment group
(4) Posttreatment (ex post) conditions of treatment group

Several comparisons can be made among these categories. For example, a sample of water users drawn from the treatment group after the program can be compared to itself before the program. In Figure II-1, this is referred to as posttreatment/pretreatment comparisons. The treatment group after the program can also be compared to a sample representing the control group after the program; this is referred to as a posttest. A comparison of the treatment and

FIGURE II-1
TYPES OF COMPARISON IN ALTERNATIVE RESEARCH DESIGNS



control groups prior to program implementation is referred to as pretest. A number of other comparisons can also be made.

Several methods can be used to estimate program effects based on such comparisons. Depending on the types of data available and the required information, these methods may range from a simple comparison of mean water use or other characteristics of treatment and control groups to sophisticated econometric modeling aimed at predicting attitudes and behavior of water users.

With respect to research designs (as opposed to estimation techniques), the distinction between different design types is based on the manner in which the control and treatment groups are selected. Generally, almost all possible evaluation designs can be classified into the following three types:

(1) Experimental design (or true experimental design), which involves choosing both treatment and control groups by random sampling
(2) Quasi-experimental design, which fails to satisfy one or more of the conditions of the true experimental design
(3) Nonexperimental design, which satisfies none of the conditions of the true experimental design

These three types of research designs follow a decreasing order of internal validity. However, the true experimental design is often impossible to achieve and therefore less valid, but acceptable, designs are often used. If external validity is considered, the ordering of the three designs may be different. For example, a pilot program using an ideal experimental design may have much less applicability to other areas than a good evaluation of a large-scale program using a nonexperimental design. A description of each general type of evaluation design is given below.

Experimental Designs

This is the classic design for evaluations that employ probability sampling procedures (e.g., simple random sampling). Because both the treatment and control group are randomly selected, an assumption can be made that any changes exclusive of the conservation program that occur over time or between individuals within the treatment (or participant) group will also appear within the control group.

The validity of the true experimental design rests on the random process of selecting the sample and constructing the treatment and control groups. In the experimental design described above, this random process maximizes the probability that:

(1) The treatment and control groups are identical in every respect except for program participation.
(2) Each group is representative of the sampled population (e.g., all single-family homes in the service area).

The first condition, if satisfied, allows the analyst to measure, for example, the reduction in average water use among the participants relative to nonparticipants. If both groups are identical, this reduction represents the true net effect of the program (or the change in water use in the treatment group that is clearly attributable to the conservation program). The second condition, if actually satisfied, ensures that both the control and treatment groups are microcosms of the entire class of customers under consideration (e.g., all single-family customers). This means that the statistics obtained from the sample (e.g., average water use, variance in water use) are unbiased estimates of the true parameters of the entire population of the customer class. If both the control and treatment groups are representative of the entire class of customers, then the program savings obtained from the comparison can confidently be generalized to the entire customer class.

In practice, randomization of treatment and control groups is often insufficient to achieve their comparability and representativeness. This is because the random assignment of subjects into treatment and control groups ensures that these two groups will not differ, on average, if this process is repeated often enough (i.e., if many samples are taken and each assigned to a treatment and control group). When only one sample is selected, and the assignment process is random, the experimental group and the control group may differ from each other and from

EXAMPLE II-1
EXAMPLE OF EXPERIMENTAL DESIGN

An example of the experimental design measuring impacts of a conservation program as a difference of means would be to:

(1) Select a sufficiently large random sample of water customers from a customer class.
(2) Randomly assign customers in the sample into treatment and control groups.
(3) Administer the treatment (i.e., conservation program) to each customer in the treatment group.
(4) Obtain observations on consumer behavior or average water use in each group for the duration of the program.
(5) Measure program impacts in terms of differences in water use behavior between the treatment and control groups.

the population due to poor luck of the draw. In order to address this problem, it is necessary to ascertain the degree of similarity and representativeness of the treatment and control group after the sample is selected and observations on water use are taken. The validation procedures and the assumptions that relate to the validity of results are discussed later.

Use of an experimental design can address many evaluation problems. For example, the inclusion of the control group allows for the free-rider problem. This problem arises when there are members of the participation group who would enact the measures inherent to the conservation program even if the program did not exist. That is, these members are gaining the incentive to conserve, such as by receiving free conservation devices, even though they would have installed such devices in the absence of the program. Therefore, their behavior is not being modified. The effect of these free riders is captured by the control group if it is a representative sample in the sense that it also includes consumers who would conserve in the absence of the program.

Often, the knowledge of the difference in average water use between the treatment and control groups is not sufficient to judge the effectiveness of the program. We also need to know whether the program has produced significant savings. The term "significant" has at least two meanings: practical and statistical. In the practical sense, for example, the savings of 0.5 gallons per day at an average daily use of 300 gallons may be considered insignificant with respect to a 15 percent reduction goal (i.e., 45 gallons/day). From the statistical point of view, the savings of 0.5 gallons per day may be considered as significant given the variances in water use of the treatment and control groups, the acceptable error (relative or absolute), and the acceptable chance of being wrong.

In cases where additional information about the estimates is needed, the research design must include additional measurements. For example, in order to determine the statistical significance of the observed savings, it is necessary to record and analyze water use of individual customers who make up the treatment and control groups (in order to estimate variance in water use). The knowledge of aggregate water use in each group is insufficient for this purpose. Also, in order to check if the samples are truly random, one may have to take observations on water use not only during the program, but also prior to the implementation of the program. The experimental design would be judged as valid if the mean water use, variance, and other parameters of the treatment and control groups and the entire population were very similar prior to implementation of the program (or if the observed differences would be very small and statistically insignificant). Usually, such checks reveal that the evaluation design has not achieved the conditions of a true experiment and one or more implied assumptions are violated.

Quasi-Experimental Designs with Comparison Group

In many research undertakings, it will be difficult, if not impossible, to achieve all conditions required for a true experiment. This situation is certainly true in the measurement of water conservation savings. Because of the great variability of water use among individual customers and changes in customer use over time, it is usually impossible to obtain random samples of customers for treatment and control groups that are very similar in every respect.

In order to remedy this situation, researchers have devised evaluation designs that closely resemble true experiments but fail to satisfy one or more of the conditions of the true experiment. These are called "quasi experiments" and are used more often in applied research due to their greater semblance to real-life situations. Quasi experiments have less internal validity than true experiments because they fail to control for one or more of the externalities that potentially threaten the validity of the design. However, if a study based on quasi-experimental design is performed with sufficient rigor, the quasi experiments may have more external validity than true experiments. The usefulness of quasi experiments is determined by the extent to which they control for the effects of relevant externalities on outcome measures. The preferred quasi-experimental designs are those that control for the effects of chosen externalities and provide valid results given the environment of the program under scrutiny.

Two types of quasi-experimental designs are often used in program evaluation. Depending on whether one or both groups of customers (i.e., treatment and control group) are constructed by random sampling, these designs are called:

(1) Randomized experiments with comparison group
(2) Nonrandomized experiments with comparison group

Both designs reflect the fact that is often impractical or impossible to construct a control group by selecting a random sample. A control group constructed by methods other than random sampling is commonly called a comparison group. Each of the two variants of quasi-experimental design is described below.

Randomized Experiments

In this design, the treatment group is constructed through random sampling, while the control group is nonrandom (i.e., a comparison group). This design is often used in evaluation problems which have to deal with small groups of relevant customers. For example, the evaluation may be directed toward an industry for which companies in different geographic or service areas are so heterogeneous that comparisons between areas may not be meaningful. Therefore, it is more relevant to compare the participant group with the other companies within that particular area. This type of design may also be preferred in the case of programs funded by state or federal agencies that may wish to obtain a preliminary evaluation of an existing program or program proposal and in order to provide a specific cost and time schedule for the evaluation. In order to have meaningful results, the comparison group must be chosen so that it has similar characteristics as the participant group. Two procedures are commonly used:

(1) Individual matching method
(2) Aggregate matching method

In individual matching, the members of the comparison group are be chosen to match certain selected characteristics of the members of the participant group; in aggregate matching, the matching may be executed on the basis of characteristics of the entire participant group. However, problems exist for each method. Individual matching is expensive, time-consuming, and, for practical purposes, must be performed for fewer variables than aggregate matching. Either method, however, may introduce bias into the analysis if some key characteristics that are significant determinants of the difference between the two resultant groups are not considered. In the real world, some matching is always better than none. Finally, it is important to note that a significant degree of researcher bias can also be introduced during the matching process when the desired results are known to the person making selections.

In the case of sampling account-level water use records, a successful matching would be expected to result in similar water use levels of the participant group and the matched comparison group as well as in similar water use variance. After completion of the program, when the participant group has been exposed to the effects of the program and the comparison group has not, the difference between them should be due to the program. For this study design, the problem of self-selection bias described above is significant, since randomized selection is not present to control for its occurrence.

Randomized experiments with comparison groups are appropriate under certain circumstances and can yield significant results when carefully analyzed, especially since it can be argued that any comparison group is better than having no control group at all. It is very helpful to rule out certain confounding effects derived from invalidating externalities than none at all. The analyst can indicate the possible consequences of these effects on the results of the evaluation.

Nonrandomized Experiments

In this design, both the treatment (i.e., participant) and comparison (nonparticipant) groups are constructed in a nonrandom fashion. For example, in a small pilot program the participant group may be too small to be considered a representative random sample of the population from which it is drawn. In this case, it would not be meaningful to construct the control group as a random sample (i.e., because the treatment group is nonrandom). Instead, the comparison group (nonrandom) can be carefully designed (through either individual or aggregate matching) to provide a suitable comparison with the participant group.

The typical small size of the groups, which is characteristic of this design, can make it difficult to generalize the results to any significantly larger samples in broader subsequent follow-up studies or programs. The generalization may be risky, at best, simply due to the nonrepresentativeness of the participant group. Nevertheless, a small pilot study could provide valuable information regarding customer acceptability of the program and estimation of program costs. Such a study cannot produce easily generalized measurements of water conservation savings, but it can demonstrate the potential effectiveness of the type of program under consideration.

Nonexperimental Designs

In some cases, it is not possible to use either experimental or quasi-experimental designs for program evaluation. The analyst must then resort to nonexperimental designs. Such designs provide a relatively simple preliminary method of assessing conservation savings. Their usefulness is primarily limited to situations that show that the conservation program is ineffective (i.e., does not produce conservation savings). If this is the case, then it is probably not worthwhile to invest in a more extensive evaluation design. However, the null results from nonexperimental designs should not be always accepted at their face value.

The benefit of nonexperimental designs is the relatively low cost of data acquisition and analysis. However, such designs leave much more room for criticism, since they are vulnerable to many of the previously discussed threats to validity. Basically there are two types of nonexperimental designs:

(1) Designs with reflexive control group in which the participant group is taken to be its own control group
(2) Designs with comparison group

Each type of nonexperimental design is described below.

Designs with Reflexive Control Group

In practice, this design is necessary when the participant group represents a major part or the entire customer class. In such situations, it is impossible or impractical to form a comparable group. For example, a mass-media conservation campaign may reach a large portion of the service area population, and it is impossible to isolate a group of customers from the campaign. Because of these constraints, the participant group is taken to be its own control group (i.e., the reflexive control group).

Reflexive control group designs can be implemented with a comparison of participant performance after the program with their performance before the program began. Alternately, the performance after the program can be compared with what the outcome would have been expected to be without the program (i.e., with and without comparison). In either case, the major drawback of this method is the inability to control for historical externalities such as drought, changes in economic climate, and others. When such external changes occur simultaneously with the conservation program, the effects of the program cannot be separated from the confounding effects of these externalities. To produce meaningful results, the analyst must make many assumptions regarding the effects of the historical externalities. The presumed validity of such assumptions determines the value of any conclusions derived from the results of the evaluation.

Designs with Comparison Group

The pretreatment condition of the participant group can also be contrasted against a comparison group with characteristics as similar to the participant group as possible. This design provides for greater control over invalidating factors than the reflexive group design; however, without a posttreatment comparison of the two groups, their comparability cannot be established. Prior differences between the two groups may complicate the interpretation of evaluation designs.

SAMPLING PLANS

Advantages of Sampling

The previous discussion pointed out the critical importance of the sample selection process to the validity of program evaluations. Samples of water customers are used in both process evaluations and impact evaluations.

Retail water supply agencies have the ability to monitor the water use of all customers or entire classes of customers. In statistical terms, studies involving all users would represent the use of entire populations. However, a complete enumeration or inventory of all users may not always capture the "entire population" because in addition to "populations" defined in terms of users, which can be viewed as finite (or delimited), some studies may require expanded definitions of population. For example, a study population can be defined as monthly water use quantities of all customers over time. Because such a definition includes future water use, the historical billing records would constitute only a part (or a sample) of the total population. Also, in many cases, a study of an entire population must limit the number of measurements on each unit (due to cost constraints) and may not be capable of producing answers to a number of research questions.

Because of these considerations, our knowledge is almost invariably based on samples or fragments of total populations. Sampling has many advantages over a complete enumeration (or inventory) of the population under study. These advantages include reduced cost, greater speed of obtaining information, and a greater scope of information that can be obtained. In addition, a greater precision of measurements can be secured by employing trained personnel to take the necessary measurements and analyze the data.

Probability and Nonprobability Sampling

Scientific sampling designs specify methods for sample selection and estimation of sample statistics that follow the principle of specified precision at the minimum cost, i.e., they provide, at the lowest possible cost, estimates that are precise enough for the study objectives.

Probability sampling refers to any sampling procedure that relies on random selection and is amenable to the application of sampling theory to validate the measurements obtained through sampling. This requires that, within the sampled population, one is able to define a set of distinct samples (where each sample consists of sampling units) with known and equal probabilities of being selected. One of these samples is then selected through a random process. In practice, the sample is most commonly constructed by specifying probabilities of inclusion for the individual units, one by one or in groups, and then selecting a sample of desired size and type.

Nonprobability sampling refers to sampling procedures that do not include the element of random selection. Some common types of nonprobability sampling include:

(1) Samples restricted only to a part of the population that is readily accessible (e.g., customers who happened to be at home on the day of canvassing)
(2) Samples selected haphazardly, without prior planning
(3) Small samples of "typical" units (as judged by impression) from a small but heterogeneous population
(4) Samples consisting entirely of volunteers

The only way of examining how good the nonprobability sample may be is to know parameters for the entire population or to compare it with probability sample statistics taken from the same population.

Types of Sampling Plans

There are many ways of constructing a probability sample. Several popular sampling plans are described below.

Simple Random Sampling

Simple random sampling refers to a method of selecting n sampling units out of a population of size N, such that every one of the distinct samples (where each sample consists of n sampling units) has an equal chance of being drawn. The process of drawing a simple random sample consists of:

(1) Numbering units in the population from 1 to N
(2) Drawing a series of numbers from 1 to N from a table of random numbers (or using a random number generator of a computer program)
(3) Making sure that at any draw the process used gives an equal chance of selection to any number in the population not already drawn.

If a unit number that has been drawn is removed from the population for all subsequent draws, this method is called simple random sampling without replacement. Sometimes, simple random sampling with replacement is used because the calculations of estimated variances of sample estimates are often simpler when sampling with replacement than when sampling without replacement.

Stratified Sampling

In stratified sampling, the sampled population of N units is first divided into several nonoverlapping subpopulations. These subpopulations are called strata because they divide a heterogeneous population into homogeneous subpopulations. If a simple random sample is taken from each stratum, then the sampling procedure is described as stratified random sampling. In order to design a stratified random sampling plan, it is necessary to determine:

(1) Which population characteristic (i.e., variable) should be used in stratification.
(2) How to construct the strata (i.e., how many strata to use and where to set the stratification boundaries).
(3) What sample sizes should be obtained from each stratum.

The best characteristic (i.e., variable) for the construction of the strata depends on the purpose for which the sample is taken. If the purpose is to obtain estimates of water use, then the best characteristic is the frequency distribution of the water use itself. The next best characteristic is presumably the frequency distribution of some other variable highly correlated with water use. However, for the purpose of developing water use models, stratification should indeed be based on one of the independent variables (e.g., income or home value). Stratification, based on the dependent variable (i.e., water use), may result in unknown bias in statistical estimates of the model parameters.

The statistical theory of stratified sampling offers some methods for selecting the optimal number of strata, strata boundaries, and sample sizes in advance. However, it is usually necessary to collect and examine some data before designing a good sampling plan.

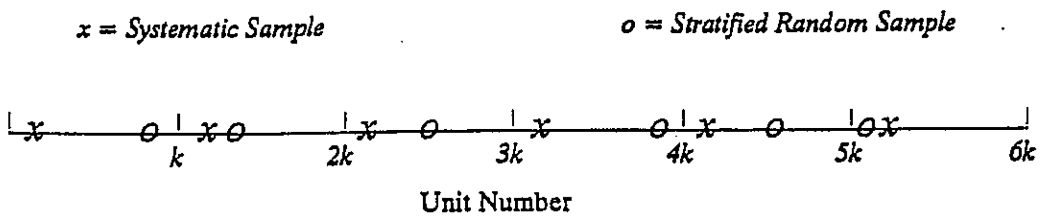
Systematic Sampling

Systematic sampling is often the most expeditious way of obtaining the sample and may be used in situations where time is critically constrained. The units in the population sampled are first numbered from 1 to N in some order. To select a sample of n units, one should take the first unit at random from the first k units and every kth unit thereafter. The selection of the first unit determines the whole sample, which is often called an every kth systematic sample.

Because the population is divided into k large sampling units, each of which contains n of the original units, a systematic sample taken from a sampling frame with no particular order is a simple random sample of one cluster unit from a population of k cluster units. It is important to remember that systematic sampling should always begin with a random start.

If individual sampling units are arranged according to some characteristic or variable (e.g. water use), than the systematic sample is equivalent to a stratified sample in which one sampling unit is taken from each stratum. Figure II-2 shows the difference in selections of sampling units from the arranged sampled population in a systematic and stratified sample.

FIGURE II-2
SYSTEMATIC AND STRATIFIED RANDOM SAMPLING



Cluster Sampling

Constructing a list of sampling units can be avoided by dividing a geographic area into areal units such as city block or pressure zones. Cluster sampling can result in significant cost savings. For example, a simple random sample of 600 houses may cover a town more evenly than 20 city blocks containing a sample of 30 houses each, but it will cost more because of the time devoted to travel and finding individual houses. However, cluster sampling creates a greater risk of obtaining a nonrepresentative sample.

Sample Size Requirement for Continuous Data

The size of the sample depends on the precision of measurement that is required by the evaluation design and the variance in the parameters to be estimated. The precision of an estimate refers to the size of the deviations from the mean of all sample measurements obtained by repeated application of the sampling procedure. In contrast, the term accuracy is usually applied to indicate the deviations of the sample measurements from the true values in the population.

For example, a simple random sample can be used to estimate average daily water use and variance in water use of all single-family customers in the service area during a given year. According to sampling theory, the mean water use $\bar{y}$ obtained from the simple random sample is an unbiased estimate of the average water use Y for all customers (i.e., the population mean). Also, $\hat{Y} = N\bar{y}$ is an unbiased estimate of total water use of the population (N customers).

The standard error of $\bar{y}$, which describes the precision of the estimated mean value, is

$$\sigma_{\bar{y}} = \left(\sqrt{\frac{N-n}{N}}\right)\frac{S}{\sqrt{n}} \tag{1}$$

where S is obtained from population variance S^2 (by taking its square root). Because in practice S^2 may not be known, it must be estimated from the sample data using the formula:

$$s^2 = \frac{\sum_{i}^{n} (y_i-\bar{y})^2}{n-1} \tag{2}$$

which provides an unbiased estimate of S^2 and where n is the sample size. Usually, with a simple random sample having mean $\bar{y}$, control of the following probability condition is desired:

$$\Pr\left(\left|\frac{\bar{y}-\bar{Y}}{\bar{Y}}\right| \geq r\right) = \alpha \tag{3a}$$

where α is a small probability (e.g., 0.05) and r is relative error expressed as a fraction of the true population mean. By multiplying both sides of the parenthetical expression in equation (3a) by $\bar{Y}$, the same condition can be restated as

$$\Pr\left(|\bar{y}-\bar{Y}| \geq r\bar{Y}\right) = \alpha \tag{3b}$$

If, instead of the relative error r, control of the absolute error d (i.e., the absolute value of the difference between the sample mean and the population mean) in $\bar{Y}$ is desired, the formula can be written as

$$\Pr\left(|\bar{y}-\bar{Y}| \geq d\right) = \alpha \tag{3c}$$

It is usually assumed that $\bar{y}$ is normally distributed about the population mean $\bar{Y}$, and given its standard error from equation (1), therefore

$$r\bar{Y} = t\sigma_{\bar{y}} = t\sqrt{\frac{N-n}{N}} * \frac{S}{\sqrt{n}} \tag{4}$$

where t is the value of the normal deviate corresponding to the desired confidence probability. This value is 1.64, 1.96, and 2.58 for confidence probabilities 90, 95, and 99 percent, respectively. Solving equation (4) for n gives

$$n = \left(\frac{tS}{r\bar{\bar{Y}}}\right)^2 / \left[1 + \frac{1}{N}\left(\frac{tS}{r\bar{\bar{Y}}}\right)^2\right] \tag{5}$$

The expression in brackets represents a finite population correction, and it should be used when n/N is appreciable. Without this correction, we can take the first approximation of the desired sample size n_o as

$$n_o = \left(\frac{tS}{r\bar{\bar{Y}}}\right)^2 \tag{6}$$

According to Equation (6), n_o depends on the coefficient of variation (the ratio $S/\bar{\bar{Y}}$) of the population that is often more stable and easier to guess in advance than S itself. It also depends on the error r that can be tolerated and the confidence level that is needed as captured by the value of t. For the absolute error specification as in (3c), Equation (6) is changed into

$$n_o = \left(\frac{tS}{d}\right)^2 \tag{7}$$

EXAMPLE II-2
EXAMPLE OF SAMPLE SIZE DETERMINATION FOR CONTINUOUS DATA

A retail water agency serves 80,000 single-family customers. The analysis of billing frequencies for the entire fiscal year indicates that average daily use per single-family customer is 250 gallons and the standard deviation is 180 gallons. Using simple random sampling, how many single-family customers must be taken to estimate average daily use within 2 percent of the true value, apart from a chance of 1 in 20 (or 5 percent)?

Solution: $N = 80{,}000$; $S = 180$ gallons; $\bar{Y} = 250$ gallons; $t = 1.96$; and $r = 0.02$

$$n_0 = \frac{t^2 S^2}{r^2 \bar{Y}^2} = \frac{(1.96)^2\ (180)^2}{(0.02)^2\ (250)^2} = 4{,}979$$

where

n = sample size (n_0 is the first approximation)
N = population size
S = population standard deviation
Y = population mean
t = confidence probability (t-statistic)
r = relative error

Because n_o/N is not negligible, we need to take the finite population correction

$$n = \frac{n_0}{1 + \frac{n_0}{N}} = \frac{4{,}979}{1 + \frac{4{,}979}{80{,}000}} = 4{,}687$$

The results indicate that if the average water use is unknown, to estimate it by sampling billing records with an error of 2 percent (or 5 gallons), a sample of 4,687 single-family homes would be required.

Sample Size Requirement in Sampling for Proportions

In some evaluation problems, it may be necessary to obtain estimates of the percent of households that adopted the conservation measure (e.g., installed one or more of conservation devices) by surveying a sample of households. The sampling problem in this case is referred to as "sampling for proportions," where the respondents are classified into two classes: installers and noninstallers (or participants and nonparticipants).

In order to determine the required sample size, we must decide the margin of error d in the estimated proportion p of units that installed the devices and the risk α that the actual error will be larger than d. Therefore, control of the following probability condition is desired

$$\Pr\left(|p-P| \geq d\right) = \alpha \tag{8}$$

Assuming simple random sampling and a normal distribution of p, the standard error of p, σ_p, is given by

$$\sigma_p = \sqrt{\frac{N-n}{N-1}}\sqrt{\frac{PQ}{n}} \tag{9}$$

where

N = population size
n = number of respondents in the sample
P = proportion of installers in the population
Q = proportion of noninstallers in the population (i.e., Q = 1-P)

The formula for the desired degree of precision is

$$d = t\sqrt{\frac{N-n}{N-1}}\sqrt{\frac{PQ}{n}} \tag{10}$$

where t is the value of normal deviate corresponding to the desired confidence probability (i.e., the abscissa of the normal curve that cuts off an area of α at the tails). Solving (10) for n gives

$$n = \left(\frac{t^2PQ}{d^2}\right) \Big/ \left[1 + \frac{1}{N}\left(\frac{t^2PQ}{d^2} - 1\right)\right] \tag{11}$$

If n/N is negligible because N is large, we can take the first approximation of n_o by using an advanced estimate p for P (and q for Q) from the formula

$$n_o = \frac{t^2pq}{d^2} \tag{12}$$

After obtaining n_o, we can introduce the finite population correction to sample size from the formula

$$n = \frac{n_o}{1 + (n_o / N)} \tag{13}$$

The sample size for different expected percentage of installation rates and error limits are shown in Table II-1.

TABLE II-1
SAMPLE SIZE FOR PROPORTIONS WITH 95 PERCENT CONFIDENCE

Expected Installation Rate p	Error Limit d	Sample Size n_o
0.50	0.01	9,604
	0.03	1,067
	0.05	384
0.60	0.01	9,220
	0.03	1,024
	0.05	369
0.70	0.01	8,067
	0.03	896
	0.05	323
0.80	0.01	6,146
	0.03	683
	0.05	246

EXAMPLE II-3
EXAMPLE OF SAMPLE SIZE DETERMINATION FOR PROPORTIONS

A retail water agency that serves 80,000 single-family customers delivered water conservation kits to all homes (e.g., by hanging them on the doorknobs). The program is expected to achieve a 70 percent installation rate. The installation rate actually achieved is to be estimated by conducting a survey of a random sample of single-family homes in the service area. The agency can tolerate an error limit of 2 percent and is willing to take a 1 in 20 chance of getting an unlucky sample (that is in error by more than 2 percent).

Solution: $d = 0.02$; $p = 0.70$; $q = 0.30$; $t = 1.96$; $n = 80,000$

$$n_o = \frac{(1.96)^2\ (0.70)\ (0.30)}{(0.02)^2} = 2,017$$

where

n = sample size (n_0 is the first approximation)
p = estimated proportion
q = $(1-p)$
t = confidence probability
d = margin of error

If n_0/N is not negligible, we make the finite population correction

$$n = \frac{2,017}{1 + \frac{2,017}{80,000}} = 1,967$$

Step-by-Step Sampling Process

In order to obtain an adequate sample for evaluation of a conservation program, it is helpful to perform various activities that can be grouped into the following seven steps:

(1) Review evaluation objectives
(2) Define the population to be sampled

(3) Specify data (or measurements) to be collected
(4) Determine the desired degree of precision and calculate sample size
(5) Develop the sampling frame
(6) Select a sampling plan
(7) Draw the sample

The activities that must be undertaken during each step are discussed below and illustrated in Example II-4 using an actual case of a sampling plan developed for a mid-size water agency in California.

Review of Objectives

Sample design is a function of the specific objectives of the evaluation. These objectives will indirectly define the desired precision in measuring conservation savings as well as the customer classes and dimensions of water use that need to be evaluated. Also, the review of other elements of evaluation design will be necessary before sampling.

Sampled Population

The sampled population should coincide with the target population. The latter denotes the aggregate from which the sample is chosen. The analyst must decide what group of customers is to be investigated. For example, it is necessary to determine if the results obtained from the sample should apply to all residential customers or to all single-family homes. The definition of the sampled population relates to the question of external validity, i.e., for what customer group, external to the program, should the results be valid?

A precise definition of the sampled population will allow the field personnel to decide whether or not a doubtful case belongs to the population. In cases where the sampled population is smaller than the target population, the conclusions apply only to the sampled population. In order to apply the findings to the target population, supplemental information will be required on the nature of differences between the two populations.

Data Specifications

Once a sampling unit (e.g., single-family customers) is selected, the relevant data (or measurements) for this unit must be obtained. The analyst must make sure that all data to be collected are relevant with respect to the research objectives and that no essential data or information are omitted.

Precision and Sample Size

Before calculating sample size, it is necessary to decide what amount of error can be tolerated. Larger samples will produce estimates with smaller error. However, improved precision can also be achieved by employing more efficient sampling plans, such as stratified sampling. The data analysis technique to be employed for estimating water savings will also affect the precision of the estimates. For example, multivariate models will yield greater precision of an estimate of water savings than the comparison of means method for the same sample size.

Sampling Frame

A sampling frame is a list of all sampling units. In some cases this may be a major practical problem. For example, the sampling frame for the population of <u>all</u> customers served by a water agency is the computerized billing system. However, if the sampled population should consist of all single-family customers, then only billing systems that recognize such customers can be used as the sampling frame.

Sampling Plan

There are many ways of selecting a sample. The four previously described sampling plans (i.e., simple random, stratified, systematic, and cluster sampling) should be examined for ease of application as well as precision. Nonprobability sampling should be avoided because it will undermine the validity of results.

Sample Selection

In some evaluation designs, samples can be selected and recorded prior to obtaining the data. In other cases, sample selection is performed concurrently with data collection. For example, in telephone surveys, the random digit dialing method can be used to select the customers and conduct interviews with respondents who agree to the interview.

EXAMPLE II-4
EXAMPLE OF STEP-BY-STEP SAMPLING PROCESS

Review of Objectives

A water agency implemented a citywide low-flow showerhead/toilet dam program (i.e., retrofit program). The retrofit devices were distributed door-to-door to all single-family detached homes. The objective of the program evaluation was to determine the annual water savings that resulted from the distribution of the retrofit kits. On an a priori basis, it was decided that the determination of program impacts would be measured in terms of differences in water use behavior between the treatment and control groups (this and other methods of impact evaluation are described in **Step 7**). Therefore, an experimental design and sampling procedure was necessary.

Sampled Population

The sampled population was all single-family detached homes in the specified city.

Data Specifications

In order to conduct the comparison of water use between treatment and control groups both prior to, during, and after the distribution of the retrofit kits (See Figure II-1), water use data for the sampling units (e.g., single-family detached homes) had to be obtained for a prespecified time period. The selected time period for analysis was the one year prior to the retrofit program, the one-year during the program implementation, and the one year after the retrofit program. The water agency, in this example, bills its residential customers on a bimonthly basis; therefore, water use data from the bimonthly billing records were necessary for each sampled customer.

Precision and Sampling Size

Using the method for determining the sample size requirement for continuous data, it was determined that about 2,000 sampling units would be required for both the treatment group and the control group in order to estimate average daily water use with 90 percent confidence probability and 2 percent relative error.

EXAMPLE II-4 (Continued)
EXAMPLE OF STEP-BY-STEP SAMPLING PROCESS

Sampling Frame

In selecting treatment and control groups for the evaluation of the retrofit program, it was determined that it would be a logistical problem to have individual control group homes scattered around the target retrofit area; it would be difficult to isolate control group homes from receiving the retrofit kits during the mass distribution. Therefore, it was decided that city blocks would be chosen to represent treatment and control groups. The sampling frame therefore became all city blocks within the target area.

Sampling Plan

From the sampling frame, the average number of single-family homes per city block was determined. Therefore, it was known how many city blocks had to be chosen to obtain the appropriate sample size. From the sampling frame, the city blocks (clusters) were chosen by systematic selection, with a random start.

Sample Selection

With the above sampling plan, city blocks were chosen to represent the control and treatment group. Single-family homes within the selected blocks were identified from water billing records.

TYPES AND COMPONENTS OF EVALUATION PROGRAMS

Program evaluations can be performed at different points in time relative to the time of implementation and the duration of water conservation programs being evaluated. Some evaluation programs can be undertaken prior to or during the implementation of conservation programs. Interim evaluations can be undertaken to provide information that can be used by the designers and administrators of a conservation program during its development or as feedback after initial implementation to help to improve it. An interim evaluation can be used to support decisions regarding improvements, additions, or deletions of various elements or procedures of the conservation programs. It may also be applied with regard to devices employed or promoted in program implementation (i.e., focus studies on the type of showerhead to select for a give-away campaign). An interim evaluation can also be helpful in accepting or rejecting a proposed program approach. Such interim evaluations are sometimes referred to as formative evaluations.

Final evaluations are normally performed following the completion of the conservation program (or when the implementation process is completed). It can be viewed as a backward-looking review process describing what was achieved and how. Its purpose is to provide information to decision makers about the efficacy and economic effectiveness of the program. The final evaluation is useful in determining whether a program is worth continuing and whether similar programs should be instituted elsewhere. In cases where several competing programs are considered, the final evaluation results can be used in allocating financial and human resources between the programs. The final evaluations are sometimes referred to as summational evaluations.

For the purpose of this manual, we distinguish three major parts of program evaluation: process evaluation, impact evaluation, and monitoring. The evaluation program designs differ markedly among three program components. **Part II: Program Evaluation** comprises three steps where each step corresponds to each major component of the evaluation process, i.e., process evaluation, impact evaluation, and monitoring.

Process Evaluation

The purpose of process evaluation, described in **Step 6**, is to track the operational efficiency of the program. This is done in order to obtain measurements of the effectiveness of program implementation methods and to assess the overall effects of the program. The process evaluation design should cover all elements and effects of the conservation program, except its impacts on water use. In some cases (especially where funds are limited), the results of the process evaluation may be combined with engineering estimates of water savings (or with results of previous evaluation studies) to generate estimates of aggregate savings from the conservation program. Typically, interim (or formative) evaluations are used in process evaluations.

Impact Evaluation

The most critical component of evaluation is the measurement of savings in water use described in **Step 7**. The purpose of impact evaluation is to obtain accurate measurements of changes in water use which are clearly attributable to the conservation program. Additional objectives may include attributing water savings to each element (or conservation measure) of the conservation program. The decisions to be made based on the results of impact evaluation are much more important than those associated with the evaluation of the implementation process. Therefore, greater precision of measurements is very desirable. Because the data required by impact evaluation may need special collection and/or processing, the cost of the impact analysis may be very high. Impact evaluation procedures are likely to be final (or summational).

Monitoring

This component of the evaluation process, described in **Step 8**, has proven its usefulness in managing conservation programs of electric utilities. Ongoing (i.e., long-term) monitoring of water use and conservation has many benefits. The most important benefit relates to the ability to assess the progress toward reaching overall goals of water conservation. Without such knowledge, water agencies may not be able to adjust their long-term water management plans. Also, the current status of water conservation evaluation and planning in the water supply industry indicates that an important and cost-effective means for advancing water conservation would be to establish and maintain an adequate monitoring program.

STEP 6. EVALUATE IMPLEMENTATION PROCESS

OBJECTIVES

(1) To prepare detailed documentation of the procedures and other design elements of the program (e.g., targeted customer groups, geographic locations, notification, delivery modes, incentives, and others)

(2) To assess the effectiveness and efficiency of program operations, including the identification of factors that enhance or impede these operations

(3) To determine whether the program's administrative and delivery procedures (including program management, customer contact, and data tracking) are adequate

(4) To assess the opinions of program participants on program delivery procedures and their participation outcomes

(5) To identify barriers to program participation among program "dropouts" and "nonparticipants"

(6) To develop specific recommendations for refining program implementation as the program continues

RESEARCH DESIGN

Process evaluation is a method of program evaluation that is performed to measure the effectiveness of program implementation methods. It is a type of formative evaluation that is used to support decisions regarding changes of various elements or procedures of the conservation programs. Its focus is on program description and the documentation of all aspects of program implementation. Process evaluation is especially useful when applied to pilot- or demonstration-type programs where the feedback from the analysis can be used, if necessary, to modify program operations prior to full-scale implementation.

The process evaluation design should cover all elements and effects of the conservation program under study, except its impacts on water use. However, the design of the process evaluation will depend on the type of conservation program being evaluated and the goals and objectives of the evaluation. Process evaluation can provide useful information to the water conservation planner or program administrator including:

(1) Feedback from the program that can be used to modify and improve the program (e.g., delivery procedures, satisfaction with devices or services)

(2) Market penetration of the program devices or services (e.g., success in reaching target population)

(3) Input data for the impact evaluation (analysis of water savings) and benefit-cost analysis (e.g., participant and nonparticipant characteristics)

The first step in designing the process evaluation is to determine the objective of the analysis. This will, in turn, determine the specific measurements that have to be procured during the evaluation. An illustrative list of measurements is shown in Table 6-1. When the objectives of the process evaluation are known, the tools and methods for meeting those objectives can be selected.

The need for early planning cannot be overstated with respect to the process evaluation. The sources of information for the process evaluation must be determined well in advance of program implementation. In most cases, selected data parameters for the process evaluation are gathered during the delivery of services. Therefore, data collection forms and procedures must be prepared prior to program implementation, and program implementation staff must be trained in the data collection methods.

The following sections discuss various objectives of process evaluation and describe methods of data collection and analysis.

PROGRAM DESCRIPTION

Assuming that a conservation program has already been designed, the process evaluation typically begins with a review of program documentation on goals and objectives, responsibilities, and procedures. The conservation program must be described with respect to the following elements:

(1) Program contents
(2) Definition of the target population
(3) Program incentives
(4) Customer contact mode(s)
(5) Schedule of program implementation and duration
(6) Specification of responsible agencies
(7) Program evaluation plan

Each of these elements should be part of the implementation plan of a given conservation program (see **Step 3**).

TABLE 6-1
POTENTIAL MEASUREMENTS FOR PROCESS EVALUATION

Questions	Potential Measurements
Who?	Total number of eligible customers (i.e., target group)
	Characteristics of eligible customers (e.g., single-family homes built prior to 1980, commercial establishments with large turf areas)
	Number of eligible customers receiving notification (percent)
	Number of eligible customers contacted during fieldwork (percent)
	Number of contacted customers who agreed to participate in the program
	Characteristics of participants (e.g., family size, age, income, type of establishment)
How?	Detailed procedures of conducting program (e.g., delivery modes, incentives, advertising)
What?	Number of contacts with program participants (and outcomes of each)
	Number of devices (of each type) installed
	Number of and type of services performed
	Number of audits/devices delivered per fieldworker (per day or per week)
	Customer satisfaction
Where/when?	Location of participants (geographically)
	Economic environment (e.g., water and wastewater prices)
	When program took place (day, month, year)
How much?	Costs of providing program (e.g., equipment/devices, labor, transportation, supplies)

The process evaluation can be conducted by the program implementation staff or by an independent reviewer (e.g., contract consultant). It should be noted that independent evaluations of conservation programs will provide added validity to findings (especially when the conservation programs are issues of public and political debate). Assuming that the program will be evaluated by an independent reviewer, a series of interviews with program implementation staff should be conducted. The interviews should involve staff responsible for various aspects of program implementation, including project management, customer contact, and data tracking. The purpose of the interviews is to develop full understanding of the implementation process. A review of any contracting arrangements for equipment or services should also be documented.

DESIGN OF RECORDKEEPING SYSTEMS

Rossi et al. (1979) identify four potential data sources that should be considered in the design of a process evaluation program:

(1) Service records (from data collection forms)
(2) Direct observations by the program evaluator
(3) Data from program staff who are service providers (general observations)
(4) Information on program participants

One of the most important aspects of the process evaluation (and also the impact evaluation) is the development of the service records (i.e., data collection forms). In monitoring the program implementation process, three types of recordkeeping systems should be considered:

(1) Cost accounting
(2) Personnel and equipment monitoring
(3) Field monitoring

Cost Accounting

In order to assess the economic efficiency of the conservation program, it is necessary to document all costs related to the program effort. As discussed in Step 4, costs for water conservation programs can vary by size and type of program and by whether the program is conducted by in-house personnel or contracted. However, the general categories that should be monitored include:

(1) Administration costs (of contract or field labor including any labor surcharge)
(2) Equipment purchases and equipment rentals
(3) Other direct costs (printing costs, postal cost, office supplies)
(3) Labor (management, supervisory/technical, field labor)

(4) Publicity costs
(5) Survey costs
(6) Evaluation costs
(7) Overhead costs

Resources expended in these categories should be accounted for on a regular basis. The time intervals for tracking program costs should be based upon program duration.

Personnel and Equipment Monitoring

In order to assure accountability by project staff, field personnel should be supervised on a daily basis. Especially when conducting home visits or site visits, data collection forms should identify field personnel conducting the visitations. This allows accountability for the delivery of services at specific locations. By assessing parameters such as the number of site visits per day or the number of devices delivered, the efficiency of field personnel can be identified. It is also important to keep track of program "downtime," including canceled appointments, travel time, meetings, etc.

When the conservation program includes the distribution of materials such as plumbing retrofit devices or requires the utilization of other equipment, daily check-out/check-in forms can be developed and monitored. It is not unusual to have up to 10 percent unaccounted inventory loss. However, these losses could be minimized through proper monitoring.

Field Monitoring

One of the most important recordkeeping systems for the process evaluation is field monitoring. With respect to the conservation program, it is necessary to document all aspects of the delivery of services. Two important elements are (1) access to the target population (Is the target population being reached?) and (2) delivery of service (Are the desired services/devices being provided?). A conservation program may fail to achieve the desired results because of the failure to provide the services according to prespecified procedures. Several reasons can be identified for the failure to achieve the desired outcomes of the program (Rossi et al., 1979):

(1) No treatment is provided to the targets (e.g., target households missed, high portion of the population unreachable at time of treatment, language barriers).
(2) Wrong treatment is delivered (e.g., low-flow showerheads provided to households which already have such devices).
(3) Treatment is uncontrolled, unstandardized, or varies across the population (treatments varied by field labor).

Monitoring the actual delivery of services allows for the potential identification of faults in operational procedures or, perhaps, in the initial assumptions regarding the target population. As an example, in door-to-door retrofit kit distributions, it is necessary to collect information on each canvass and the outcome of each home visitation. Some of the potential measurements include:

(1) Number of contacts with program participants (and outcome of each)
(2) Description of number and type of devices provided
(3) Description of the number and type of services provided
(4) Number of missed appointments
(5) Number of non-English-speaking households or specific language spoken
(6) Initial satisfaction with devices and or services
(7) General characteristics of program participants

The field-monitoring data can be utilized to obtain estimates of the coverage of the target population. Assuming that the total number of eligible customers is known prior to program implementation, determinations can be made regarding the percent of eligible customers contacted during fieldwork and the percent of eligible customers who participated in the program. Field monitoring will also provide useful information regarding the geographic distribution of participants and nonparticipants.

Other potential measurements to be obtained during field monitoring are presented in Table 6-1 (p. 161). It is necessary that the data collection forms prepared for field monitoring contain the checklist of information desired. Field labor must be sufficiently trained in completing the field- monitoring forms. Trial applications and pretesting of data collection forms with field labor can help assure the collection of necessary data. It may also be necessary to assign staff fluent in appropriate languages for certain areas.

Often, the field-monitoring procedures provide only limited information regarding the delivery of services. In fact, true outcomes of the services delivered may not be known at the time of delivery (or even follow-ups). For example, in door-to-door retrofit kit distributions, field-monitoring records may indicate how many homes were reached and how many devices were delivered. However, the true outcome of the delivered services may not be known until after one has access to the home. Therefore, in addition to monitoring the recordkeeping systems of the conservation program, additional information regarding the program implementation can be obtained by conducting sample surveys of the target population.

SURVEYS OF TARGET POPULATION

As stated previously, there are three main objectives for conducting a process evaluation: obtaining feedback regarding the program, assessing market penetration, and providing input for the impact evaluation. Survey research can provide useful information to the water conservation planner or program administrator for each of these objectives, and if surveys are conducted prior to the program implementation, information can be obtained to facilitate more efficient program designs.

Often, desired information for the process evaluation is not possible to obtain from field monitoring because true outcomes are not known until after the delivery of services or because the collection of desired information (participant/nonparticipant characteristics) might impede the delivery of services. Three types of sample surveys of the target population may be considered: (1) surveys of the target population, (2) surveys of program participants, and (3) surveys of program nonparticipants. If appropriate sampling techniques are used, a sample can be used to represent the desired population (see introduction to **Part II** of this manual for discussion of sampling plans and sample size).

Several other advantages of conducting sample surveys should be noted. First, more detailed information can be obtained from a sample of customers without impeding the delivery of services. Second, sample surveys can be used to assess the characteristics of nonparticipants. Third, sample surveys can be used to conduct follow-ups to measure program dropouts (i.e., those participants who discontinue recommended practices or who remove installed devices) and program satisfaction.

Survey Methods

Generally, there are three types of survey methods:

(1) Mail surveys
(2) Telephone surveys
(3) Personal interviews/field surveys

Each of the methods has its comparative strengths and weaknesses with regard to administrative costs, data quality, and in obtaining a representative sample. Table 6-2 compares the three survey methods qualitatively. The advantages and disadvantages of the survey methods are described below (also see Lake and Harper, 1987).

Mail surveys tend to be the least costly of the three approaches. For this reason, mail surveys can be used to obtain relatively large samples. Because the surveys are completed at the respondents convenience and because the questions can be reread at their discretion, more complex and detailed questions can be asked. However, the response rates to mail questionnaires can be very low if not followed up with reminders (postcards or additional questionnaires). However, follow-up reminders will add to the cost of administering the survey. Mail surveys also lack the control of other survey methods, including clarification of procedures, question ordering, or selection of respondent (e.g., head of household). Because response rates tend to be lower for mail questionnaires, there is a greater chance of nonrespondent bias (i.e., nonrespondents having significantly different characteristics than respondents).

TABLE 6-2
COMPARISON OF MAIL, FACE-TO-FACE, AND TELEPHONE SURVEYS

Factor	Mail	Face-to-Face	Telephone
Administration			
(1) Cost	1	4	2
(2) Personnel requirements: interviewers	n/a	4	3
(3) Personnel requirements: supervision	2	3	4
(4) Time for implementation	4	4	1
Sample			
(5) Sample coverage	3	1	1
(6) Response rate--general public	4	2	2
(7) Refusal rate	unknown	3	3
(8) Noncontact/nonaccessibility	2	3	2
(9) Ability to obtain response from elite population	4	1	2
(10) Respondent within household	4	1	1
(11) Sampling special subpopulation	4	2	2
Data Quality			
(12) Interview control	n/a	3	1
(a) Control consultation	4	1	1
(13) Obtaining socially desirable responses	1	4	3
(14) Item nonresponse	3	2	3
(15) Impact of questionnaire length on response	3	1	2
(16) Confidentiality	4	4	3
(17) Ability to ask sensitive questions	2	1	2
(18) Ask complex questions	3	1	3
(a) Ability to clarify	4	1	2
(b) Use of visual aids	3	1	4
(19) Use of open-ended questions	4	1	2
(a) Ability to probe	4	1	2

Key: 1 = major advantage.
2 = minor advantage.
3 = minor disadvantage.
4 = major disadvantage.
n/a = not applicable.

Source: Developed from Frey (1989), p. 76.

Telephone surveys tend to have the fastest turnaround time. Although they tend to be more costly than mail surveys, they are less costly than personal interviews. Telephone surveys can be used to screen the population (e.g., heads of households, program participants). This method also allows for more in-depth probing of questions and will allow for clarification of responses. However, telephone survey methods can also be subject to nonrespondent bias from households without telephones or households with unlisted numbers. When sampling from telephone directories or other listings, unlisted telephone numbers can cause significant nonresponse bias. However, random digit dialing methods typically used by marketing research firms can overcome the problem of unlisted telephones and can also help reduce sampling bias. The length of telephone interviews is also limited and therefore may reduce the number of questions possible and also limit the complexity of questions. It also should be noted that the interviewer's contact with the respondent may also lead to potential biases.

Personal interviews (field surveys) tend to be the most costly survey method. However, there is much greater control over the selection of respondents, and response rates tend to be higher than for the other methods. The time respondents are willing to devote to personal interviews tend to be longer than with telephone interviews. Therefore, more complex questions can be asked, and the interviewer can provide clarification to responses with follow-up questions. As with telephone interviews, the personal contact between the interviewer and the respondent may lead to response biases. With personal interviews, situational data can be obtained without even posing questions (type of residence, type of yard, size of house). Personal interviews tend to be practical only for small sample sizes without large geographic constraints.

Program Feedback

It may be useful to conduct a survey of the target population prior to the implementation of the conservation program. A baseline survey will provide program administrators with information regarding the characteristics of the population and may help refine program goals and procedures. The baseline survey may include information on customer's situational characteristics, attitudes, beliefs, and previous water use and conservation behaviors. This information may identify factors that can affect the likelihood of program participation (see Table 6-3). Knowledge of consumers' current conservation behaviors may preempt some aspects of planned programs. For example, for a plumbing retrofit program, it may be useful to assess the level of low-flow devices already in use by the population. Furthermore, prior knowledge of the target population's preferences with respect to contact modes and distribution methods may serve to refine the implementation plan of the conservation program.

TABLE 6-3
POTENTIAL SURVEY TOPICS

(A) Preprogram Survey

- (1) Belief about the effectiveness of potential conservation program
- (2) Beliefs about the economic benefits of potential conservation program
- (3) Preferred implementation methods of potential conservation program (e.g., retrofit program: depot, mail, door-to-door distribution)
- (4) Beliefs about the fairness of potential conservation program

(B) Postprogram Survey

- (1) Whether conservation program service or device was received
- (2) Whether conservation program service was implemented or device installed (what components? how many?)
- (3) Whether conservation program recommendations or devices were maintained
- (4) Satisfaction with program services or devices
- (5) Satisfaction with program implementation methods

(C) Pre- And Postprogram Surveys

- (1) Socioeconomic (household/business characteristics)

  If residential:
  - (a) Type of residence (single-family, duplex, townhouse, etc.)
  - (b) Ownership of residence
  - (c) Family size and age of family members
  - (d) Home value (or contract rent)
  - (e) Socioeconomic status (income, education, occupation)
  - (f) Lot size and type of yard (lawn, garden, etc)

  If business:
  - (a) Type of business (by Standard Industrial Classification)
  - (b) Primary service or product
  - (c) Number of employees (number of hotel rooms, number of students)
  - (d) Size of operation (production or business volume)

- (2) Information on water-using fixtures and appliances
- (3) Information on water-using activities and frequencies
- (4) Awareness of conservation activities
- (5) Attitudes about water conservation
- (6) Other conservation practices

Program participants may not be an adequate representation of the target population. Furthermore, field-monitoring records will likely have only limited information on program nonparticipants. In order to fully assess the level of program participation (with respect to the entire target population) and the impetus for program participation, it is useful to obtain detailed characteristics of both program participants and nonparticipants. A random sample survey of the target population conducted after program implementation should provide a representative breakdown of program participants and nonparticipants. Measuring differences between program participants and nonparticipants with respect to socioeconomic characteristics, program awareness, attitudes, and behaviors may provide useful information to program administrators and will also provide necessary data for an impact evaluation. The identification of characteristics unique to participants or nonparticipants may allow administrators to modify the program to better target certain sectors of the target population.

Market Penetration

After the delivery of services, a random sample survey can also be used to assess the market penetration of the program (with respect to its intended target population), including the dropout rate of participants (see Table 6-3). A postprogram survey will also allow an assessment of participant satisfaction with the services provided or the products delivered. Again, using a plumbing retrofit program as an example, the installation of devices may not have occurred until after the initial delivery. Therefore, follow-up surveys can be used to assess whether the desired outcome (i.e., the installation of devices) has occurred. Follow-up surveys can also be used to determine whether the desired behaviors are being maintained for an extended period.

In addition to survey techniques, water audits can be conducted to verify the installation of conservation devices or appliances or the modification of existing water-using equipment. The water audits would involve site visits to a sample of customers in a given urban sector and the visual inspection of plumbing, appliances, or other water-using equipment. If performed in conjunction with a water conservation program, the water audits performed on a sufficiently large and representative sample can provide accurate estimates of market penetration. However, there is a potential for self-selection bias considering the willingness of customers to participate in the audits. A variant of this approach proposed by Rodrigo and Dziegielewski (1991) would be to conduct water audits during the resale (new sale) of property. This approach can be implemented with the cooperation of real estate agencies and would eliminate the problem of self-selection bias. However, for the purposes of program evaluation, conducting water audits only during the sale (resale) of property may not provide the timely information necessary for program feedback.

Impact Evaluation

For conducting impact evaluations, three types of data are generally required (EPRI, 1991):

(1) Information on the factors that affect water use (household or business characteristics)

(2) Information on how factors affecting water use have changed over time

(3) Information on the target populations' attitudes, beliefs, and water use and conservation behaviors

It is often useful to conduct surveys of the target population both prior to and after program implementation (see Table 6-3). First, a preprogram survey will provide baseline conditions on those factors that are likely to affect the probability of program participation such as customers' situational characteristics, attitudes, beliefs, and water use and conservation behaviors. Second, pre- and postprogram surveys provide a means of comparison for evaluating the before-and-after characteristics of the population. This will allow an analysis to determine whether the program had any impacts on the factors that affect water use, including their attitudes, beliefs, and water use and conservation behaviors.

Prior to analyzing the differences between pre- and postprogram survey respondents, it is necessary to ensure (1) that the demographic characteristics of the respondents are representative of the target population and (2) that the differences in attitudes and behaviors that do occur between the two surveys are not the result of differences in the demographic characteristics of the two samples. If it is determined that there are differences between the responses to the two surveys with respect to demographic characteristics, a weighting procedure can be applied so that the distribution of selected demographic characteristics will not be statistically different between the two surveys. The impact of the conservation program intervention can be determined when all other factors affecting the population are measured and controlled (including other interventions that occurred simultaneously with the conservation program intervention e.g., changes in water rates).

Although survey data can be used to estimate the program impact on the factors that affect water use (attitudes, beliefs, and water use and conservation behaviors), the survey data can also be a valuable input to the measurement of water savings resulting from the conservation program. The usefulness of these data are further discussed in Step 7 of this manual.

STEP 7. MEASURE WATER CONSERVATION SAVINGS

OBJECTIVES

(1) To measure the average reduction in water use among the program participants (who adopted one or more measures comprising the conservation program)

(2) To measure seasonal variability of conservation effects

(3) To measure the variability of conservation savings over time (i.e., the persistence of program impacts)

(4) To assess the variability of conservation savings among different participants and to identify factors causing this variability in the residential sector (e.g., family size, income, education, water pressure)

(5) To measure the effect of other conservation measures (or programs) on the observed reduction in water use among program participants

(6) To estimate reductions in total urban water use for average- and maximum-day demands that can be attributed to the conservation program

(7) To develop estimates of uncertainty surrounding the estimates of conservation effects

PREPARATION OF DATA SETS

Types of Data

There are two types of data that can be used in program evaluation designs: primary and secondary. Primary data are collected solely for the purpose of program evaluation and the data collection process is an integral part of the evaluation design. Typically, special measurements are taken to acquire the data. For example, continuous measurement of water flows in a sample of residential homes may be obtained in order to model peak flows. Secondary data are measurements taken for a purpose unrelated to the study at hand. They simply exist somewhere and may be used for the purposes of the study. For example, monthly water use data obtained for the purpose of charging the customers for the amount of water they used can also be used for estimating statistical water use models.

Secondary water use data obtained from sources described in **Step 1: Analysis of Water Use and Service Area Data**, will be adequate for most evaluation designs. Data on variables which influence water use such as weather, income, household size, price, and others, may be either primary or secondary, depending on the variable in question.

Aggregate versus Disaggregate Data

In economics, data on economic activities (or variables) are collected at micro- or macrolevels. Observations on individual households, families, or firms are referred to as microdata. National level accounts and observations on entire industries are called macrodata.

In water use modeling and analysis, the corresponding types of data are referred to as disaggregate and aggregate data. Levels of aggregation may vary from the end-use level (e.g., toilet flushing, lawn watering) to the municipal level (e.g., total production or total metered use).

Types of Variables and Measurements

In developing research designs, it is necessary to distinguish among different types of variables and their levels of measurement. The latter are also referred to as scales.

In mathematical sense, a variable is a quantity or function that may assume any given value or a set of values as opposed to a constant that does not or cannot change or vary. Depending on the character (or type) of values that can be assumed by a variable, the following can be distinguished:

(1) Continuous variables
(2) Discrete variables
(3) Random variables

A continuous variable can assume any value within the interval where it exists (e.g., monthly water use of a customer). A discrete variable can assume only discrete values (e.g., number of persons in a household). Finally, a random (or stochastic) variable is a variable that can take any set of values (positive or negative) with a given probability. Random variables can be discrete or continuous.

The data on a variable can be measured on different kinds of scales. Such scales are used to describe the data and variables used in the analysis. The data can be:

(1) Nominal
    a. Ordinal
    b. Nonordinal
(2) Interval
    a. Ratio

Nominal or "categorical" data are measurements that contain sufficient information to classify and count objects. Nominal data can be classified according to ordinal or nonordinal scales.

Ordinal scales rank data according to the value of the variable that is being analyzed. Objects in an ordinal scale are characterized by relative rank so that a typical relationship is expressed in terms such as "higher," "greater," or "preferred to." Ordinal ranking of data commonly occurs in the use of surveys. For example, survey data of household income is usually ranked (or classified ordinally) by income range, such as 1 = <$25,000; 2 = $25,000-$49,999; 3 = 50,000-74,999; etc. Notice then that ordinal rankings are hierarchial.

Nonordinal data are ranked by variable type and therefore cannot be ranked hierarchically on a numeric scale. A recent example of nonordinal data comes from a survey of residential landscapes in southern California. Survey teams were asked to classify turf landscapes as 1 = Bermuda grass; 2 = other warm season grasses; 3 = tall fescue; and 4 = cool season grasses. Unlike the example of ordinal ranking given above, category 2 is not in any sense greater than category 1, because the categorization is based on landscape type without reference to numeric measurement of the distance between ranked objects.

Finally, there are interval data that contain numerical values from a continuous scale. Variables with interval data are therefore most frequently called continuous variables. Because a continuous variable can assume an infinite number of values, continuous variables can theoretically be measured only over an interval. Hence, the name interval data. If the continuous measurement scale contains a true theoretical zero (e.g., water use or temperature), then it is called a ratio scale.

In more sophisticated designs for estimating water conservation savings, both nominal and interval data are likely to be used.

Another classification of variables is used in statistical or econometric modeling. In constructing statistical relationships, an attempt is usually made to predict or explain the effects of one variable by examining changes in one or more other variables that are known or expected to influence the former variable. In mathematics, the variable to be predicted is called the dependent variable, while variables that influence it are called independent. However, in the analytical literature from various disciplines, a number of alternative terms are often used to describe and classify variables. Table 7-1 contains a list of such terms.

TABLE 7-1
ALTERNATIVE TERMS FOR DEPENDENT AND INDEPENDENT VARIABLES

Dependent	Independent
Explained	Explanatory
Predictand	Predictor
Regressand	Regressor
Response	Causal
Endogenous	Exogenous
Target	Control

Source: Maddala, 1977.

Configurations of Data Sets

For analytical purposes, data (or observations) on the variables under investigation can be obtained and arranged in several ways. Depending on which type of arrangement is used, the following types of data configurations can be distinguished:

(1) Time series data
(2) Cross-sectional data
(3) Pooled time series and cross-sectional data
(4) Panel (or longitudinal) data

In time series data, observations on all variables in the data set are taken at regular time intervals (e.g., daily, weekly, monthly, annually). In cross-sectional data, observations are taken at one time (either point in time or time interval) but for different units such as individuals, households, sectors of water users, cities, or counties. Pooled data sets combine both time series and cross-sectional observations to form a single data matrix. Finally, panel data represent repeated surveys of the same cross-sectional sample at different periods of time.

DATA COLLECTION METHODS

Another critical part of the evaluation design is the selection of appropriate techniques of data analysis to be used in estimating water conservation savings attributable to the water conservation program. However, the evaluation design (especially its data-gathering component) and the selection of the data analysis technique are not independent. The data analysis technique that is adopted depends a great deal on the type of data that is available. For example, if data on water use are unavailable for the period prior to the implementation of the program, then it is meaningless to consider an evaluation design and data analysis technique that requires such data. Also, if the budget of the evaluation is strictly restrained, then experimental or quasi-experimental designs, and such analytical techniques as pooled cross-sectional time series regression analysis may have to be ruled out due to the high cost of collecting the necessary data.

In order to estimate water conservation savings, the following types of water use data (and information) can be used:

(1) Laboratory measurements of flows and volumes of water used in various plumbing fixtures and appliances

(2) Monthly billing records for individual customers that could be sampled for various periods of time

(3) Monthly billing summaries (or sales data) for various classes of customers showing aggregate water use in each class

(4) Production meter records with continuous or daily recordings

Water conservation savings can be estimated using each of the above types of water use data or their combinations. Also, each type of data can be matched with the various analytical techniques and types of water conservation measures for which they are most suitable. Each combination is briefly described below.

Laboratory Data

Laboratory performance data of conservation hardware can be used to calculate differences in water use rates between plumbing fixtures of different designs or between various water-using appliances. The differences provide estimates of conservation savings for measures that rely on replacing certain fixtures or appliance designs with more efficient designs. However, the application of laboratory data in estimating the effects of conservation programs poses many problems that are discussed in the subsequent sections.

Billing History of Individual Customers

The usefulness of billing records depends on the frequency and continuity of customer meter readings. The best billing history data are obtained by reading meters once a month and not using estimated consumption in place of actual readings. The usefulness of bimonthly, quarterly, semiannual, and annual meter readings diminishes with their decreasing frequency . However, this does not preclude their use for the estimation of water conservation savings.

Databases can be built from billing records by supplementing them with data from other sources such as random samples of customers. The possible data configurations which can be constructed from billing histories of individual customers include:

(1) Time series of billing period water use data for individual customers

(2) Time series of billing period water use data for all customers in the sample

(3) Cross-sectional water use data for a billing period extending across all customers in the sample

(4) Cross-sectional water use data aggregated for two or more billing periods representing seasonal or annual use extending across all customers in the sample

(5) Pooled time series cross-sectional data for all billing periods and all customers

(6) Pooled time series cross-sectional data aggregated over two or more billing periods for all customers

In mathematical terms, we can describe each data configuration by designating water use of customer i during billing period t as q_{it}. If n and m represent, respectively, the number of customers in the sample and the number of billing periods, we can describe the six data configurations as:

(1) Customer time series data

q_{it}; where i = constant, $t = 1 \ldots m$

Interpretation: Total water use of customer i in each time period t

(2) Aggregate time series data

$$\sum_{i=1}^{n} q_{it}; \text{ where } t = 1 \ldots m$$

Interpretation: Total water use of customers in the entire sample in each time period t

(3) Cross-sectional billing period data

q_{it}; where $i = 1 \ldots n$ and t = constant

Interpretation: Total water use of each customer, i, during billing period t

(4) Seasonal (or annual) cross-sectional data

$$\sum_{t=1}^{k} q_{it}$$

where $i = 1 \ldots n$; and k = number of billing periods in each season

Interpretation: Total water use of each customer i during seasonal or annual period k

(5) Pooled time series cross-sectional data

q_{it}; where $i = 1 \ldots n$ and $t = 1 \ldots m$

Interpretation: Water use per customer i in each time period t

(6) Pooled time series cross-sectional data with seasonal (or annual) aggregations

$$\sum_{t=1}^{k} q_{it}$$

where $i = 1 \ldots n$, $t = 1 \ldots k$, and k = number of billing periods in each season

Interpretation: Water use per customer i in each season comprising k billing periods

If water use and program participation are the only variables in the data set, then the appropriate data analysis technique would be the "difference of means" method. Configurations (2), (3), and (4) would support such an analysis. If observations on water use, q_{it}, are supplemented with data on variables that are believed to be predictors of residential water use (e.g., income, family size, price, air temperature), then regression analysis can be applied to any of the above configurations.

Billing Summaries for Classes of Customers

A record of total water sales during each billing period can also be used to estimate conservation savings if (1) the sales record is of sufficient quality, and (2) the sales are disaggregated by homogeneous user sectors (e.g., single-family residential, multiunit residential, commercial, industrial, public, and other classes of users). However, in most cases the record of sales cannot be easily disaggregated into user classes because individual user records do not contain any information on the user type. In some instances, it may be possible to disaggregate sales by meter size, thus approximating various classes of users. In general, aggregate sales provide very poor data for measuring conservation savings. However, they can be used to verify savings derived from analyses of individual customer billing records.

If high quality disaggregate sales data are available, a time series data set can be constructed using monthly or bimonthly sales. Usually, five or more years of data (i.e., 60 or more monthly observations) prior to the implementation of the water conservation program would be required in order to conduct a time series regression analysis. The reliability of estimates will depend on the scale of the conservation program. Full-scale and large pilot programs may produce sufficiently large savings to be measured by this type of aggregate analysis.

Daily Production Records

Water utilities usually have one or more production meters that are read at least daily. Because there are generally only one or two production meters, they are regularly maintained for accuracy, and therefore usually produce highly reliable measurements of water-flows into the distribution system. A time series data set can be constructed with daily (or weekly) time intervals and used in a time series regression analysis. This is the only type of secondary data that has daily observations, and as such, it can be used to measure the effects of conservation programs on peak-day (or even peak-hour) demands. Again, such programs must be of sufficient scale (e.g., full-scale or large pilot programs) to produce discernible conservation effects.

Selecting Appropriate Data and Techniques

The selection of appropriate data and methods of their analysis depends on the specific objectives of the evaluation program. For example, time series regression analyses of aggregate data can be used to measure gross savings of large-scale programs or the combined conservation effect of all conservation activities in the service area. If estimates of water savings attributable to specific conservation measures are desired, then customer-level data (i.e., billing histories) are most appropriate. The desired reliability of estimates will also influence the selection of data and methods of analysis. Generally, time series analyses of aggregate data will provide estimates that are less reliable than those obtained from pooled time series cross-sectional analyses of customer level data. The following sections provide a detailed discussion and examples of five basic approaches for estimating water conservation savings.

The five methods in order of discussion are:

(1) Mechanical estimates
(2) Comparison of means
(3) Simple regression
(4) Multiple regression
(5) Econometric end-use modeling

The use of mechanical estimates and the comparison of means approach will be found to be descriptive first steps in analyzing water savings. These methods are inexpensive and simple to utilize. However, these techniques are based on stringent assumptions that are often violated. Simple regression procedures, much like the use of mechanical estimates and the comparison of means approach, will be found easy to use, yet void of the types of additional information that can be utilized by multiple regression procedures. The multiple regression approach is shown to be more appealing because of the wealth of information the method uses to explain variance in household water use. Finally, an example of econometric end-use modeling will detail the potential application of this innovative method to the measurement of water savings.

MECHANICAL ESTIMATES

Mechanical estimates have the advantage of being inexpensive and easy to obtain. This method, also known as the "engineering approach," uses laboratory estimates or published data on water savings per installed device (or adoption of a given conservation practice). These data are combined with assumptions regarding the magnitude of factors expected to impact on the results of the conservation programs in order to develop estimates of program impacts. Therefore, mechanical estimates should not be considered an empirical evaluation technique. Rather, they are the best summation of a priori knowledge about potential conservation.

However, estimates of conservation savings obtained using the mechanical approach are quite sensitive to the underlying assumptions and relationships. The validity of these assumptions can easily come under attack, since they often rely on subjective conclusions and a great deal of professional judgment of the engineer or analyst. Such assumptions are simply no substitute for actual field measurements, although through experience and careful analysis, they may produce a fair approximation of reality.

Although mechanical estimates have been found to overestimate water savings, these estimates may be considered appropriate for providing preliminary estimates of potential conservation savings when field measurements are not available. When field measurements are available, mechanical estimates may still be used to augment the statistical approach. Statistical models, on their own, may not be able to provide all of the impact estimates necessary for an evaluation. Furthermore, the engineering approach may be able to provide estimates for program participants that cannot be assessed by the statistical method. However, sole reliance on mechanical estimates for major investment decisions concerning the allocation of water resources should be discouraged.

COMPARISON OF MEANS

The comparison means method of estimating conservation savings is derived from the statistical theory of randomized controlled experiments, where households are first randomly allocated into groups that do and do not receive conservation equipment. Thus, this method utilizes a treatment/control design in which conservation savings are estimated as the difference in the mean level of water use between the treatment group and the control group. Not unlike laboratory estimates, comparison of means is a method that requires stringent assumptions in order to produce valid results. Unless the analyst can empirically justify the reasonableness of these assumptions, one has cause to doubt the results.

The comparison of means method must follow two key empirically testable assumptions that deal directly with the random allocation of treatment and control groups:

(1) The two random variables (i.e., water use in the treatment and control groups) are drawn from the same population distribution.

(2) The distribution is normal.

To begin with assumption (2), it must be stressed that empirical distributions of water use have most often been found not to follow a normal distribution. Typically, distributions of water use show a long right-hand tail, and thus do not conform to the symmetric bell-shaped appearance associated with the normal distribution.

The violation of assumption (2) is not a fatal flaw, however, if a normalizing transformation of the data is used. It is recommended that a logarithmic transformation be used as the best a priori normalizing transformation. Although it may be possible in some situations to find a better transformation, taking the log of water use should at least pull in the right-hand tail and minimize the leverage of "contaminated" or outlying data points.

Unfortunately, assumption (1) is much easier to violate and is also much more costly to correct. In the classic experimental design on which the comparison of means method is based, the experimenter has careful control over all factors that might affect the variable under consideration. Therefore, by carefully designing the samples to be used in the experiment, any difference between the treatment and control groups can be attributed solely to the "treatment." Alternately, the water planner is not likely to have complete control over the confounding factors that affect household water use. Although statistical theory suggests that randomly assigning households into treatment and control groups will result in groups that are less likely to be systematically different in terms of water use, this does not ensure that the two groups are similar with respect to household income, persons per household, yard size, and many other factors. Therefore, unless a great deal of matching or sampling work is done, water use cannot be considered a random variable. It is related, if not caused, by the uncontrolled-for factors that differ between the treatment and control groups. In other words, one runs the risk of <u>incorrectly</u> attributing observed changes in water use to the treatment (e.g., a retrofit), when in fact they are caused by the different average values of external factors in each group.

Supposing that the analyst can perform (and afford) the difficult methodological task of carefully controlling and randomizing the experiment, the comparison of means method is statistically rather straightforward. The following sections detail how the comparison of means method can be used to estimate the water savings within the treatment/control design framework.

Basic Relationships

The conservation effect attributable to a residential retrofit (or similar conservation program) is estimated as

$$d = \bar{q}_t - \bar{q}_c \qquad (7.1)$$

where

$$\bar{q}_t = \frac{\sum_{t=1}^{n_1} q_t}{n_1} \tag{7.2}$$

and where

$$\bar{q}_c = \frac{\sum_{c=1}^{n_2} q_c}{n_2} \tag{7.3}$$

d	=	conservation effect (difference between means)
$\bar{q}_t$	=	mean water use in the treatment sample
$\bar{q}_c$	=	mean water use in the control sample
q_t	=	water use of customer *t* in the treatment sample
q_c	=	water use of customer *c* in the control sample
n_1	=	number of customers in the treatment sample
n_2	=	number of customers in the control sample

One must test whether the observed difference *d* can be attributed to chance, or whether it is indicative that the two samples come from populations of unequal means. Given that the parent population distribution of the differences in means is unknown or not normal, and that the population standard deviation of water use in each group (σ_t and σ_c) are unknown but assumed equal, the *sampling* distribution of the differences in mean water use should follow a t-distribution for large samples.[1] A calculated t-statistic can be used to test the hypothesis that the differences between mean water use of the treatment and control samples is zero. In order to calculate a t-statistic, the standard error of the difference between the two means must be determined using the following formula

$$S_d = \sqrt{\left(\frac{(n_t - 1)\, s_t^2 + (n_c - 1)s_c^2}{n_1 + n_2 - 2}\right)\left(\frac{n_1 + n_2}{n_1\, n_2}\right)} \tag{7.4}$$

[1]The Central Limit Theorem (and the concept of repeated sampling) implies that for large sample sizes, the sampling distribution of the difference in means between groups will approach a normal distribution. This allows statistical inference about population parameters when the population distribution is unknown or not normal. However, in order for the sampling distribution of the difference in two means to be approximated by the normal distribution, the population standard deviations (σ_t and σ_c) must be known. If σ_t and σ_c are not known but are assumed equal, one may use the sample estimates of σ_t and σ_c (s_t and s_c) and the t-distribution for statistical inference. For large sample sizes, the t-distribution will approximate the normal distribution.

where

S_d	=	estimated standard error of the conservation effect *d*
s_t	=	standard deviation of water use in the treatment sample
s_c	=	standard deviation of water use in control sample
n_t	=	number of customers in the treatment sample
n_c	=	number of customers in the control sample

The t-statistic is then calculated as

$$t = \frac{\bar{q}_t - \bar{q}_c}{S_d} = \frac{d}{S_d} \tag{7.5}$$

Using the properties of the t-distribution, one can now construct and test the following hypotheses:

Null hypothesis, H_o: $\mu_t = \mu_c$ (or $\mu_t - \mu_c = 0$)
The null hypothesis states that the true population mean of the treatment group is equal to the population mean of the control group.

Alternative hypothesis, H_a: $\mu_t \neq \mu_c$ (or $\mu_t - \mu_c \neq 0$)
The alternative hypothesis states that the population means of the treatment and control groups are different.

The value of the t-statistic calculated by equation (7.5) uses the sample estimates of μ_t and μ_c, $\bar{q}_t$ and $\bar{q}_c$, to infer whether the difference *d* is large enough to reject the null hypothesis that the true difference in means is equal to zero. To test the null hypothesis, the resultant value of *t* must be compared to statistical tables of the t-distribution. These tables may be found in any standard statistics textbook. The next section includes examples of hypothesis testing, and describes the proper use of significance tests and confidence intervals based upon the sampling distribution of *d*.

Two-Tail and One-Tail Tests of Significance

Tests of significance enable the analyst to decide whether a difference between two sample means can be attributed to chance, or whether it is statistically significant (i.e., too large to be "reasonably" attributed to chance). The level of significance is the probability of rejecting the null hypothesis when the null hypothesis is in fact true. In the case of comparing the means of the treatment and control groups, it is the probability one is willing to risk by drawing the conclusion that a statistical difference exists between the two means, even though in reality this difference is zero.

Depending on the type of assertion to be made about the difference between means, one may use either a one-tail or two-tail (also called one-sided or two-sided) test of significance.

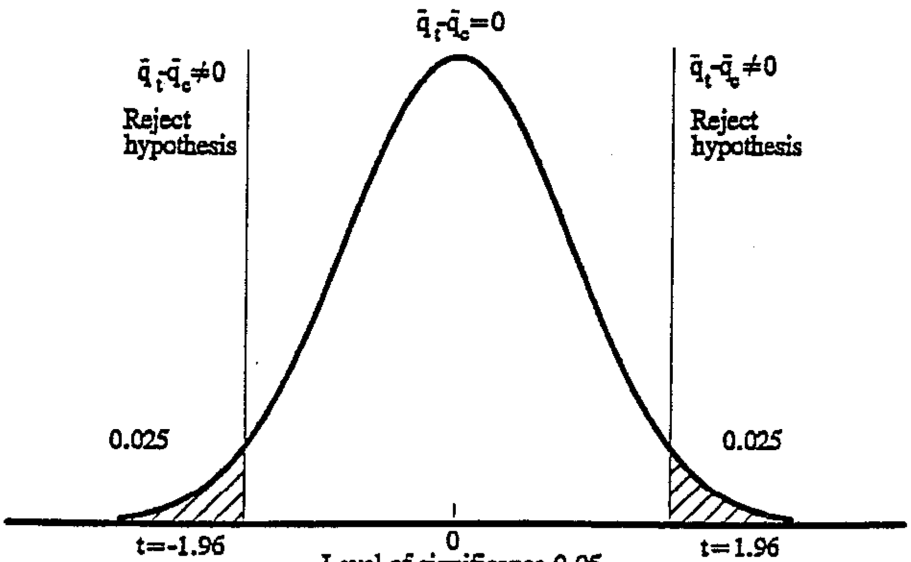
Two-Tail Test

Figure 7-1 shows the t-distribution of the difference in means with two shaded tails. As can be seen, the t-distribution is almost identical to the standard normal distribution. (In fact, the t-distribution approaches the standard normal distribution as sample sizes become larger). Each tail represents 2.5 percent of the area under the normal curve for the level of significance of 0.05, or 0.5 percent of the area for the level of significance 0.01. The two-tail test should be used to test the hypothesis that the difference between means, d, is zero, against the alternative hypothesis that the difference in means is positive or negative. Example 7-1 describes the use of the two-tail test.

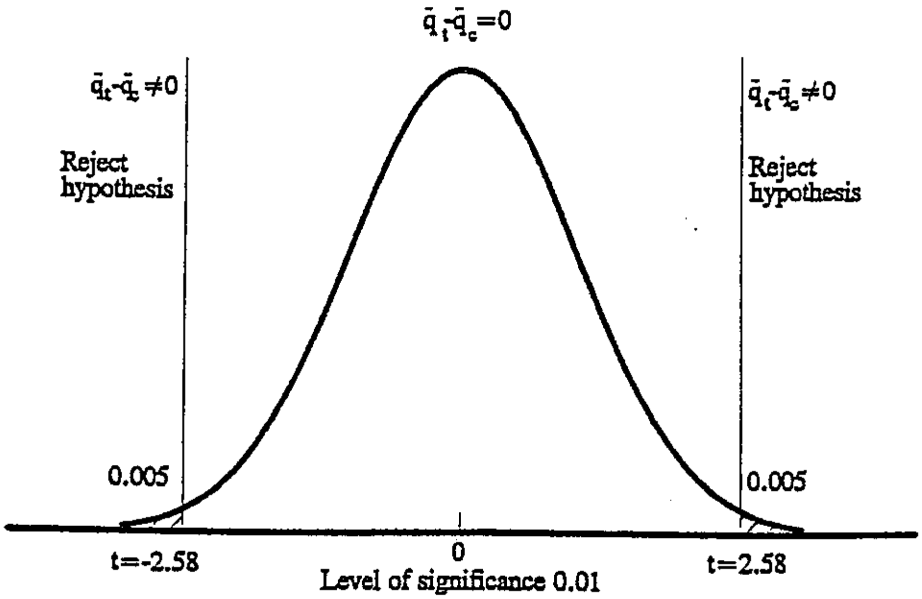
One-Tail Test

The one-sided test of significance should be used to test the null hypothesis of no difference in means against the alternative hypothesis that, after the treatment, the mean water use in the treatment group is lower than mean water use in the control group. Figure 7-2 shows that by using a one-sided test, the probability of concluding that the means are different (as indicated by the shaded tail area) has doubled when compared to the two-sided test for the same level of significance. Example 7-2 shows an application of the one-tail test.

FIGURE 7-1
TWO-SIDED TEST OF SIGNIFICANCE



Level of significance 0.05



Level of significance 0.01

EXAMPLE 7-1
EXAMPLE OF TWO-TAIL TEST

In order to use the comparison of means method to estimate water conservation savings, the analyst wants to test the hypothesis that mean water use in both the treatment and control groups was the same prior to the implementation of the conservation program. During a 12-month period prior to the program, average water use in the treatment sample consisting of 1,200 single-family residential customers was 414.6 gallons per day (gpd). During the same period, average water use in the control sample consisting of 800 single-family residential customers was 436.9 gpd. Standard deviations of water use in the treatment and control samples were 397.2 gpd and 402.4 gpd, respectively.

Prior to the program, the value of the difference between means of the treatment and control groups was

$$d = 414.6 - 436.9 = -22.3 \text{ gpd}$$

The question is whether this difference is due to chance, or whether it really means that the two samples come from populations whose mean water use differs. In order to answer this question, the standard error of the difference between the two means should be calculated using Equation (7.4) on page 183:

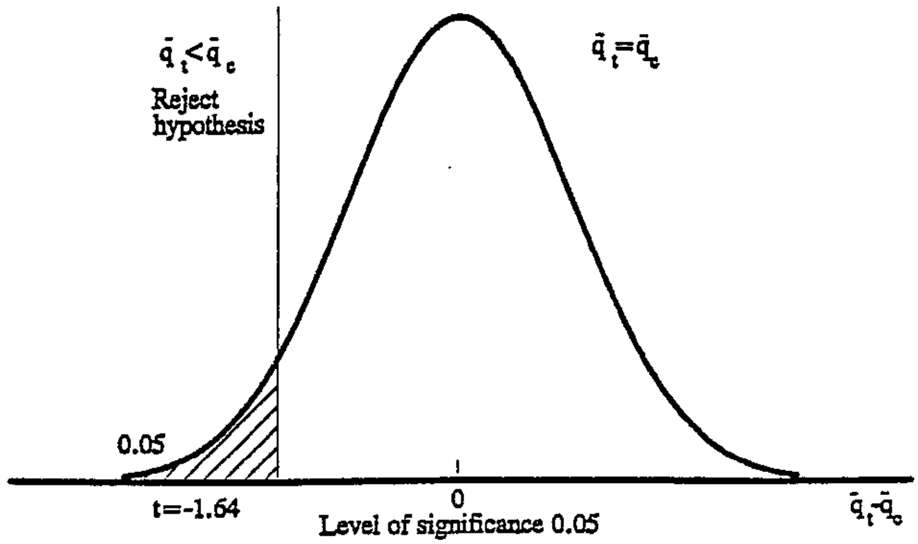
$$S_d = \sqrt{\left(\frac{1{,}199(397.2)^2 + 799(402.4)^2}{1{,}998}\right)\left(\frac{2000}{(1{,}200)(800)}\right)} = \sqrt{332.1} = 18.2$$

Now, the difference between means can be divided by its standard error in order to calculate the value of t

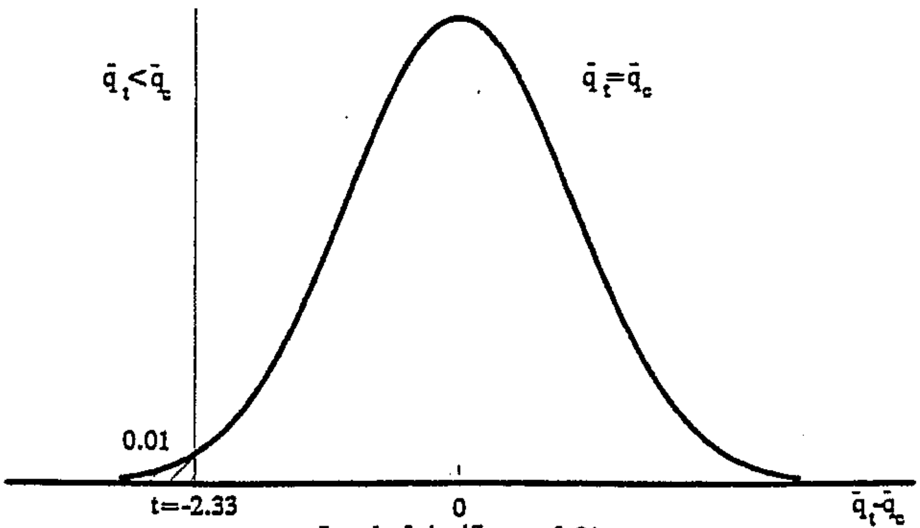
$$t = \frac{d}{S_d} = \frac{-22.3}{18.2} = -1.23$$

According to Figure 7-1, the value of $t = -1.23$ does not fall into either of the tails, thus indicating that the initial assertion is true (namely, that the mean water use in treatment and control groups was essentially the same prior to the program). In order to conclude that the means are different, the value of t would have to be greater than 1.96 or smaller than -1.96 for the 0.05 level of significance or greater than 2.58 or smaller than -2.58 for the 0.01 level of significance.

FIGURE 7-2
ONE-SIDED TEST OF SIGNIFICANCE



Level of significance 0.05



Level of significance 0.01

EXAMPLE 7-2
EXAMPLE OF ONE-TAIL TEST

During a 12-month period after implementing the conservation program in the previous example, the mean water use in the treatment sample had decreased to 409.5 gpd, and the standard deviation had decreased to 343.1 gpd. Mean water use in the control sample had increased to 438.7 gpd, and standard deviation had decreased to 372.3 gpd.

The difference between means of the treatment and control samples is

$$d = 409.5 - 438.7 = -29.2 \text{ gpd}$$

The standard error of this difference is

$$S_d = \sqrt{\left(\frac{1{,}999(343.1) + 799(372.3)^2}{1{,}998}\right)\left(\frac{2{,}000}{(1{,}200)(800)}\right)} = \sqrt{262.6} = 16.2$$

The value of t is

$$t = \frac{-29.2}{16.2} = -1.80$$

According to Figure 7-2, this value of t would fall into the shaded area if the significance level of 0.05 is used. Thus, the hypothesis that mean water use in the treatment and control groups was the same would be rejected. However, the calculated t-statistic would not fall into the shaded area if the 0.01 level of significance was used. In order to be significant at the 0.01 level, the absolute value of the observed difference between sample means would have to be greater than 37.7 gpd (i.e., standard error of 16.2 gpd multiplied by the critical value of t = -2.33).

Interpretation of Observed Differences

Table 7-2 presents the data used in the two examples, which consist of four means and four standard deviations. These results may cause some confusion when it is necessary to determine the actual effect of conservation. The difference of -29.2 gpd observed after the program would be the logical choice. However, how should one treat the fact that prior to the program, the mean water use in the treatment group was lower than the mean water use in the control group? This difference was not statistically significant at the 0.05 level of probability. However, if taken into account, it would result in the "net" program effect of only -6.9 gpd. One way of dealing with this problem is to construct a 95 percent confidence interval around the estimated difference of -29.2.

A 95 percent confidence interval can be constructed using the standard error of the estimated difference and the value of t of 1.96 (as in Figure 7-1 for the two-sided test of significance at the 0.05 level of probability). The lower and upper limits of the interval are calculated as

$$\text{Lower limit} = d - tS_t = -29.2 - 1.96(16.2) = -61.0 \text{ gpd}$$

$$\text{Upper limit} = d + tS_t = -29.2 + 1.96(16.2) = 2.6 \text{ gpd}$$

Because we construct the limits by subtracting or adding the product $t * S_t$ to the estimated difference, one can report the estimated conservation savings as:

$$d = -29.2 \pm 31.8 \text{ gpd}$$

This relatively wide confidence interval (extending from 2.6 to -61.0 gpd) easily captures the difference between means prior to the program. However, it also signifies the possible failure of the comparison of means method to produce meaningful and easily interpretable results.

Appendix C contains two more examples of how comparison of means has been used in actual evaluation studies.

Other Applicability Issues

When adhering to a strict experimental design, the comparison of means method is more likely to produce meaningful and reliable results in situations where

(1) The expected conservation effect is large when compared to mean water use.
(2) The variance in water use is small.

TABLE 7-2
COMPARISON OF DIFFERENCES BETWEEN MEANS IN THE TEXT EXAMPLES

	Treatment Group q_t	Control Group q_c	Difference $q_t - q_c$
Before the program	414.6 (397.2)	436.9 (402.4)	-22.3
After the program	409.5 (343.1)	438.7 (372.3)	-29.2*
Difference $q_{after} - q_{before}$	-5.1	+1.8	-6.9

Standard deviation is given in parentheses under each mean.

*The difference is significant at the 0.05 probability level.

(3) The mean and variance in water use are very similar (in terms of size) for both groups prior to treatment.

(4) The sample sizes in the treatment and control groups are large.

The first condition indicates that if the expected savings represent a small fraction of overall mean water use, this method may not be capable of separating the signal (i.e., decrease in water use) from the noise in the data (i.e., the normally observed variability in water use). For example, this method is usually inadequate for measuring relatively small savings of indoor plumbing retrofit programs. The comparison of means method may be more appropriate for measuring the effects of such measures as residential indoor and outdoor audit programs (which include showerhead and toilet retrofits, the repair of indoor leaks, and detailed instructions on efficient landscape maintenance). The expected savings of such a program are likely to be in excess of 10 percent, and therefore, would more likely be detected in the observed mean water use. However, this method would not be capable of measuring the effects attributable to specific devices or separating the effects into indoor and outdoor components.

The second condition is very difficult to achieve. The variance in water use is likely to be smaller when the population from which the participant and the control groups are drawn is homogeneous (e.g., single-family residential customers). An additional reduction in variance can be achieved by aggregating water use during individual billing periods into seasons (e.g., winter and summer) or into total annual water use. However, such aggregation precludes the ability to measure changes in conservation savings over time.

In order to ensure that the means and variances in treatment and control groups are of similar size (i.e., condition 3), both groups should be very similar in terms of both the socioeconomic characteristics (such as family size and composition, income, and lot size, in the case of single-family residential users) and their response to changes in external conditions such as the price of water, drought conditions, or weather. The use of a strict experimental design, with random sampling of customers and their random assignment into treatment and control groups, is often expected to produce equal means and variances (prior to the conservation program), but oftentimes it does not.

In order to increase the likelihood of obtaining similar groups, it is necessary to obtain a sufficiently large sample for each group (i.e., condition 4). The use of an experimental design combined with large sample sizes of experimental and control groups will enhance the reliability of the estimates of savings obtained by comparing means. Otherwise, in order to ascertain that the groups are similar in every respect except for program participation, it would be necessary to obtain information on many socioeconomic characteristics of each sampling unit and determine whether there are significant differences. However, once such data become available, it is possible to employ analytical techniques that are considerably more powerful than the comparison of means method with even smaller sample sizes. These techniques are discussed below.

In summary, the comparison of means method can produce reliable and informative results if used in conjunction with experimental designs and large sample sizes. Without the careful sample considerations and/or matching described earlier, the use of this method should be advised as a descriptive first step toward deriving conservation estimates. In order to determine how large the treatment and control samples should be for the use of comparison of means, use of the aforementioned formulas and development of assumptions about variance in water use and the confidence level are described in the following section.

Sample Size Considerations

In order to determine a sample size that would enhance the reliability of estimates obtained by comparing means, the following assumptions are suggested:

(1) The standard deviation of water use in each group (if not known in advance) should be assumed to equal the overall mean water use of the two groups (i.e., the coefficient of variation, measured as the ratio of the standard deviation to the mean, should be cv = 1).

(2) The desired confidence level should be set at a high level of probability because of chances that smaller sample sizes are more likely to differ on some characteristics.

(3) Sample sizes of treatment and control groups should be the same.

Using these assumptions, a sample size may be calculated that would be sufficiently large to test the hypothesis that mean water use in the treatment and control groups are equal given the expected level of the difference *d*. Sample size can be obtained from the previously used formula for *t*

$$t = \frac{d}{S_d} = \frac{(\bar{q}_t - \bar{q}_c)}{\sqrt{\left(\frac{(n_t - 1)s_t^2 + (n_c - 1)s_c^2}{n_t + n_c - 2}\right)\left(\frac{n_t + n_c}{n_t\, n_c}\right)}} \tag{7.6}$$

which, given assumption (3), implies

$$n = \frac{(s_t^2 + s_c^2)\,(t^2)}{(\bar{q}_t - \bar{q}_c)^2} \tag{7.7}$$

For an example, consider that overall mean water use for a set of households is 250 gpd. Suppose also that engineering estimates suggest an expected difference in water use between the treatment and control groups of 25 gpd. Given a t-value of -2.33 (for a 0.01 level of probability in a one-sided test of significance), the desired sample size would be

$$n = \frac{[(250)^2 + (250)^2]\,(-2.33)^2}{(25)^2} = \frac{678{,}612.5}{625} = 1{,}086$$

Thus, under the three assumptions listed above, and an expected difference in means of 25 gpd, the sample size would have to be at least 1,086 customers from each group in order to detect this potential difference. Table 7-3 shows how the calculated sample size would vary with different assumptions concerning the expected difference in means as well as with a lower significance level of 0.05 (corresponding to a t-value of 1.64 for a one-sided test of significance). Notice that larger sample sizes are required for higher levels of significance probability and smaller expected differences in means. The results imply that the smaller the expected effect of treatment, the larger the sample size must be in order to detect the potential effect.

TABLE 7-3
AN EXAMPLE OF CALCULATED SAMPLE SIZES UNDER VARYING ASSUMPTIONS OF EXPECTED DIFFERENCE IN MEANS AND SIGNIFICANCE LEVELS

Expected Difference in Mean Water Use *d* in gallons/day	Minimum Sample Size* 0.05 Level of Confidence	0.01 Level of Confidence
10	3,362	6,786
15	1,494	3,016
20	841	1,697
25	538	1,086
30	374	754
35	274	554
40	210	424

*Calculated sample size is for each group.

SIMPLE REGRESSION MODELS

Basic Relationships and Assumptions

A simple regression model can be used to measure the conservation effect in the treatment and control group setting. A basic line or relationship between two variables, called a simple two-variable linear regression, may be written as

$$y_i = \alpha + \beta X_i + \epsilon_i \tag{7.8}$$

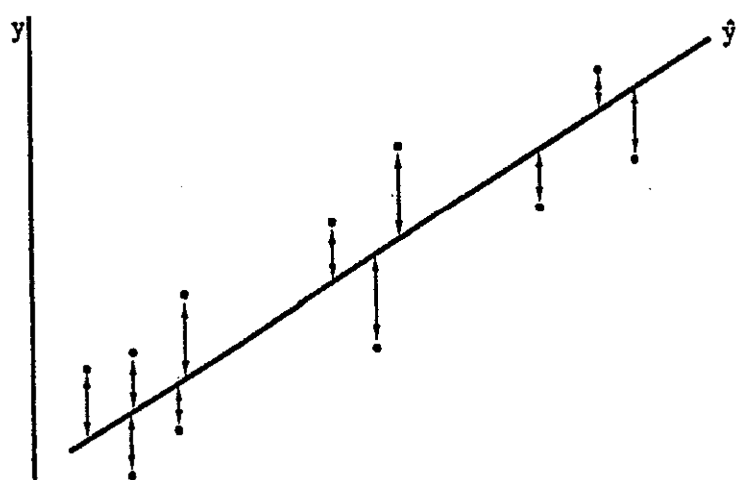
where

- y_i = water use of customer *i*
- α = intercept term of the equation and the component of the effect of *X* upon *y* that is constant regardless of the value of *X*
- β = slope coefficient of the equation and the component of the effect of *X* upon *y* that changes depending upon the value of *X*
- ϵ_i = error term for the *i*th customer, and $i = 1,2 \ldots n$, which measures the difference between the estimated value of *y* and the true observed value of *y*

This model also assumes that X, called the independent variable, influences y, called the dependent variable, while the dependent variable does not influence the independent variable in any way. Model (7.8) decomposes water use, y_i, into "explained" and "unexplained" components, where the explained component is expressed as a function of a systematic force X. The unexplained component is expressed as random noise. In other words, in Equation (7.8), $\alpha + \beta X$ is the deterministic component of y, and ϵ is the stochastic or random component.

In ordinary least-squares (OLS) regression analysis, the parameters α and β are estimated by fitting a regression line to water use data so that the sum of squared residuals ($\Sigma \epsilon_i^2$) away from the line is minimized. This concept is illustrated in Figure 7-3. The line labeled $\hat{y}$ shows the estimated relationship between y (water use) and the independent variable x. The dots represent actual observations on the dependent variable, water use, and the independent variable x. As can be seen, each observation is a certain vertical distance away from the estimated line. The length of the double-ended arrows measures the deviations between actual observation and the estimate ($y-\hat{y}$) and are called residuals. The method of least squares dictates that one choose the line where the sum of the squared deviations of the points from the line $(y-\hat{y})^2$ is a minimum, resulting in a line that "fits" the data as well as possible.

FIGURE 7-3
MINIMIZING THE SUM OF SQUARED RESIDUALS



In order for OLS to yield valid results, the method must meet the five assumptions of simple linear regression:

(1) Zero Mean. $E(\epsilon_i) = 0$ for all i, or the expected value of mean error is zero. In other words, the errors are expected to fluctuate randomly about zero and, in a sense, cancel each other out.

(2) Common Variance. Var $(\epsilon_i) = \sigma^2$ for all i, which states that each error term has the same variance for each customer.

(3) Independence. ϵ_i and ϵ_j are independent for all $i \neq j$.

(4) Independence of X_j. ϵ_i and X_j are independent for all i and j, which says that the distribution of ϵ does not depend on the value of X.

(5) Normality. ϵ_i are normally distributed for all i. This also implies that ε_i are independently and normally distributed with mean zero and a common variance σ^2.

When the five basic assumptions of the regression model are satisfied, OLS provides unbiased estimates of the regression coefficients α and β, which have minimum variance among all unbiased estimates. In other words, the least-squares estimators $\hat{\alpha}$ and $\hat{\beta}$ indeed yield the estimated straight line that has a smaller residual sum of squares than any other straight line. For this reason, OLS estimates are referred to as Best Linear Unbiased Estimates (or BLUE). Any violation of these assumptions can reduce the validity of the OLS method. The greater the departure of the model from this set of assumptions, the less reliable is OLS. In such situations, one must use alternative estimation procedures depending on the type of violation of the above assumptions. One alternative estimation technique called generalized least squares (GLS) is described later in this chapter. Appendix D and the section below provide examples of how simple linear regression might be used to estimate conservation savings.

Regression Equation of Difference of Means

A regression equation can be estimated using information on water use in the combined treatment and control groups in order to determine, for example, whether the difference of -6.9 gpd in Table 7-2 is statistically significant. The regression equation can be formulated as

$$(q_b - q_a)_i = \alpha + \beta D_i + \epsilon_i \tag{7.9}$$

where

q_b	=	water use of customer *i* <u>before</u> the conservation program (e.g., 12-month use)
q_a	=	water use of customer *i* <u>after</u> the implementation of the conservation program
α	=	the constant term representing the change in mean water use over time
β	=	the difference between mean water use in the treatment and control groups
D_i	=	a binary variable equal to 1 when customer *i* is in the treatment group and 0 if in the control group
ϵ_i	=	the error term

An example of Equation (7.9) was derived from household level water use data collected from the city of Phoenix in order to evaluate the 1985 Emergency Retrofit Program described in Dziegielewski and Opitz (1988). The estimated equation was

$$(q_a - q_b) = \underset{(3.81)}{26.3} - \underset{(-2.56)}{19.9D} \tag{7.10}$$

where the values in parentheses are t-statistics. The model statistics were

n	=	816 (635 treatment and 181 control)
R^2	=	0.007
$\bar{q}_a$	=	275.6 gpd
$\bar{q}_b$	=	279.1 gpd

The extremely low R^2 indicates that the unexplained portion of the difference between q_a and q_b is very large. Such a poor fit should be expected from simple regression models that do not explicitly account for the external factors (e.g., household income, persons per household) which are known to drive the dependent variable. Simple regression assumes that these external factors affect both the treatment and the control groups equally, although closer examination may reveal that this is not true. In order to incorporate the information contained in the error term into the deterministic component of the model, one might suggest the use of a <u>multiple</u> regression model that includes more independent (or <u>explanatory</u>) variables. The next section details the multiple regression approach and includes, as an example, a multivariate model estimated as an alternative to Equation (7.10) above.

MULTIPLE REGRESSION TECHNIQUES

There are two important reasons why multiple regression techniques should be used to model a dependent variable instead of simple regression. First, as implied in the last section, the dependent variable can be predicted more accurately if more than one independent variable is used. Second, if the dependent variable depends on more than one independent variable, a simple regression on a single independent variable may result in a biased estimate of the effect of this independent variable on the dependent variable.

The theoretical model of multiple regression is basically the same as in simple regression. The only difference is that the dependent variable is assumed to be a linear function of more than one independent variable. For example, if there are three independent variables, the model is

$$y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \qquad (7.11)$$

where

X_1, X_2, X_3	=	independent variables assumed to affect the dependent variable y
ϵ	=	random error term
$\alpha, \beta_1, \beta_2, \beta_3$	=	estimated coefficients

Just as in the case of simple regression, the coefficients α and β_i are estimated by finding the value of each that minimizes the sum of the squared deviations for the observed values of the dependent variable from the values of the dependent variable predicted by the regression equation. Furthermore, in order to obtain least-square estimates, multiple regression must follow each of the five assumptions required by simple regression, with two added conditions. The first condition is that none of the independent variables can be an exact linear combination of any of the other independent variables. In other words, no one variable can be an exact multiple (or linear combination) of any other independent variable. For example, X_1 cannot be written as aX_2. This situation is called multicollinearity. The second condition is related to degrees of freedom. Specifically, the number of observations (N) must exceed the number of coefficients being estimated. In practice, the sample size should be quite a bit larger than the number of coefficients to be estimated in order to obtain meaningful information about the underlying relationship.

The following sections and Appendix E provide examples of how multiple regression procedures have been used to estimate conservation savings.

Time Series Analysis of Monthly Sales Data

A time series of the volumes of water sold in consecutive billing periods can be used to measure conservation effects of full-scale programs. The reliability of estimates will depend on

(1) The ability to disaggregate sales data into classes of similar users (e.g., single-family residential, multiunit residential, small commercial, large industrial, etc.)
(2) The ability to separate (or account for) the seasonal effects and weather effects in the time series data
(3) The ability of the estimation technique to deal with nonconstant error variance and correlation of model errors through time (violations of assumptions 2 and 3 on p. 195, respectively)

A theoretical time series model can be written as

$$y_t = a + \sum_{i=1}^{N} b_i S_{i,t} + \sum_{j=1}^{M} c_j W_{j,t} + \sum_{k=1}^{P} d_k X_{k,t} + \sum_{r=1}^{R} e_r C_{r,t} + \epsilon_t \qquad (7.12)$$

where

y_t	=	aggregate volume of water sold to a homogeneous class of customers during a monthly or bimonthly billing period t where $t = 1 \ldots T$
a	=	model intercept
S_i	=	a set of N seasonal variables that capture the seasonal variability of water use ($i = 1 \ldots N$)
W_j	=	a set of M weather variables that capture the effect of actual weather conditions on water use ($j = 1 \ldots M$)
X_k	=	a set of P "trend forming" variables that capture changes in water use unrelated to seasonal and weather effects ($k = 1 \ldots P$)
C_r	=	a set of R conservation effects to be measured ($r = 1 \ldots R$)
ϵ_t	=	error term
b_i, c_j, d_k, e_r	=	coefficients to be estimated

The selection and definition of variables to represent the four types of systematic forces that affect aggregate water use over time are discussed below.

Seasonal Effects

The seasonal component in water use data can be captured in many ways. Three possible specifications used in modeling time series water use data include:

(1) A seasonal index
(2) A discrete step function
(3) A Fourier series of sine and cosine terms

A seasonal index is usually expressed as the average fraction of total annual water use to be expected during a given calendar month. This fraction can be estimated using the time series data on water use. For example, the value of the index in July can be obtained by dividing water use during the month of July by total annual use for each calendar year and then calculating the average value of the index for all years in the data set. The process is repeated for each calendar month until all 12 values of the seasonal index are obtained. The seasonal index is then used as a simple variable to capture the seasonal component of water use in Equation (7.12).

A discrete step function can be represented by 12 indicator variables corresponding to individual calendar months (e.g., $M_1, \ldots M_{12}$, where $M_1 = 1$, if the month in the data is January, and $M_1 = 0$ elsewhere). When bimonthly data are modeled, six indicator variables would be created, one for each bimonthly period. In order to avoid multicollinearity, only M-1 indicators should be specified, where M denotes the number of monthly or bimonthly periods.

A Fourier series of sine and cosine terms is a harmonic function that can be applied to the data to generate a smooth sinusoidal cycle of seasonal effects. In the case of monthly data, the Fourier series may include six sine and cosine harmonics that can be written as

$$\sum_{h=1}^{6} \left(a_h \sin \frac{2\pi hm}{12} + b_h \cos \frac{2\pi hm}{12} \right) \tag{7.13}$$

where

a_h, b_h = coefficients to be estimated
m = calendar month (m=1 for January, m=2 for February, etc.)

The cycle corresponding to $h = 1$ has a 12-month period. The cycles corresponding to $h = 2$ are harmonics of the 6-month period. All six harmonics represent the seasonal cycle of water use, which is periodic but not directly sinusoidal.

Because the lower harmonics tend to explain most of the seasonal fluctuations, in most situations, it may be possible to omit higher frequency harmonics in Equation (7.13), thus, representing the seasonal component as

$$\sum_{i=1}^{4} b_i S_{i,t} = b_1 \mathrm{SIN}(1) + b_2 \mathrm{COS}(1) + b_3 \mathrm{SIN}(2) + b_4 \mathrm{COS}(2) \tag{7.14}$$

where

b_1, b_2, b_3, b_4 = coefficients to be estimated
SIN(1) = $\sin (2\pi m/12)$
COS(1) = $\cos (2\pi m/12)$
SIN(2) = $\sin (4\pi m/12)$
COS(2) = $\cos (4\pi m/12)$

The significance of each cycle is usually tested first. The cycles with insignificant amplitudes (i.e., b_i) can then be deleted from the equation.

Weather Effects

Air temperature and rainfall are usually used to capture the effects of weather on water use. In most cases, these two variables will be correlated with the seasonal variables. Therefore, the weather variables should be measured as deviations from their normal values for each month (or billing period). Also, lagged weather variables can be used to take into account (1) the fact that the recorded consumption in any given month represents water use which took place during the current and the previous month and (2) the short-term memory in water use (e.g., water use in month t is affected by rainfall in month $t - 1$).

The following weather variables can be included in the specification of the weather effects in Equation (7.12):

(1) Deviation of monthly rainfall from monthly norms
(2) Deviation of monthly average of maximum daily temperatures from monthly norms
(3) Deviation of the number of days with precipitation greater than 0.01 inches from monthly norms
(4) Deviation of cooling-degree days from monthly norms

These deviations can be specified both as contemporaneous and lagged measurements. The "normal" values can be calculated for the period of the time series data or for weather data extending up to 30 years back (i.e., long-term averages).

Prices and Customer Characteristics

In addition to properly measuring the seasonal and weather effects, it is necessary to include the effects of variables such as the number of customers, the price of water, the cost of wastewater disposal, and other factors such as income in residential sectors and productivity in nonresidential sectors.

The changes in the number of customers can be incorporated by expressing the dependent variable in terms of water use per customer (by dividing total volume of water by the number of customers billed).

The price of water and wastewater disposal should be included in the model. In modeling aggregate water use data, it is difficult to determine what measure of price should be used. The relevant measure is the marginal price faced by an individual customer. This price is the same for all customers when a uniform rate structure is used. If increasing block rates are used, then average price determined for an average consumption level can be used, so that only actual increases in the price of water and wastewater are captured by the price variable. All nominal values of price should be converted into constant dollars using the Consumer Price Index (CPI) for all items.

Median household income should also be included among the variables if the data are available and expressed in constant dollars. Usually, household income statistics can be obtained for each quarter from the Internal Revenue Service. Monthly values of income can be obtained by interpolating the quarterly data.

Several other variables that are known to influence water use can be omitted if the changes over time are minimal (e.g., average number of persons per customer connection, average lot size). If changes in such variables are significant, then these variables should be included in the model.

Conservation Effects

The effects of the conservation program under investigation can be measured in the time series model by including an indicator variable which separates the data into pre- and post-program periods. This variable takes on the value of 0 for all months before the program, and the value of 1 for the months after program implementation.

It is also important to capture the effects of other passive and active conservation measures which are adopted independently of the program under evaluation. For example, the effects of a conservation-oriented plumbing code should be included in the model. This can be accomplished by introducing a variable that measures the cumulative number of new service connections sold after the code went into effect.

Specification of the Error Term

The error term can be specified as additive or multiplicative. A logarithmic transformation of the water use variable will result in a multiplicative error term. Such a transformation will often produce a better fit of the model than untransformed water use.

The potential problems with estimating the parameters of the time series regression model are endogeneity of the price variable, nonconstant error variance (a.k.a., heteroskedasticity) and autocorrelation. Most regression software packages have routines that attempt to correct for the problem of autocorrelation. Nonconstant error variance and endogeneity are problems best suited for alternative regression methods such as Generalized Least Squares (as discussed in a later section).

Example of Time Series Aggregate Sales Data Model

An illustrative example of a time series model estimated from actual aggregate sales data is shown in Table 7-4. The model was estimated using time series data on water use per single-family account in Phoenix, Arizona (Dziegielewski and Paredes, 1991). Monthly sales data covered a 60-month period from July 1987 to June 1991. In February 1989, the city began a retrofit program that by June 1991 had covered approximately 38,000 single-family residences (or 15 percent of all single-family residences).

The linear regression model in Table 7-4 includes data on seasonality, weather, price, and conservation among the explanatory variables. The individual variables are:

QSF	=	monthly water use in CCF/account
SIN1, SIN2, SIN3, COS1, COS2, COS3	=	sine and cosine harmonics of a Fourier series capturing the seasonal effects in water use data
MAXT2_M	=	departures from normal of 2-month moving average of maximum daily temperatures during transitional months (April-May, October-November), degrees F
MAXT2D_H	=	departure from normal of 2-month moving average of maximum daily temperature during the high-use season (June-September), degrees F
PREC2D	=	departures from normal of 2-month moving average precipitation, inches
WSCHARGE	=	fixed charge for water and sewer service, constant 1990 dollars
MPRICE	=	marginal price, constant 1990 dollars
RETROFIT	=	total number of retrofitted homes in each month

TABLE 7-4
TIME SERIES AGGREGATE SALES DATA MODEL

Dependent Variable: Log Q_{SF}, log of monthly water use (log CCF/ACCT)

Independent Variable	Coefficient	t-Value	Sig. Level (One-Tail)	Std. Error
Constant	28.246	5.439	0.000	5.194
SIN1	-4.912	-11.282	0.000	0.435
COS1	-6.737	-11.515	0.000	0.585
SIN2	0.872	4.417	0.000	0.197
COS2	1.469	6.867	0.000	0.214
SIN3	-0.460	-2.265	0.014	0.203
COS3	-0.416	-1.943	0.029	0.214
MAXT2_M	0.465	4.313	0.000	0.108
MAXT2D_H	0.647	2.912	0.003	0.222
PREC2D	-0.978	-2.343	0.012	0.417
WSCHARGE	-0.422	-1.273	0.105	0.332
MPRICE	-3.509	-1.360	0.090	2.580
RETROFIT	-0.000014	-0.946	0.201	0.000016

R^2 = 0.964. MAE = 0.724.
SE = 1.068. Durbin-Watson = 2.17.

The results indicate that each retrofitted residence decreased the average water use per account by 0.000014 CCF/month. During the last month of the data series (June 1991), the reduction in average water use per account attributable to the retrofit would be

0.000014 CCF/month * 37,896 retrofitted accounts = 0.53 CCF/account/month

This implies that the total reduction in water use by all single-family residences in Phoenix would be (0.53 * 246,448) 130,752 CCF per month. Dividing this monthly volume by the total number of retrofitted accounts, the average reduction in water use in retrofitted residences would be (130,752/37,896) 3.45 CCF per month. Converting into gallons per day, this implies that, on average, the retrofitted homes reduced their monthly water use by 85 gallons per day. This amount is more than twice the mechanical estimate of the retrofit savings of 20 to 30 gallons per day, perhaps indicating a possible effect of the retrofit program on other indoor and outdoor uses of water in participating households and the influence of a period of drought accompanying the retrofit program. Notice, however, that the significance level of the retrofit coefficient is far below what is customarily accepted to be significant (i.e., the coefficient is not significant at the 0.05 level) and such straightforward interpretation may not, in truth, be realized. This is a good example of how it is oftentimes difficult to provide reliable estimates of conservation savings using only monthly time series aggregate sales data.

Time Series Analysis of Daily Production Data

The impact of some conservation programs on water use can be analyzed using daily production records. A daily water use model can be developed for the service area, and then a prediction of a time series of daily water use for a period of one to two years after the program implementation can be developed. The analytical procedure used here can be called the intervention analysis of daily water use.

In order to measure the response to a conservation program, it is necessary to isolate the confounding effects of weather on daily and monthly water use. Maidment et al. (1985) have developed a very sensitive model that explains the daily variability in water use in terms of maximum daily temperature, rainfall events, and the delayed response of water users to weather. This model, referred to as "WATFORE" (water use forecasting), can be used to reconstruct a time series of daily water use after the implementation of the conservation program.

Shaw and Maidment (1987, 1988) used the WATFORE model to measure the impacts of water use restrictions in two Texas cities: Austin and Corpus Christi. Their analysis was based on a formulation of a time series with a single intervention variable (similar to a dummy indicator variable) as proposed by Hipel et al. (1975)

$$y(t) = y^*(t) + N(t) \tag{7.15}$$

where

$y^*(t)$ = the dynamic response of the process $y(t)$ to an intervention event
$N(t)$ = a stochastic background noise

The intervention model used by Shaw and Maidment (1987) was

$$W_s(t) = \bar{W}_s + \frac{\omega_{01}}{1-\delta_{11}B} T(t) + \frac{\omega_{02} - \omega_{12}B}{1 + \delta_{12} B} R(t) + \sum_{i=1}^{v} y^*(t) + \frac{1}{1-\phi_1-\phi_2B^2-\phi_7B^7} a(t) \tag{7.16}$$

where

$\underline{W}_S(t)$	=	short-term memory water use
W_s	=	mean level component of short memory series
T	=	daily maximum air temperature
R	=	previous day's seasonal water use level for rainfall days
a	=	random shock input
ω, δ	=	transfer function coefficients
Φ	=	autoregressive coefficients of the noise model
B	=	backshift operator

and

$$y^*(t) = \frac{\omega(B)}{\delta(B)} B^b I(t)^T \qquad (7.17)$$

where

y^*	=	intervention response term (ν in Equation (7.16) indicates the number of interventions affecting the series)
I(t)	=	a pulse function input representing the event, I(t) = 0 when the event is not occurring

This model and the procedure used by Shaw and Maidment (1987, 1988) can be followed in order to estimate the reduction in average-day and maximum-day water use resulting from the intervention in the form of a drought emergency program or programs aimed at reducing maximum-day water use. For more information about intervention analysis and the use of transfer functions to model daily water use, see also Box and Tiao (1975) and Maidment et al. (1985).

Multiple Regression of Pooled Customer-Level Data

If customer-level monthly (or billing period) data on water use for a period of two to four years can be supplemented with information on customer characteristics, and external factors such as price of water and weather, then a pooled Time Series Cross-Sectional (TSCS) data set can be constructed and used to estimate the parameters of a multiple regression model. The theoretical form of the model may be written as

$$y_{it} = \beta_1 + \sum_{k=2}^{k} \beta_k X_{k,it} + e_{it} \tag{7.18}$$

where

y_{it}	=	monthly water use of customer *i* in month *t* (instead of months, billing periods may be used)
β_1	=	the intercept term
β_k	=	regression coefficients
X_k	=	a set of independent variables that represent all possible systematic forces which affect that use
ϵ_{it}	=	the error term

Explanatory Variables

In order to explain the types of variables that may be used in Equation (7.18), Table 7-5 lists 28 household characteristics and other variables that are important explanatory variables in residential water use models. Measurements on these variables (or as many variables as possible) should be obtained for each customer and each time period using such sources of information as:

(1) Telephone or mail surveys of customers in the sample
(2) Real estate and tax assessor records
(3) Aerial photographs
(4) "Driveby" surveys of residences
(5) Water and wastewater prices and rate structures
(6) Meteorological stations

Many variables will have values that are constant over time or will have only one observation in time that is available. In the latter case, their values can be assumed constant over the period for which water use data is obtained.

In order to estimate conservation effects, the analyst can construct a set of independent variables that describe (1) program participation (i.e., a dummy variable D_p where $D_p = 1$ if yes, $D_p = 0$ if no), (2) installation of one or more conservation devices, or (3) the actual number of conservation devices of each type that were installed.

TABLE 7-5
IMPORTANT EXPLANATORY VARIABLES FOR RESIDENTIAL WATER USE MODELS

Category/Variable			Category/Variable		
(A)	Family characteristics		(E)	Frequency of outdoor uses	
	(1)	Family size (number of persons)		(1)	Lawn and landscape watering per week
	(2)	Number of children under 18		(2)	Car washing per week
	(3)	Household income		(3)	Hosing of concrete (blacktop) surfaces
	(4)	Ownership of residence	(F)	Price	
(B)	Household fixtures and appliances			(1)	Marginal price of water
	(1)	Number of showers		(2)	Rate structure
	(2)	Number of toilets		(3)	Wastewater charge
	(3)	Washing machine (presence of)	(G)	Weather variables	
	(4)	Dishwasher (presence of)		(1)	Monthly average of maximum daily temperatures
	(5)	Garbage disposal		(2)	Total monthly precipitation
(C)	Frequency of appliance use			(3)	Number of days with precipitation greater than 0.01 inches
	(1)	Laundry loads per week		(4)	Cooling degree days
	(2)	Dishwasher loads per week	(H)	Other characteristics	
(D)	Outdoor features			(1)	Age of the house
	(1)	Lot size		(2)	Type of sewerage system
	(2)	Lawn size			
	(3)	Total irrigated area			
	(4)	Automatic sprinkling system			
	(5)	Swimming pool			

Functional Form of the Model

Once the TSCS database is complete, an appropriate form of the functional relationship between water use and its determinants must be selected. Also, in the context of the structure of systematic forces, we should consider the appropriate structure of the model error.

Residential water demand models are often estimated using one of the following functional forms:

(1) Linear model

$$y_{it} = \beta_1 + \sum_{k=2}^{k} \beta_k X_{k,it} + e_{it} \tag{7.19}$$

in which the error is additive

(2) Log-linear (or double-log) model

$$\log\left(y_{it}\right) = \log(\beta_1) + \sum_{k=2}^{k} \beta_k \left(\log X_{k,it}\right) + \log\left(e_{it}\right) \tag{7.20}$$

with multiplicative error

(3) Exponential model

$$\log\left(y_{it}\right) = \beta_1 + \sum_{k=2}^{k} \beta_k X_{k,it} + e_{it} \tag{7.21}$$

with multiplicative (and/or exponential) error

The following section provides an example of a TSCS multivariate regression model used in a Phoenix, Arizona, evaluation study.

Multivariate Linear OLS Model

Most frequently, pooled time series cross-sectional analyses use the linear functional form of the model and estimate parameters using the Ordinary Least Squares (OLS) estimation technique.

Table 7-6 gives an example of such a model. The model was used to estimate water conservation savings attributable to the indoor plumbing retrofit program conducted by the city of Phoenix Department of Water and Wastewater in the summer of 1985. Considering the "pooled" nature of the data set, the R^2 coefficient of 0.292 indicates a reasonably good fit of the model. The estimated regression coefficient for the binary installation variable is -14.90, indicating that households that installed retrofit devices during the campaign use, on average, 14.90 gallons per day less water than households without such devices. The 95 percent confidence interval for this regression coefficient with a standard error of 3.91 gpd is

TABLE 7-6
EXAMPLE OF MULTIPLE REGRESSION OLS MODEL: PHOENIX RETROFIT PROGRAM

Variable Name	Mean Value	Regression Model Coefficient B	Regression Model Error of B
Cooling degree days	387.864	0.450430	0.005549
Home area (square feet)	2,650.356	0.047069	0.003056
Yard type*	2.230	66.436672	2.852955
Swimming pool*	0.424	66.543475	4.133670
Persons per household (number)	3.231	25.491133	1.677783
Home value ($1,000)	63.967	1.363130	0.079635
Green area (square feet)	3,980.032	0.004799	4.0651E-04
Frequency of yard watering (per week)	1.947	9.094600	1.234908
Washing machine*	0.980	83.380171	14.388552
Frequency of dishwasher use	1.516	8.274248	1.422690
Toilets per residence	2.023	34.144858	5.392878
Yard watering*	0.879	39.706526	6.921498
Ownership of residence*	0.921	39.723777	7.033249
Sewerage system*	0.952	-40.258573	9.102407
Date of structure*	0.825	23.038494	5.195400
Binary installation*	0.435	**-14.897659**	**3.912404**
Frequency of washing machine use*	3.065	2.045341	1.393758
Constant	---	-402.564016	19.478269

Sample size = 28,285 pooled observations.
R^2 = 0.292 F = 684.911(0.000).
Gallons per day = 496.637.

*Yard type (0 = no yard; 1 = desert; 2 = desert/green; 3 = green).
Swimming pool (0 = no; 1 = yes).
Washing machine (0 = no; 1 = yes).
Frequency of washing machine use (0 = zero/don't know; 1 = 1-2 loads; 2 = 3-4 loads; 3 = 5-6 loads; 4 = 7-8 loads; 5 = 9-10 loads; 6 = 11-15 loads; 7 = 16-20 loads; 8 = 21-25 loads; 9 = 26 or more loads.
Yard watering (0 = no; 1 = yes).
Ownership of residence (0 = rent; 1 = own).
Sewerage system (0 = septic; 1 = sewer).
Date of structure (0 = built since 1980; 1 = built prior to 1980).
Binary installation (0 = no; 1 = yes).
Frequency of dishwasher use (0 = zero/don't know; 1 = 1-2 loads; 2 = 3-4 loads; 3 = 5-6 loads; 4 = 7-8 loads; 5 = 9-10 loads; 6 = 11-5 loads; 7 = 16-20 loads; 8 = 21-25 loads; 9 = 26 or more loads).

$$-14.90 + 1.96\,(3.91) < \beta < -14.90 - 1.96\,(3.91)$$

$$-7.24 < \beta < -22.56$$

The Phoenix model provided satisfactory estimates of conservation savings that were confirmed by several independent analyses.

Effects of Pooled Data on OLS Estimators

The nature of pooled time series cross-sectional data often results in the violation of one or more of the basic regression assumptions listed on page 195. Two common problems that have been encountered in practical research are:

(1) Heteroskedasticity. The variance of the error term ε is not constant across all observations. When this occurs, the scale of the dependent variable and the explanatory power of the OLS model tend to vary across observations. Heteroskedasticity usually arises from cross-sectional data.

(2) Autocorrelation. The disturbances ε_i are not independent of each other, they are correlated. Autocorrelation is usually found in time series data. Time series data often display a "memory" such that variation is not independent from one period to the next. For example, an earthquake or flood may affect water use in a particular community for many periods following the actual event. Note, however, that it does not always take such a large disturbance to produce autocorrelated errors.

If either one of these problems exists, the coefficient estimates of the OLS model no longer have minimum variance among all linear unbiased estimators. In other words, the OLS estimators are no longer BLUE.

Several diagnostic tests for heteroskedasticity and autocorrelation are commonly available in statistical software packages. Perhaps the simplest diagnostic check is to plot the residuals. Figure 7-4 shows an example of plotting the residuals (y_i - $\hat{y}_i$) against the estimated value of the dependent variable to detect heteroskedasticity. Figure 7-5 shows an example of detecting autocorrelation by plotting successive residuals, where ε_{t-1} is the residual of the last observation in time.

FIGURE 7-4
PLOTTING RESIDUALS AGAINST ŷ TO DETECT HETEROSKEDASTICITY

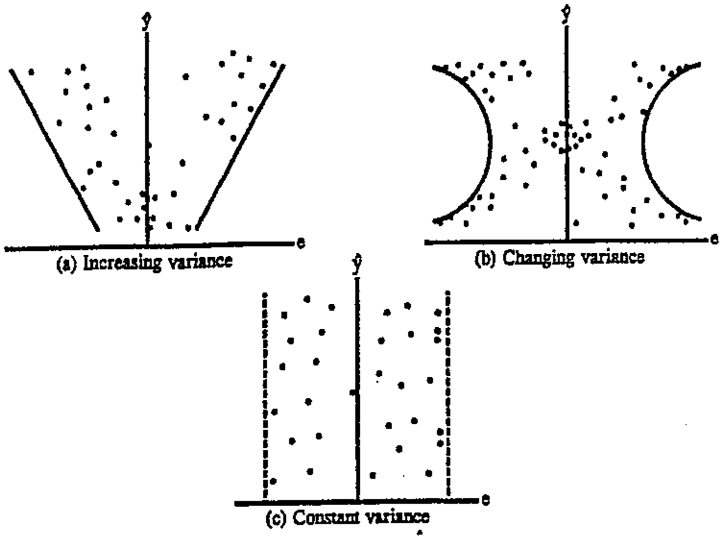
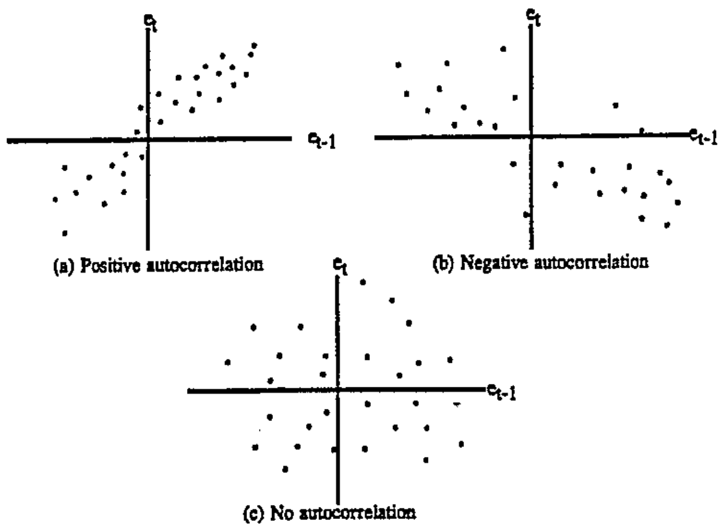


FIGURE 7-5
PLOTS OF SUCCESSIVE RESIDUALS



If heteroskedasticity and/or autocorrelation are suspected, it is advisable to specify an alternative to the OLS model. One such model, called the Generalized Least-Square (GLS) regression model can be shown to provide the best linear unbiased estimators under these conditions. Instead of minimizing the sum of squared residuals as in OLS estimation, the GLS procedure produces a more efficient estimator by minimizing a weighted sum of the squared residuals. Observations whose residuals are expected to be large because the variances of their associated disturbances are known to be large are given a smaller weight. Observations whose residuals are expected to be large because other residuals are large are also given smaller weights (Kennedy, 1985). In order to produce coefficient estimates using GLS, the variance-covariance matrix of the disturbance terms must be known (at least to a factor of proportionality). In actual estimating situations, however, this matrix is usually not known. A procedure called EGLS (estimated GLS) can then be employed to estimate the variance-covariance matrix of the disturbances. EGLS estimators are no longer linear or unbiased, but because they account for the effects of heteroskedastic and autocorrelated errors, they are thought to produce better coefficient estimates.

Error Components Model

The EGLS estimation technique is used to estimate what are called *error components* models of pooled time series and cross-sectional data (see Kennedy, 1985). The general specification for the random effects model can be written as

$$y_{it} = \beta_0 + \sum_{i=1}^{K} \beta_k X_{k,it} + \epsilon^* \qquad (7.22)$$

where

$$\epsilon^* = u_i + v_t + \epsilon_{it}$$

Notice that this model has an overall intercept and an error term that consists of three components. The u_i represent the extent to which the *i*th cross-sectional units intercept differs from the overall intercept. The v_t represent the extent to which the *t*th time period's intercept differs from the overall intercept. The u_i and v_t are each assumed to be independently and identically distributed with a mean of zero and variance of σ_u^2 and σ_v^2, respectively. The third component ϵ_{it}, represents the traditional error term that is unique to each observation. All three error components are assumed to be mutually independent. The extent to which the intercept coefficients differ across cross-sectional units and across time is assumed to be randomly distributed. Because of this, the error components model is sometimes referred to as the random effects model.

A good example of an error components model estimation can be found in Chesnutt and McSpadden (1990) in the evaluation of the Westchester Water Conservation Pilot Program. The model was applied to mean household water use during 23 bimonthly billing periods, which extended from the June-July period of 1986 to the December-January period of 1989. Water use data were obtained for 418 single-family customers in the participant group and 127 in the control group. Chesnutt and McSpadden used the EGLS procedure to estimate the error components model. For comparison, an OLS model was also estimated using the same data. Table 7-7 shows the results of the two alternative models. The following is a list of explanations for the example:

(1) A natural log transformation of the dependent variable was used because it yielded the best fit and maximized the likelihood of observing the realized data.

(2) The seasonal component of systematic effects was specified as a Fourier series of sine and cosine terms of various harmonics in the following linear combination.

$$\mu + \sum_{j=1}^{2} \left(\beta_{1,}j \sin \frac{2\pi jT}{6} + \beta_{2,}j \cos \frac{2\pi jT}{6} \right) \quad (7.23)$$

where

μ,β_i = coefficients to be estimated
j ≡ the harmonic index, where $j = 1$ defines a first (annual) harmonic
T ≡ the time index, where $T = 1,2. . .t$ and $t =$ the total number of time observations

This Fourier specification served as a constant seasonal filter that captured the constant seasonal fluctuations in the water use data.

(3) The climatic component used four variables that used the average of maximum daily temperatures and the total amount of rainfall in each 2-month billing period. The seasonality in the weather variables was captured by the interaction of the departure from normal temperature and the first cosine harmonic (DLT_COS1).

(4) Thirteen independent variables were used to capture the cross-sectional characteristics of individual households.

TABLE 7-7
EXAMPLE OF ALTERNATIVE REGRESSION MODELS

$$\text{Ln } Q_{it} = \beta_o + \sum_{k=2}^{n} \beta_k X_{k,it} + e_{it}$$

Variable	OLS Model β_k	OLS Model Std. Error	EGLS Model β_k	EGLS Model Std. Error	Variable Definitions
CONSTANT	5.1248	0.0317	5.1189	0.1197	Constant term
SIN1	-0.3435	0.0148	-0.3461	0.0098	First sine harmonic, annual frequency
COS1	-0.2264	0.0086	-0.2284	0.0056	First cosine harmonic, annual frequency
SIN2	0.0524	0.0142	0.0532	0.0093	Second sine harmonic, semiannual frequency
DLR	-0.0765	0.0196	-0.0804	0.0124	Deviation of Ln(1+Rain) from its bimonthly mean
DLR_1	-0.1122	0.0226	-0.1094	0.0143	Two-month lag of rain measure
DLT	2.4682	0.3715	2.4000	0.2362	Deviation of Ln(Temp) from its bimonthly mean
DLT_COS1	-2.3721	0.4084	-2.3709	0.2582	Interaction of DLT and COS1
LNPARCEL	0.6225	0.0372	0.6233	0.1444	Ln(parcel size) - mean(Ln(parcel size))
LNHOME	0.3971	0.0216	0.3815	0.0824	Ln(home size) - mean(Ln(home size))
PRE1980	0.2236	0.0289	0.2252	0.1120	Indicator for pre-1980 construction
NEWMETER	0.0351	0.0158	0.0205	0.0127	Indicator for installation of new water meter
POOL	0.1016	0.0194	0.1027	0.0758	Indicator for pool
RENT	0.0901	0.0219	0.0957	0.0852	Indicator for rental of residence
WASH_2MO	0.0029	0.0002	0.0029	0.0008	No. of laundry loads washed in a 2-month period
CARS_2MO	0.0036	0.0008	0.0037	0.0032	No. of cars washed in a 2-month period
DESERT	-0.0685	0.0157	-0.0707	0.0614	Indicator for desert landscaping
GREEN	0.0458	0.0050	0.0465	0.0186	Indicator of how green the lawn is kept on a five-point scale (-2 = very brown, 2 = very green)

TABLE 7-7 (Continued)
EXAMPLE OF ALTERNATIVE REGRESSION MODELS

$$\text{Ln } Q_{it} = \beta_o + \sum_{k=2}^{n} \beta_k X_{k,it} + e_{it}$$

Variable	OLS Model		EGLS Model		Variable Definitions
	β_k	Std. Error	β_k	Std. Error	
WATER2MO	0.0151	0.0061	0.0118	0.0057	Ln(no. of lawn waterings in a 2-month period+1)
LNPEOPLE	0.2780	0.0135	0.2743	0.0525	Ln(number of people residing in the household)
LNKIDS	-0.1320	0.0229	-0.1274	0.0892	Ln(number of children residing in the household)
RETRO	-0.0790	0.0200	-0.0620	0.0138	Indicator for reception of retrofit kit (0 before 3/88 and 1 after, for experimental group)
CRETRO	0.0200	0.0208	-0.0396	0.0155	Indicator for control group conservation effect (0 before 3/88 and 1 after, for control group)
RETWATER	-0.0037	0.0096	-0.0091	0.0062	Interaction of RETRO and WATER2MO
SH_NO	-0.0468	0.0066	-0.0196	0.0087	Number of low-flow showerheads installed in this billing period (0 = none, 1 = one, 2 = two or more)
σ_ϵ	0.472		0.302		
$\sigma_{\beta o}$	—		0.460		
R^2	0.383		0.746		

Source: Chesnutt and McSpadden (1990).

(5) Conservation effects were captured in the model by four variables: (a) a binary indicator for reception of retrofit kit, (b) a binary indicator for conservation in control group, (c) an interaction effect of receiving the retrofit and frequency of lawn watering, and (d) the number of low flow showers installed.

The natural logarithmic transformation of water use gives a relative (percent) interpretation to the conservation indicator variables. In order to translate the coefficients into expected percent of decreases in water use, a small-scale correction must be made. Assuming lognormality, an unbiased estimate of the percent change can be derived as

$$1 - e^{\beta - .5\sigma_\beta^2} * 100 \tag{7.24}$$

Using the coefficient and standard error of the indicator variable RETRO, the expected percent decrease in average water use attributable to receiving a retrofit can be found to equal

$$1 - e^{[-0.062 - .5(0.0138)^2]} \approx 0.060 \approx 6 \text{ percent}$$

By comparing the R^2 for each of the models in Table 7-7, it can be seen that the error components EGLS model clearly outperformed the OLS model that ignored the effects of household heterogeneity. Meanwhile, the OLS estimated standard errors are for some variables widely divergent from the EGLS estimation. The generally smaller standard errors of the OLS model imply that one might be led to be more certain of the estimated OLS parameter than what is truly justified. Chesnutt and McSpadden (1990, p. 34) conclude that "careful attention to model specification and estimation can avoid bias, improve precision, and yield a much richer characterization of the conservation effects of a water conservation program."

ECONOMETRIC END-USE MODELING

Econometric end-use models have recently been introduced in two analyses of household demand for electricity (McCollister and Hesterberg, 1986; EPRI, 1984). In the electric industry, end-use models are referred to as microeconometric conditional demand models. The general specification of such models was originally formulated by Parti and Parti (1980). Conditional demand analysis permits the disaggregation of total household demand for electricity into the component demand functions for electricity of particular appliances, even though no direct observations on the energy use of specific appliances exist.

The component demand functions can be used to estimate monthly and annual energy use of each appliance, as well as the corresponding price and income elasticities. By using a treatment/control evaluation design, the end-use model also allows the analyst to single out changes in energy consumption stemming from external factors such as the introduction of a new conservation technology or conservation program.

In its application to end-use modeling of water consumption, a straightforward but expensive method for disaggregating total household water use would be to observe a sample of households in which water meters were attached to specific water appliances and fixtures. The volume of water used by these appliances during a month or year could be regressed upon various explanatory variables, including household characteristics and weather.

The conditional demand methodology allows the analyst to obtain such end-use demand functions even though no observations on water use of the appliances are available. The conditional analysis rests on the fact that the total water use in a household is the sum of water used through all fixtures, appliances, and facilities such that

$$Q = Q_0 + \sum_{i=1}^{n} Q_i \tag{7.25}$$

where Q_i ($i = 1 \ldots n$) is water use through a set of <u>specified</u> fixtures and appliances and Q_o is water used through a set of <u>unspecified</u> fixtures and appliances.

For each Q_i, we can write

$$Q_i = f_i\ (X_j) \tag{7.26}$$

where Q_i is the conditional household demand for water use through the ith appliance, and X is the vector of j explanatory variables of this function.

Equation (7.26) can be rewritten by adding a dummy variable A_i, which takes on a value of one (1) for those households possessing the ith appliance and zero (0) otherwise. Equation (7.26) then becomes:

$$Q_i = f_i\ (X_j) * A_i \tag{7.27}$$

Water use in the unspecified appliances can also be assumed to be a function of the explanatory variables such that

$$Q_0 = f_0\ (X_j) \tag{7.28}$$

If Equations (7.27) and (7.28) are linear, Equation (7.25) can be rewritten

$$Q = \sum_{i=0}^{n} \sum_{j=0}^{m} b_{ij} (X_j A_i) \tag{7.29}$$

where each b_{ij} ($i = 0 \ldots n$; $j = 0 \ldots m$) is the coefficient of the jth exogenous variable in the ith conditional demand function, the X_j ($j = 0 \ldots m$) are the exogenous variables in the conditional demand functions, and X_o and A_o are unity. This framework allows for the possibility that the conditional demand functions are in a semilog or other nonlinear form. Equation (7.29) can be estimated by using linear regression techniques. The estimated coefficients for this equation would be estimates of the parameters of the conditional water demand functions and of the demand for water through the unspecified group of appliances.

Although this method permits estimation of the parameters of the conditional demand functions, it requires a large number of explanatory variables, many with common components. For example, a strict interpretation of Equation (7.29) would require the estimation of $n + 1$ price coefficients. This suggests that there may be a high degree of correlation among the regressors, and that the identification of all the appliance-specific parameters might be impossible unless certain parameter restrictions are imposed. Usually a number of restrictions are imposed to alleviate this problem.

At the time of writing this manual, no statistical end-use models could be found in the water industry evaluation studies. The following example of model specification is offered to illustrate the theoretical description of these models.

Example of an End-Use Water Use Model

Total water use in a household during a time period t is the sum of water use from all indoor and outdoor water outlets including:

(1) Toilets
(2) Showers
(3) Washing machine
(4) Dishwasher
(5) Bathroom sinks
(6) Kitchen sink/garbage disposal
(7) Ice-maker (automatic)
(8) Evaporative cooler
(9) Outdoor faucet/hose
(10) Sprinkling system
(11) Swimming pool
(12) Spa
(13) Fountains

By using data on the presence of these fixtures and appliances in a sample of homes, differences in total water use should be observed depending on the subset of appliances present and other household characteristics. However, not all appliances have to be modeled separately. Nearly all single-family homes have toilets and showers, and almost all homes possess a washing machine, dishwasher, kitchen sink, and bathroom sink. Therefore, no comparison could be made between homes with and without these fixtures and appliances. The common appliances can be modeled as all indoor fixtures and appliances (or IFA), which represent indoor use. Major differences in total household water use should result from the presence or absence of outdoor features.

For illustrative purposes, assume that a household's total water use, W_t, during time period t is the sum of water used for indoor fixtures and appliances (IFA_t), sprinkling systems (SS_t), garden hose irrigation (GH_t), and a swimming pool (SP_t). This can be written as

$$\mathbf{W_t = IFA_t + SS_t + GH_t + SP_t} \tag{7.30}$$

Water used by indoor fixtures and appliances (or indoor water use) can be expressed by the following relationship

$$\mathbf{IFA_t = b_0 + b_1H_t + b_2I_t + b_3P_t + b_4T_t} \tag{7.31}$$

where

H = number of persons
I = household income
P = price of water
T = outdoor air temperature
t = time period

Water use by sprinkling systems can be expressed as

$$\mathbf{SS_t = M_t * Al_t} \tag{7.32}$$

where

M = application rate (irrigation depth)
Al = landscape area (in square feet) covered by the sprinkling system

The application rate (M_t) can be expressed as the following function

$$\mathbf{M_t = b_4 + b_5P_t + b_6I_t + b_7T_t + b_8R_t} \tag{7.33}$$

where

R = precipitation

Similarly, garden hose irrigation can be expressed as

$$GH_t = D_t{*}A2_t \qquad (7.34)$$

where

D = application rate (depth) for landscape and hard surface areas
A2 = landscape and hard surface area not covered by the sprinkling system

$$D_t = b_9 + b_{10}P_t + b_{11}I_t + b_{12}T_t + b_{13}R_t \qquad (7.35)$$

Finally, the swimming pool use can be expressed as

$$SP_t = b_{14} + b_{15}T_t + b_{16}H_t \qquad (7.36)$$

Substituting all of these relationships into (7.30) gives

$$\begin{aligned} W_t = {} & b_o + b_1H_t + b_2I_t + b_3P_t + [(b_4 + b_5P_t + b_6I_t + b_7T_t + \\ & b_8R_t){*}A1_t]{*}SS_t + [(b_9 + b_{10}P_t + b_{11}I_t + b_{12}T_t + b_{13}R_t){*}A2_t]{*}GH_t + \\ & [(b_{14} + b_{15}T_t + b_{16}H_t){*}SP_t] + b_{17}CPG \end{aligned} \qquad (7.37)$$

The *SS*, *GH*, and *SP* terms in Equation (7.37) are indicator terms that are equal to one (1) if the household has that specific outdoor feature, and zero (0) otherwise. The last term, b_{17} *CPG*, represents household participation in the conservation program. The indicator variable *IFA* is omitted in the equation as an "unspecified appliance" captured by the intercept, b_0. After performing all multiplications, the resultant linear equation can be estimated using a regression procedure. It should be obvious that the data collection efforts for such an end-use model would be quite extensive, and possibly quite expensive as well.

SUMMARY OF ESTIMATION TECHNIQUES

Table 7-8 provides a summary of advantages and disadvantages of each of the five basic estimation techniques that have been discussed. The table also lists the types of water use and other related data that are required in the use of each technique. As mentioned previously, mechanical estimates should be used only when field measurements are unavailable or as supplements to field measurements. Comparison of means and simple regression are inexpensive methods best suited for the derivation of descriptive information. Multiple regression methods

TABLE 7-8

SUMMARY OF TECHNIQUES FOR ESTIMATING WATER CONSERVATION SAVINGS

Technique	Data Required	Advantages	Disadvantages
(A) Mechanical Estimates	(1) Laboratory estimates (2) Published data on water savings per installed device	(1) Relatively inexpensive (2) Easy to obtain from published data (3) Appropriate for providing preliminary estimates of water savings when savings cannot be assessed by statistical methods	(1) Not an empirical evaluation technique (2) Estimates obtained are sensitive to underlying assumptions which are often based on subjective judgement (3) Have been found to overestimate water savings
(B) Comparison of Means	(1) Monthly, bimonthly, or annual water use of treatment and control customers	(1) Relatively inexpensive (depending on the level of experimental design) (2) Statistically straightforward (3) Provides valuable descriptive information (4) Can produce reliable estimates of water savings if used in conjunction with an experimental design and large sample sizes	(1) Requires stringent assumptions in order to produce reliable results (2) Difficult and costly to control for external factors that affect household water use (3) May not be capable of detecting relatively small water savings (i.e., savings less than 10 percent of average use) (4) If expected water savings are small, very large sample sizes may be required
(C) Simple Regression	(1) Monthly, bimonthly, or annual water use of treatment and control customers	(1) Technique is widely available in statistical computer software packages (2) Can be used as an extension of the comparison of means method (3) If regression assumptions are met, the method provides the best linear unbiased estimates of water savings	(1) Method must meet the five assumptions of linear regression (2) Simple regression models often depart from the necessary assumptions (3) Does not explicitly account for external factors which affect water use; the effects of these factors are captured in the model error term

TABLE 7-8 (Continued)

SUMMARY OF TECHNIQUES FOR ESTIMATING WATER CONSERVATION SAVINGS

Technique	Data Required	Advantages	Disadvantages
(D) Multiple Regression Methods	(1) Daily, monthly, bimonthly, or annual water use per customer or class of customer in sample (2) Data on independent variables for corresponding time periods	(1) Ability to incorporate several variables that are hypothesized to affect water use, including seasonal and weather effects and price (2) Multiple regression techniques are available in most statistical software packages (3) Can choose from a variety of multiple regression methods, depending on the types of data available and the accepted level of estimation complexity (4) Many multiple regression applications can be found in the literature (5) Can be used to estimate savings from pooled time-series, cross sectional data (6) Generalized Least Squares can be used to account for the effects of heteroskedastic and autocorrelated errors	(1) Possible endogeneity of the price variable under certain rate structures (2) The nature of time-series and cross-sectional data often results in the violation of one or more of the basic regression assumptions (3) Because of added data and computational costs, multiple regression methods are considered more expensive than simpler methods
(E) Econometric End-Use Modeling	(1) Daily, monthly, bimonthly, or annual water use per customer or class of customer in sample (2) Data on independent variables for corresponding time periods	(1) Uses a multiple regression framework to estimate water savings (2) Allows the analyst to isolate conservation savings by addressing the volume of water used by various appliances or end-uses	(1) No documented cases of the use of the approach in the water industry (2) Requires a large number of explanatory variables (3) Data collection is extensive and likely expensive

allow the analyst to incorporate information on several variables that are hypothesized to affect water use. Depending on the data that are available, multiple regression techniques are preferred for the empirical estimation of water conservation savings.

OTHER ESTIMATION ISSUES

Data Quality Control

The issue of data quality is very critical. The availability and quality of data determine the accuracy of the estimated water conservation savings. Data quality controls are needed as part of the data acquisition and manipulation processes.

The following is a list of examples of data quality controls used in the process of data gathering and the construction of data sets for program evaluation.

(1) Maintaining copies of original data sources. Photocopies of original records should be made, together with all comments by the data recorder, which pertain to special conditions and other factors that can affect the accuracy of measurements. For example, photocopies of the original completed questionnaires should be made available to the analyst.

(2) Double-checking of encoded data. All data that are transferred into a format useful for engineering or statistical analyses should be double-checked for accuracy of the transfer.

(3) Maintaining master data files. Once a complete data set is prepared and checked for accuracy, it should be set aside as a "master data set" that is never changed. Working files should always be prepared from the master set and properly described in terms of changes made. It is also helpful to prepare a hard copy of the master data set.

(4) Data verification checks. A careful transfer of data does not ensure that the data is error free. Additional screening of the data should be undertaken in order to test for data irregularities. For example, a set of descriptive statistics such as mean, mode, median, standard deviation, lowest value, and highest value should be obtained for each variable in the data set in order to check for decimal point errors and unusually high or low values. Often, a graphical display of the data on the computer screen will easily point out highly irregular measurements.

Interactions among Conservation Measures

Conservation savings obtained through the simultaneous implementation of two or more conservation programs will be affected by the degree to which the program or conservation measures constituting the programs interact with each other. Theoretically, the combined conservation savings of two or more measures can be calculated as a fractional reduction in water use for each water use sector and dimension (e.g., average-day, peak-day) using the formula

$$P_{s,d,t} = \sum_{m=1}^{n} \left[(R_{m,s,d} * C_{m,s,t}) * \prod_{g=1}^{m-1} (I_{m,g,d}) \right] \qquad (7.38)$$

where

$P_{s,d,t}$ = the adjustment factor for the effect of all conservation measures implemented in sector *s* (e.g., single-family residential) and use dimension *d* (e.g., winter water use) in year *t*.

$R_{m,s,d}$ = fraction reduction in the use of water in sector *s* for use dimension *d* expected as a result of implementing measure *m* (e.g., conservation-oriented plumbing code).

$C_{m,s,t}$ = coverage of measure *m* in use sector *s* at time *t* expressed as a fraction of sectoral water use: e.g., if a plumbing code is implemented on January 1, 1988, then the coverage value for the single-family residential sector *s*, in year *t*, is defined as the proportion of that sector's water use occurring in dwelling units built since the implementation date; this proportion can be approximated by the ratio of the new single-family housing units to the total number of single-family units in year *t*.

$I_{m,g,d}$ = interaction factor for the combinations of individual pairs of measures, *m* and *g*, for dimension *d*, where *g* = each preceding measure, and *n* = total number of measures implemented.

The estimated water use with conservation for each water use sector and dimension (i.e., water use considering the effects of conservation) is calculated as

$$Q_{c,s,d,t} = Q_{u,s,d,t} (1-P_{s,d,t}) \qquad (7.39)$$

where

$Q_{c,s,d,t}$ = water use with conservation for sector *s* and dimension *d* in year *t*.

$Q_{u,s,d,t}$ = unrestricted water use (without conservation) for sector *s* and dimension *d* in year *t*.

Typical problems associated with determining the values of conservation parameters in Equation (7.38) are given below.

Unit Water Savings (Reduction)

There is a tendency in conservation planning practice to assume a savings rate for each measure on a per capita basis and to use these savings as a constant for all communities and all time periods. For example, a savings of 15.2 gallons per capita per day can be used for a plumbing code. This savings rate is taken to represent a difference in average water use between homes that comply with the plumbing code versus older homes regardless of the level of water use in homes without the new plumbing fixtures. An alternative procedure is to use the percent savings in winter or summer water use. The percent savings, also referred to as a fractional reduction factor, measures the percent reduction in water use for a given water use sector and dimension that is expected to result from a given conservation practice. This approach mitigates, to some extent, the problem of constant savings, but it does not account for all factors that can influence actual savings.

Market Penetration (Coverage)

The market penetration (or coverage) is an indication of the percentage of total water use within a given sector affected by a given measure at a given point in time. Coverage factors may be approximated by the percent of water users who are in compliance with, or who have adopted, a given measure. The value of the coverage factor may be expected either to increase over time as more users comply with a given measure or decrease or time as the water-saving devices wear out.

This coverage factor is an unknown quantity for most measures. Typically, implementation of measures is based upon estimated compliance rates (e.g., plumbing codes) or rates of installation (e.g., voluntary retrofit programs). Usually it is necessary to conduct field studies on selected conservation programs in order to verify assumptions made for conservation parameters.

Interaction Effects

Table 7-9 identifies three types of interaction effects that are possible between two conservation measures (or alternatives).

TABLE 7-9
TYPES OF INTERACTIONS BETWEEN CONSERVATION MEASURES

Type of Interaction	Conservation Effects (Savings): Measure A Alone	Measure B Alone	Measures A & B Together
Competitive	α	β	$\alpha + \beta - k_1$*
Independent	α	β	$\alpha + \beta$
Synergistic	α	β	$\alpha + \beta + k_2$*

*$k_1, k_2 > 0$.

The competitive (or antagonistic) interaction describes a situation when the combined effectiveness (i.e., water savings) of two measures implemented together is less than the sum of water savings from each measure when implemented alone. For example, when price rises, consumers tend to reduce water use by adopting new water use habits or by installing such devices as low-flow showerheads and low-flush toilets. When water agencies undertake plumbing fixture retrofit campaigns, they seek the same response from consumers, although without the price incentive. Water conservation programs could, therefore, preempt the price response options, thereby effectively lowering the elasticity of water demand with respect to price. Similarly, a price increase may preempt the conservation response of nonprice measures (e.g., some replaced showerheads will already be of low-flow type).

The independence of two measures indicates that their savings are strictly additive. For example, the conservation effects of retrofitting showers and toilets is independent of the conservation effects of conversion of turf grass into xeriscape. Conservation effects stemming from price increases would be independent of the conservation effects of nonprice measures if the adjustments in water use induced by price increases were of different types than the adjustments affected by conservation measures. Such interaction is possible if, for example, consumers save a certain amount of water by installing a low-flow showerhead provided by the city while, at the same time, a major price increase causes them to shorten their showers from

10 to 7 minutes. If the low-flow showerhead reduced flow from 5 to 3 gallons per minute, the savings from the retrofit alone would be 20 gallons per shower. The shortening of showering time by 3 minutes would achieve an additional savings of 9 gallons per shower. Another case for independent interaction between price increases and retrofits is that while only some homes are retrofitted, price increases affect all consumers who pay water bills.

Finally, synergistic interaction indicates that when two measures are implemented together they tend to "reinforce" each other. The result is combined savings that are greater than the sum of savings if each measure were implemented alone. A good example of this is the possible interaction between price increases and public information campaigns. A significant price increase may be noticed and acted upon by only a fraction of consumers. A public information and education campaign unaccompanied by a price increase will also convince only a fraction of consumers that they can (and should) change their inefficient water-using practices. However, when a price increase and a public information campaign are implemented together, more consumers will become aware of the price increase and more of them will gain information on the best ways to reduce their water use in response to price. At the same time, more consumers will respond to the public information campaign because the price increase will serve as an additional incentive to conserve water.

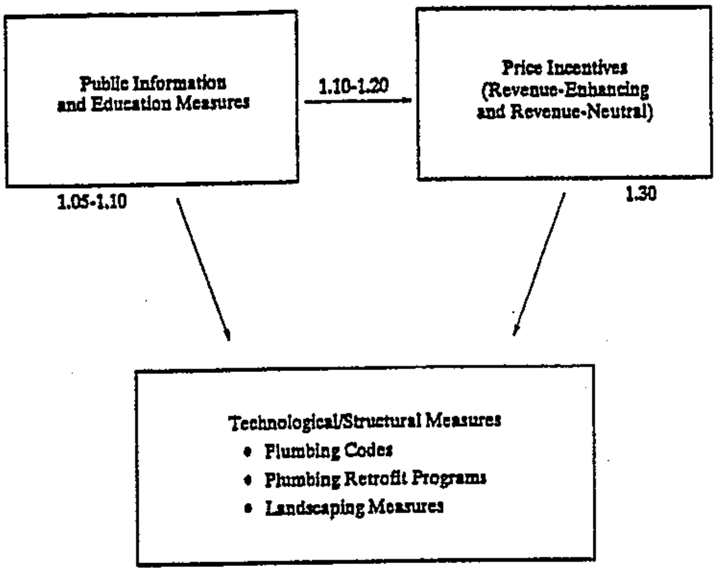
Classes of Interacting Measures

A practical way of handling interaction among measures is to consider interactions only among a limited number of classes of conservation measures. For most practical purposes, the interactions can be limited to three types of conservation measures as shown in Figure 7-6. The analysis of interaction effects can also be simplified by assuming that they are unidirectional.

For example, public information and education (PI/PE) programs will result in water savings when implemented alone. The component measures (or submeasures) of PI/PE programs may include:

(1) Printing actual use in gallons per day and comparing it with previous month and previous year (the same month), e.g., May 1990 = 420 gpd; May 1991 = 340 gpd; April 1991 = 310 gpd
(2) Elementary school education programs
(3) High school education programs
(4) Public announcements on TV and radio
(5) Distribution of brochures with conservation tips
(6) Demonstration gardens

FIGURE 7-6
UNIDIRECTIONAL INTERACTION EFFECTS



In addition, PI/PE measures have the effect of enhancing the effectiveness of pricing measures and technological/structural measures (unidirectional interaction). For example, the price elasticity of revenue-neutral pricing measures could be increased by 10 to 20 percent (interaction factor 1.1 to 1.2) because PI/PE programs will increase the awareness of rate designs. The effects of PI/PE on technological/structural measures may increase compliance or coverage by 5 to 10 percent (interaction factor 1.05 to 1.10). An example of these interaction effects is shown in Table 7-10. However, an assumption should be made that the presence of a pricing measure will not change the reduction factors of the PI/PE program implemented alone (only unidirectional interaction).

As shown in Figure 7-6, the presence of pricing measures will have a unidirectional interaction effect on all technological/structural measures. This effect should be accounted for by increasing the coverage of these measures. In many instances, the value of coverage is a function of the design of the measure. For example, a high intensity retrofit may have a target coverage of 70 percent of eligible homes. The interaction should increase the potential of achieving or exceeding the specified target.

TABLE 7-10
EXAMPLE OF INTERACTION EFFECTS OF PI/PE PROGRAM

	Without PI/PE	With PI/PE	Interaction (With/Without)
Price elasticity	-0.15	-0.18	1.2
Coverage of retrofit	0.60	0.66	1.1

However, there is a problem of assuming constant interaction factors regardless of the magnitude and type of changes in the rate design. For example, a change from increasing block to uniform rates will possibly lower the marginal price for the highest block customers. If these customers are those who are likely to refuse participation, an interaction factor that is less than one should be used. Only customers who will see an increase in their water bill will have the incentive to accept retrofit kits (or accept other measures).

Finally, one must address the nature of interaction among technological/structural measures. Consider, for example, that the same homes cannot be, at the same time, complying with a plumbing code, installing retrofit kits, and accepting home water audits using retrofit kits. In this context, the relevant interaction effects can be sorted out by "measure design" and "accounting checks." Accounting checks can be implemented by keeping track of housing units and nonresidential establishments (or employment). Figure 7-7 illustrates the relationship between housing units covered by various measures. Notice that the solid lines in Figure 7-7 cannot be changed. Only the dashed lines can be shifted upward or tilted through interaction factors (e.g., revenue-neutral pricing). The dashed lines show homes retrofitted under different programs. These numbers have to add up to the "total retrofitted units." However, all noncomplying or nonparticipating units might never be reached.

Similar "maps" of housing stock can be made for each residential subsector, (i.e., multifamily low density, multifamily high density, nonurban housing). Outdoor measures could use similar "maps." In the nonresidential sector, accounting checks can be made based on a count of establishments or the number of employees. However, the latter is easier to handle.

Estimating Interaction Effects

Interaction effects between specific measures can be estimated using econometric models for estimating water conservation savings as described in the previous sections. The most difficult analytical task is to distinguish between the conservation effects of price and the effects of nonprice measures (e.g., retrofit of plumbing fixtures). Similarly, the effects of educational campaigns on structural measures are difficult to evaluate.

Some empirical evidence of price/conservation effects is found in the water demand literature. Moncur (1987) suggests a simple test for price interaction by recognizing that price elasticity in a linear water demand model depends on the level of water use. Price elasticity of water demand is calculated as

$$e_p = \partial Q/\partial P * P/Q \qquad (7.40)$$

where

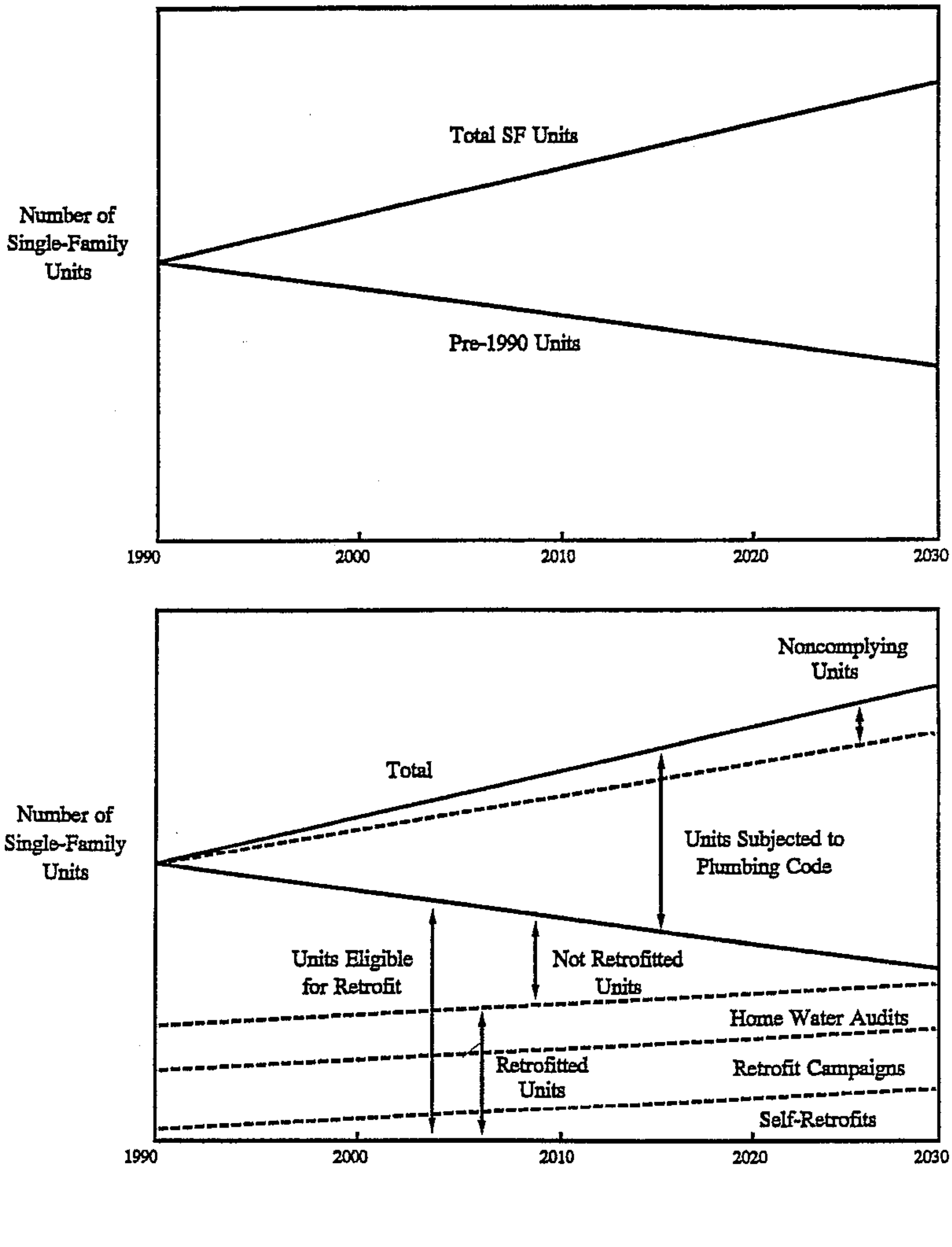
$\partial Q/\partial P$ = regression coefficient of the price variable in a linear model
P = price level
Q = water use affected by conservation

Using water use data for a sample of 1,281 single-family homes in Honolulu, Moncur (1987) estimated that when price changes are accompanied by a public information campaign (dissemination of information on methods of water conservation), the long-run price elasticity is 14 percent higher than it would be without the campaign. However, in addition to increasing price elasticity, the public information program had a direct effect on water use by reducing mean water use by 12 percent. This result indicates a synergistic interaction. It also suggests that separate effects of price and nonprice measures should be supplemented by the positive (i.e., additional conservation) interaction between price and non market programs.

Berk et al. (1981) conducted an extensive study of the effects of price, conservation programs, and other factors that affected water use in California communities during 1970-78 period. The results for the residential sector obtained by Berk et al. lend some support for the existence of a synergistic effect between price and water use restrictions (at least during a period of drought). However, Berk et al. used a cautious interpretation of this relationship, indicating that "the impact of local conservation programs is virtually independent of the impact of price (p. 133)," thus suggesting that price and conservation programs were independent, non-competing ways to reduce water use.

The findings of Moncur (1987) and Berk et al. (1981) strongly suggest that an interaction between price and nonprice measures is more likely to be found to lie between the independent and synergistic relationships than between competitive and independent effects. Consequently, the independent interaction effect would represent a <u>conservative</u> assumption in estimating the combined effect of price and nonprice conservation programs, provided that price elasticity in water demand models is measured as an "independent" effect.

FIGURE 7-7
ACCOUNTING CHECKS AND INTERACTIONS BETWEEN TECHNOLOGICAL/STRUCTURAL MEASURES



Even though price/conservation interaction may be independent-to-synergistic, estimated price elasticities may be strongly biased due to the misspecification of water demand models. When the effects of nonprice conservation programs are not measured, then the estimated price elasticity (in a misspecified model) is likely to capture the combined effect of price changes and these other programs. Therefore, a crude way for quantifying a positive bias in price elasticity estimates is to compare price elasticity estimates with and without separate measurements of nonprice conservation effects. One should expect the price elasticity estimates to be higher when conservation variables are not included in the estimated water demand model, and lower when such variables are included. Alternately, price elasticity estimates obtained for cities not practicing conservation programs should be lower than those obtained for cities with aggressive conservation programs (when the effects of these programs are not separately measured). For example, Moncur (1987) demonstrated that the inclusion of a conservation variable in his demand equation lowered the estimated short-run price elasticity from -0.482 to -0.265 (approximately a 45 percent reduction in price elasticity).

Additional evidence for comparing elasticities with and without conservation is not readily available. However, relatively low estimates of price elasticity are expected in models that include adequate controls for conservation programs. While controlling for drought conservation programs and hookup moratoriums, Berk et al. (1981) estimated price elasticity for total residential use at -0.09. Moncur (1989) obtained an estimate of price elasticity of about -0.05 when the restrictions program was in effect.

FACTORS AFFECTING CONSERVATION SAVINGS

The conservation savings of a conservation program should be expected to vary over time and across program participants. This variability has important implications for water supply and conservation planning and for the transferability of conservation savings to other service areas (or other parts of the same service area).

Two factors that are likely to affect the volume of water saved through a conservation program are discussed in the following sections.

Changes in Saturation (Adoption Rates) of Conservation Measures

In general, conservation savings result from the substitution of less efficient fixtures and appliances with more efficient ones, as well as from changes in water-using behaviors. Therefore, the actual program impact will depend on the number of the efficient devices that are installed and functioning properly. This number will change over time as some devices are removed and others reach the limit of their physical life. Therefore, the maintenance of a conservation program will determine the persistence of the program impact over time. The behavior of water users is also likely to change with time, as the beliefs in the need for water conservation and other related attitudes change. Again, in order to maintain the effects of the program, it may be necessary to conduct periodic public information and educational programs.

Effects of Customer Characteristics

Conservation savings from the same program will likely be different for different customers who participate in the program. For example, conservation savings from indoor residential measures (such as low-flow showerheads or ultra-low-flush toilets) will depend on the same household characteristics that are typically used in multiple regression techniques:

(1) Family size
(2) Family composition
(3) Household income
(4) Marginal price of water and wastewater

Similarly, savings from outdoor measures will depend on the type and size of the landscape and the prevalent patterns of outdoor water use (e.g., frequency of lawn watering).

In order to capture the effects of differences in customer characteristics on water savings, it is necessary to measure such effects through water demand models. This is usually accomplished through the use of interaction variables. The interaction variables in the model imply the existence of a causal relationship between two or more independent variables and the dependent variable.

For example, a pooled time series cross-sectional multivariate regression model may be estimated as

$$Q = a - bP + cI + dH + eT - fR - gPROG \qquad (7.41)$$

where

Q = household water use
P = price of water and wastewater
I = household income
H = household size
T = air temperature
R = rainfall
PROG = indicator variable for conservation program

In this model, both household size and program participation are assumed to have independent effects on water use. But supposing the effect *g* of program participation (i.e., conservation savings) depends on household size, then a preferred specification will include the product of the two variables

$$Q = a - bP + cI + dH - eT - fR - gPROG \pm h\,(PROG*H) + \epsilon \qquad (7.42)$$

The parameter *h* of the interaction variable, if statistically significant, will measure the effect of household size on conservation savings.

STEP 8. DEVELOP A LONG-TERM MONITORING PROGRAM

OBJECTIVES

(1) To provide an information base for the development of conservation programs that are tailored to the water use characteristics of customers in the service area

(2) To provide a database for evaluating market penetration of implemented conservation programs

(3) To provide a database for estimating water savings of implemented conservation programs

(4) To provide a database for assessing attrition of conservation devices and water savings from conservation programs

(5) To provide a means for monitoring changes in customer characteristics, attitudes, and conservation behaviors

The overall objective of a long-term monitoring program is to provide water conservation planners with information on how to tailor its conservation programs to achieve water savings in the most acceptable and cost-effective manner possible. Information on the level and pattern of water use in their water service area will allow planners to develop conservation programs that will have the most significant impacts on reducing water use. When coupled with information regarding attitudes and behaviors, conservation planners can design and market programs that consider the probable responses of the target population.

In the long run, the implementation of a long-term monitoring program would allow analyses of the cost-effectiveness of specific components of a comprehensive conservation program. The results of the monitoring, therefore, could be used as inputs to the public education/information program, providing feedback and reinforcement to those who are attempting to reduce water use. As conservation programs are implemented, the continuous monitoring and analysis of the database would facilitate an evaluation of the effectiveness of the water conservation program and an identification of opportunities for program improvement. If the data base is updated on a long-term basis, the result would be a high-quality database on water use, complete with information on major explanatory variables. These data could support the development of improved water use forecasting procedures by providing a means for developing site-specific water use models.

INITIAL DEVELOPMENT OF LONG-TERM MONITORING PROGRAM

In addition to monitoring aggregate water use of customer classes, it is recommended that the long-term monitoring program contain samples of water customers grouped into relatively homogeneous classes of users (e.g., single-family residential, manufacturing establishments, golf courses). The grouping of water customers is important because conservation programs are typically targeted to specific water use groups. Therefore, the first step in the development of the the long-term monitoring program is to analyze total water consumption and standard deviations within selected user groups. This allows for the determination of sample sizes which will result in a statistically significant representation of the user group as a whole (see introduction to **Part II** for a discussion of sample size selection). Other considerations in selecting the user groups and the sample of customers within each user group include geographic dispersion, economic activities, and the relative level of water use in the service area. A history of water billing records of the selected customers should be included into the database. The initial database of the monitoring program should include about one to two years of water billing histories (i.e., monthly or bimonthly billing cycles).

The second step in the development of the long-term monitoring program is to conduct periodic surveys of the sample customers that represent the various user groups in the database (see Table 6-2 of **Step 6** for potential survey topics). The surveys should obtain information about how water is used by the various classes of customers (e.g., lawn-watering behaviors and frequency of appliance and fixture use in the residential sector; cooling, process, sanitary, and outdoor use in the nonresidential sector). Reliable information on the end uses of water will allow water conservation planners to design programs to best meet the needs of its customers and to target specific types of uses that occur in the service area.

The surveys should also obtain information on socioeconomic characteristics, economic activities (if business customer), and attitudes toward water supplies and conservation. This will provide information to water conservation planners on the public acceptance of conservation measures, and will facilitate the development and marketing of conservation programs in the most socially acceptable manner. Furthermore, the surveys should measure the market penetration of existing conservation programs and the level of other conservation behaviors. This information would allow an evaluation of the conservation message and the modes of its delivery in order to further improve the efficacy of various program components.

The third step in the development of the water use monitoring database is to couple survey data of each sampled customer with its corresponding historical water use record. It is likely that survey responses will not be available for each sampled customer in the water use monitoring database. Therefore, to ensure that the survey responses are representative of the sample customer group, only a limited amount of information should be obtained on survey nonrespondents. As long as the nonrespondents do not significantly differ from respondents with respect to key parameters within the user group (e.g., household income in residential sector), the survey data can be deemed representative of the entire customer class.

At a very minimum, the database for the long-term monitoring program should include the following elements:

(1) A representative sample of water use accounts of one or more customer classes with a flag on each account indicating its designated customer class

(2) Water billing histories for each sampled account spanning the most recent 12 month period including meter-reading dates and meter readings

(3) Survey responses for sampled accounts including information on household or business characteristics (i.e., demographic and socioeconomic characteristics, existence of water-using appliances, and other water use behaviors)

(4) Conservation program participation information including activities performed and dates of implementation for each account based upon program tracking forms and other field surveys

(5) Time series of weather data covering the time period of the water billing histories

(6) Information on water and wastewater rates covering the time period of the water billing histories

In the short run, the database will facilitate an analysis of historical water use patterns in relationship to socioeconomic characteristics, conservation behaviors, attitudes, and end uses. For example, cross-referencing survey results of the residential population with water use monitoring data would permit the determination of characteristics of conserving and nonconserving households. If a conservation program was implemented within the time frame of the survey data and historical water use record, preliminary analyses could be conducted to determine water savings resulting from the conservation program intervention. However, given the initial development of the long-term monitoring program and its limited availability of historical water use records, preliminary data analysis is more likely to generate descriptive information such as the:

(1) Identification of general water use characteristics of each customer class (see **Step 1**) as a baseline for the monitoring program (seasonal water use patterns, process water use, cooling water use)

(2) Identification of the major factors that affect water use and conservation behavior

(3) Determination of the market penetration of existing conservation programs

(4) Identification of the characteristics of conservers and nonconservers

(5) Identification of the potential for conservation program improvement

UPDATE MONITORING PROGRAM

In order for the benefits of the long-term monitoring program to be fully realized, it is necessary to update the database on a regular basis. This includes (1) the annual update of water billing records for each customer in the database, (2) the addition of new sampled customers (to adjust for the loss of sample accounts over time), and (3) periodic surveys of customer groups. The ongoing updates of the database will allow the water conservation planner to assess changes in customer's demographic and economic characteristics, attitudes, and conservation behaviors. Furthermore, the water-monitoring database will provide the water conservation planner with a means for analyzing and synthesizing conservation results and for predicting the effectiveness of any contemplated changes in the conservation program. While controlling for changes in exogenous variables, the impact of various conservation program interventions can then be analyzed using methods described in **Step 7**. This analysis can include not only the impacts of recently implemented conservation programs, but also the measurement of the changes in conservation behaviors from previously implemented programs.

APPENDIX A

SOCIAL ACCEPTABILITY

SURVEY QUESTIONNAIRE

The following questionnaire was used in a community in Illinois to assess the social acceptability of water conservation measures. The response rate to this mail survey was about 50 percent.

For each question, please circle the number indicating your response as in the example below.

Q-0 *Are you currently a water utility customer ?*

1 YES *2 NO*

Q-1 How important, in your opinion, is the current need to conserve water in the local area?

1 UNIMPORTANT
2 SOMEWHAT IMPORTANT
3 OF CONSIDERABLE IMPORTANCE
4 URGENT

Q-2 How many gallons of water per day would you say your household uses on average?

____ GALLONS PER DAY

Q-3 Do you now own an above-ground or in-ground swimming pool?

1 YES 2 NO

Q-4 How often do you water your lawn and/or garden?

1 NEVER
2 ONLY DURING VERY DRY PERIODS
3 ABOUT WEEKLY
4 MORE THAN ONCE A WEEK

The remainder of this survey will consist of twelve (12) water conservation measures labelled A through L that will be described to you. We will ask about your opinion of each of these measures and whether you would use it to save water in your home.

For each question, please circle the number indicating your response.

MEASURE A

The city could apply a $150 discount to the connection fee for those new residential customers who put less than 50% of their yard area in grass lawn. Those with more than 50% in grass would pay a $500 penalty.

A-1 How serious would the need to save water have to be before you think this measure should be used?

1 USE AT ALL TIMES
2 USE AT FIRST SIGN OF WATER SHORTAGE
3 USE ONLY DURING SERIOUS SHORTAGE
4 USE ONLY DURING WATER SUPPLY EMERGENCY

A-2 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE B

The city may provide "water-saver kits" to all of its residential customers free of charge. These kits contain low-flow showerheads, low-flow bathroom and kitchen faucet aerators, toilet tank dams (to reduce the amount of water used per flush) and instruction on how to install them.

B-1 Have you heard of these water-saver kits?

1 YES 2 NO

B-2 If you were to receive a kit, would you install the items?

1 NO, NONE OF THEM
2 YES, SOME OF THEM
3 YES, ALL OF THEM

B-3 How much of your present water use do you think this kit would save?

1 NONE
2 ONLY A LITTLE (LESS THAN 10%)
3 A FAIR AMOUNT (10-25%)
4 A LOT (MORE THAN 25%)
5 I CAN'T MAKE A REASONABLE GUESS

B-4 How **economical** do you think installing these kits would be?

1 IT WOULD COST MORE THAN IT WOULD BE WORTH
2 IT WOULD COST ABOUT AS MUCH MONEY AS IT WOULD SAVE
3 IT WOULD RESULT IN SAVING SOME MONEY
4 IT WOULD RESULT IN BIG SAVINGS
5 I CAN'T MAKE A REASONABLE GUESS

B-5 Would you oppose or favor installation of these kits being enforced **by law** so that all residential water users must comply?

1 STRONGLY OPPOSE
2 SOMEWHAT OPPOSE
3 SOMEWHAT FAVOR
4 STRONGLY FAVOR

B-6 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE C

The city could revise its code to prohibit new commercial developments from putting more than 25% of their landscaped area in grass lawn.

C-1 Have you heard of this water conservation measure?

1 YES 2 NO

C-2 How do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE D

The city could conduct a direct contact "water audit" program free of charge for each of its large commercial and industrial water users to evaluate their water use habits and technologies and opportunities to save water.

D-1 Have you heard of this conservation measure?

1 YES 2 NO

D-2 How serious would the need to save water have to be before you think these water audits should be performed?

1 PERFORM AT ALL TIMES
2 PERFORM AT FIRST SIGN OF WATER SHORTAGE
3 PERFORM ONLY DURING SERIOUS SHORTAGE
4 PERFORM ONLY DURING WATER SUPPLY EMERGENCY

D-3 Would you oppose or favor this measure being enforced BY LAW so that all commercial and industrial users must have an audit performed?

1 STRONGLY OPPOSE
2 SOMEWHAT OPPOSE
3 SOMEWHAT FAVOR
4 STRONGLY FAVOR

D-4 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE E

The city may conduct a standard "water audit program. A city employee would make an appointment to come to your home free of charge to identify opportunities to save water in your home and yard.

E-1 If such a water audit program were available, would you have one done for your household?

1 YES 2 NO

E-2 How much of your present water use do you think a water audit would save?

1 NONE
2 ONLY A LITTLE (LESS THAN 10%)
3 A FAIR AMOUNT (10-25%)
4 A LOT (MORE THAN 25%)
5 I CAN'T MAKE A REASONABLE GUESS

E-3 How serious would the need to save water have to be before you think the city should offer the water audits?

1 OFFER AT ALL TIMES
2 OFFER AT FIRST SIGN OF WATER SHORTAGE
3 OFFER ONLY DURING SERIOUS SHORTAGE
4 OFFER ONLY DURING WATER SUPPLY EMERGENCY

E-4 Would you oppose or favor this measure being enforced **by law** so that all residential water users must have an audit performed?

1 STRONGLY OPPOSE
2 SOMEWHAT OPPOSE
3 SOMEWHAT FAVOR
4 STRONGLY FAVOR

E-5 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE F

Educational programs could be made available to elementary and high schools in the local area to teach children how to conserve water in their homes and the importance of doing so.

F-1 Do you think these programs would be **effective** in saving water?

1 THEY WOULD PRODUCE NO WATER SAVINGS
2 THEY WOULD PRODUCE ONLY MINOR WATER SAVINGS
3 THEY WOULD PRODUCE MAJOR WATER SAVINGS

F-2 How serious would the need to save water have to be before you think these programs should be used?

1 USE AT ALL TIMES
2 USE AT FIRST SIGN OF WATER SHORTAGE
3 USE ONLY DURING SERIOUS SHORTAGE
4 USE ONLY DURING WATER SUPPLY EMERGENCY

F-3 Would you oppose or favor this measure being enforced **by law** so that all local area schools must use the educational programs?

1 STRONGLY OPPOSE
2 SOMEWHAT OPPOSE
3 SOMEWHAT FAVOR
4 STRONGLY FAVOR

F-4 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE G

The city could set up and finance a program to save water used in grass watering by public facilities such as cemeteries, schools, parks, and golf courses.

G-1 Have you heard of this water conservation measure?

1 YES 2 NO

G-2 How serious would the need to save water have to be before you think this program should be implemented?

1 IMPLEMENT AT ALL TIMES
2 IMPLEMENT AT FIRST SIGN OF WATER SHORTAGE
3 IMPLEMENT ONLY DURING SERIOUS SHORTAGE
4 IMPLEMENT ONLY DURING WATER SUPPLY EMERGENCY

G-3 Would you oppose or favor this measure being enforced BY LAW so that all public facilities must participate in the program?

1 STRONGLY OPPOSE
2 SOMEWHAT OPPOSE
3 SOMEWHAT FAVOR
4 STRONGLY FAVOR

G-4 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE H

The city may revise its plumbing code to require installation of low-flush toilets and low-flow showerheads and faucets for all new or replacement construction that begins after June 1, 1991.

H-1 Have you heard of this conservation measure?

1 YES 2 NO

H-2 How much water do you think this measure would save for new residences built after June 1, 1991?

1 NONE
2 ONLY A LITTLE (LESS THAN 10%)
3 A FAIR AMOUNT (10-25%)
4 A LOT (MORE THAN 25%)
5 I CAN'T MAKE A REASONABLE GUESS

H-3 How economical do you think it would be for new home buyers, considering that energy as well as water could be saved as hot water use is reduced?

1 IT WOULD COST MORE THAN IT WOULD BE WORTH
2 IT WOULD COST ABOUT AS MUCH MONEY AS IT WOULD SAVE
3 IT WOULD RESULT IN SAVING SOME MONEY
4 IT WOULD RESULT IN BIG SAVINGS
5 I CAN'T MAKE A REASONABLE GUESS

H-4 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE I

The city could provide rebates of $100 on the purchase of ultra-low-flush toilets (1.6 gallons per flush).

I-1 Have you heard of this conservation measure?

1 YES 2 NO

I-2 Do you think that you would take advantage of this rebate program?

1 YES, I WOULD REPLACE MY EXISTING TOILET FOR AN ULTRA-LOW-FLUSH ONE AND GET THE REBATE
2 YES, BUT I WOULD WAIT UNTIL MY EXISTING TOILET STOPPED WORKING AND THEN PURCHASE AN ULTRA-LOW-FLUSH ONE AND GET THE REBATE
3 NO, I WOULD NOT PURCHASE AN ULTRA-LOW-FLUSH TOILET

I-3 If you did replace your toilet through this rebate program, how much of your total present water use do you think it would save?

1 NONE
2 ONLY A LITTLE (LESS THAN 10%)
3 A FAIR AMOUNT (10-25%)
4 A LOT (MORE THAN 25%)
5 I CAN'T MAKE A REASONABLE GUESS

I-4 How **economical** do you think replacing your **existing** toilet through this rebate program would be?

1 IT WOULD COST MORE THAN IT WOULD BE WORTH
2 IT WOULD COST ABOUT AS MUCH MONEY AS IT WOULD SAVE
3 IT WOULD RESULT IN SAVING SOME MONEY
4 IT WOULD RESULT IN BIG SAVINGS
5 I CAN'T MAKE A REASONABLE GUESS

I-5 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE J

The city may revise its code to ban the sale of high water use toilets, faucets, clothes washers, and dishwashers that do not meet American National Standards Institute efficiency standards.

J-1 Have you heard of this conservation measure?

1 YES 2 NO

J-2 How **economical** do you think it would be for new toilet, faucet, clothing and dishwasher buyers? Would the extra cost of the appliances outweigh the savings on water bills?

1 IT WOULD COST MORE THAN IT WOULD BE WORTH
2 IT WOULD COST ABOUT AS MUCH MONEY AS IT WOULD SAVE
3 IT WOULD RESULT IN SAVING SOME MONEY
4 IT WOULD RESULT IN BIG SAVINGS
5 I CAN'T MAKE A REASONABLE GUESS

J-3 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE K

The city may increase its water rates for the summer season by 30% (when demands on water supply are greatest) and use the funds to reduce water rates in winter.

K-1 How much do you think you would reduce your present summer water use to reduce your water bill?

1 NONE
2 ONLY A LITTLE (LESS THAN 10%)
3 A FAIR AMOUNT (10-25%)
4 A LOT (MORE THAN 25%)
5 I CAN'T MAKE A REASONABLE GUESS

K-2 Which practices would you **greatly reduce or eliminate** in order to reduce your water bill? (Please circle all that apply.)

1 FILLING OF SWIMMING POOLS
2 LAWN WATERING
3 GARDEN WATERING
4 CAR AND DRIVEWAY WASHING
5 LONG SHOWERS AND BATHS

K-3 How serious would the need to save water have to be before you think these rate changes should be implemented?

1 IMPLEMENT AT ALL TIMES
2 IMPLEMENT AT FIRST SIGN OF WATER SHORTAGE
3 IMPLEMENT ONLY DURING SERIOUS SHORTAGE
4 IMPLEMENT ONLY DURING WATER SUPPLY EMERGENCY

K-4 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

MEASURE L

The city may impose a voluntary restriction during water shortages that lawn and garden watering can only be done every third day from 6 to 8 p.m.

L-1 Have you heard of this water conservation measure?

1 YES 2 NO

L-2 Do you think you would follow the restrictions when they were issued?

1 NO, I WOULD IGNORE THE RESTRICTIONS
2 YES, BUT ONLY WHEN IT DOESN'T INCONVENIENCE ME
3 YES, BUT ONLY WHEN IT WOULD NOT RESULT IN DAMAGE TO MY LAWN AND GARDEN
4 YES, I WOULD FOLLOW THESE RESTRICTIONS WHEN THEY ARE ISSUED

L-3 How much of your present **total** water use do you think these restrictions would save?

1 NONE
2 ONLY A LITTLE (LESS THAN 10%)
3 A FAIR AMOUNT (10 - 25%)
4 A LOT (MORE THAN 25%)
5 I CAN'T MAKE A REASONABLE GUESS

L-4 How serious would the need to save water have to be before you think this measure should be implemented?

1 IMPLEMENT AT ALL TIMES
2 IMPLEMENT AT FIRST SIGN OF WATER SHORTAGE
3 IMPLEMENT ONLY DURING SERIOUS SHORTAGE
4 IMPLEMENT ONLY DURING WATER SUPPLY EMERGENCY

L-5 Would you oppose or favor this measure being enforced **by law** so that all water users must comply?

1 STRONGLY OPPOSE
2 SOMEWHAT OPPOSE
3 SOMEWHAT FAVOR
4 STRONGLY FAVOR

L-6 Overall, how do you evaluate this conservation measure?

1 TOTALLY UNACCEPTABLE
2 I DON'T APPROVE
3 I APPROVE
4 I ENTHUSIASTICALLY APPROVE

GENERAL CUSTOMER INFORMATION

General information on customers' age, education, home and income will aid the city in determining which type of customers favor which types of conservation measures.
Your answers are confidential.

M-1 What is your age? ___ YEARS

M-2 What is your gender? 1 MALE 2 FEMALE

M-3 Including yourself, how many members live in your household? ___ PERSONS

M-4 In what type of residence do you now live?

1 Single-family detached home
2 Townhouse
3 Attached apartment
4 Condominium
5 Mobile home
6 Duplex
7 Triplex
8 Other

M-5 Do you own your home or do you rent a house or apartment?

1 OWN 2 RENT

M-6 If you OWN your home, what would you estimate is the current value of your house or condominum if it were to go on the market today?

1 LESS THAN $40,000
2 $40,000 - $60,000
3 $60,000 - $80,000
4 $80,000 - $100,000
5 $100,000 - $150,000
6 MORE THAN $150,000
7 I DO NOT OWN MY CURRENT RESIDENCE

M-7 What is the last grade of formal education you have completed?

1 LESS THAN HIGH SCHOOL
2 HIGH SCHOOL GRADUATE
3 SOME COLLEGE
4 COLLEGE GRADUATE
5 MASTERS DEGREE
6 DOCTORATE

M-8 Which of the following groups includes your total household income for the last year?

1 LESS THAN $20,000
2 $20,000 - $30,000
3 $30,000 - $40,000
4 $40,000 - $60,000
5 $60,000 - $80,000
6 $80,000 - $100,000
7 MORE THAN $100,000

Is there anything else you would like to tell us about how you or other residents might respond to water conservation measures? Is there any way in which they can be made more acceptable? Your comments are welcome and will be considered.

Your contribution to this effort is very greatly appreciated!
Please remember to mail your survey in the pre-addressed, postage-paid envelope.

APPENDIX B

EXAMPLE CALCULATIONS OF NET PRESENT VALUE AND BENEFIT-COST RATIO

EXAMPLE CALCULATIONS OF NET PRESENT VALUE AND BENEFIT-COST RATIO

As a simple example of the use of the NPV method, suppose that a water utility wants to study the viability of implementing a full-scale voluntary retrofit of its 48,000 single-family residential customers over a planning horizon of five years. Suppose also that an in-depth analysis of benefits and costs of the project has yielded the following information:

UTILITY COSTS

(1) $265,000 in implementation and administrative costs during the year of implementation and $6,000 each year after full implementation for delivery and installation of additional equipment that is expected to be requested by utility customers

(2) Water and wastewater revenue loss based on expected program coverage and expected attrition of retrofit devices:

$100,000 during year of implementation
$470,000 during second year
$466,000 during third year
$456,000 during fourth year
$440,000 during fifth year of planning horizon

UTILITY BENEFITS

(1) Decreased costs of water purification and pumpage and wastewater treatment:

$40,000 during year of implementation
$72,000 during second year
$55,000 during third year
$53,000 during fourth year
$51,000 during fifth year

(2) Based on expected total water savings, by the fourth year after the full single-family retrofit, the utility will be able to defer, for three years, expansion of the utility water treatment plant.

Deferral costs savings: $3,000,000

DISCOUNT RATE

(1) The opportunity cost of implementation and administrative funds is equal to the rate of return the utility would be earning at the local bank.

(2) Local annual interest rates are expected to remain stable at 10 percent over the five-year planning horizon.

NET PRESENT VALUE

With this information, use of the NPV formula (Equation (4.12)) becomes straightforward. The calculations assume that program implementation is to begin in the first year (i.e., t_1). Therefore, by incorporating expected benefits, costs, and the discount rate, the NPC can be calculated as

$$NPV = \frac{(40{,}000 - 265{,}000 - 100{,}000)}{(1 + 0.10)} + \frac{(72{,}000 - 470{,}000 - 6{,}000)}{(1 + 0.10)^2}$$
$$+ \frac{(55{,}000 - 466{,}000 - 6{,}000)}{(1 + 0.10)^3} + \frac{(53{,}000 - 456{,}000 - 6{,}000)}{(1 + 0.10)^4} \qquad (4.12)$$
$$+ \frac{(51{,}000 + 3{,}000{,}000 - 440{,}000 - 6{,}000)}{(1 + 0.10)^5} = \$1{,}083{,}977$$

From the utility's perspective, the NPV formulation indicates that the utility should invest in the retrofit project.

BENEFIT-COST RATIO

This example may be extended to illustrate the use of the benefit-cost ratio criterion for evaluating conservation projects. Using the same data as described above, total discounted benefits and discounted costs may be calculated as follows.

Sum of discounted benefits =

$$\sum_{t=1}^{5} \frac{B_t}{(1 + i)^t} = \frac{40{,}000}{(1 + 0.10)^2} + \frac{72{,}000}{(1 + 0.10)^3} + \frac{55{,}000}{(1 + 0.10)^4} + \frac{53{,}000}{(1 + 0.10)^5} + \frac{3{,}051{,}000}{(1 + 0.10):}$$
$$= \$3{,}266{,}560$$

Sum of discounted costs =

$$\sum_{t=1}^{5} \frac{C_t}{(1 + i)^t} = \frac{365,000}{(1 + 0.10)} + \frac{476,000}{(1 + 0.10)^2} + \frac{472,000}{(1 + 0.10)^3} + \frac{462,000}{(1 + 0.10)^4} + \frac{446,000}{(1 + 0.10)^5}$$

$$= \$2,182,583$$

Benefit-cost ratio =

$$\frac{\sum_{t=1}^{5} \frac{B_t}{(1 + i)^t}}{\sum_{t=1}^{5} \frac{C_t}{(1 + i)}} = \frac{\$3,266,560}{\$2,182,583} = 1.497$$

With a benefit-to-cost ratio greater than 1, the utility should undertake the retrofit project as in the preceding example.

APPENDIX C

CASE EXAMPLES OF THE USE OF THE COMPARISON OF MEANS METHOD

CASE EXAMPLES OF THE USE OF THE COMPARISON OF MEANS METHOD

EXAMPLE 1

An analysis of water savings attributable to a pilot residential retrofit program that conformed to the treatment/control evaluation design was undertaken for the city of Tampa, Florida (Kiefer and Davis, 1991). All water use accounts that remained active between January 1989 and December 1990 were matched with mail survey data from a sample of treatment and control households. Average annual water use per household was derived from a sample set of 1,363 households. Out of this group, average annual water use was calculated for 1,085 treatment households and 278 control households. The table below shows annual average household water use for each group in gallons per day (gpd) before and after the retrofit program; standard deviations are in parentheses.

	Preretrofit 1989	**Postretrofit 1990**	**Difference**
Treatment (n=1085)	228.412 (157.116)	192.030 (130.396)	36.382
Control (n=278)	247.365 (182.783)	212.845 (153.502)	34.520
Difference	-18.953	-20.815	1.862

Mean water use in the treatment group was below that of the control group in both pre- and posttest periods. Using the t-test procedure, explained in **Step 7**, mean water use in the treatment and control groups were compared for both periods in order to deduce whether these differences were attributable to chance or if the two samples came from populations of unequal means. The standard error of the difference between the treatment and control means and the subsequent t-statistics were calculated as follows:

Preretrofit

$$S_d = \sqrt{\frac{(1084)(157.116)^2+(277)(182.783)^2}{(1363-2)}\left(\frac{1363}{(1085)(278)}\right)} = \sqrt{119.572} = 10.935$$

$$d_{pre} = q_t - q_c = -18.953$$

$$t = \frac{-18}{10} = -1.72$$

where

Based on a critical t-value of ±1.96 for a <u>two-tailed</u> test at a significance level of 0.05, the hypothesis that the two means were essentially the same during the preretrofit period could not be rejected. In other words, the observed difference in the mean of the two samples was not large enough to conclude that water use in the two groups differed.

Postretrofit

$$S_d = \sqrt{\frac{1084(130.396)^2 + 277(153.502)^2}{1361}\left(\frac{1363}{(1085)(278)}\right)} = \sqrt{82.866}$$
$$= 9.103$$

$$d_{post} = q_t - q_c = -20.815$$

$$t = \frac{-20}{9} = -2.29$$

Based on a critical t-value of -1.64 for a <u>one-tailed</u> test at a significance level of 0.05, the hypothesis that the means of the treatment and control groups were the same during the post-retrofit period must be rejected.

It was therefore concluded that even though average water use for both groups had declined over the two time periods under study, water use in the treatment group had declined <u>more</u> than water use in the control group, and that this difference was attributable to other than chance. The subsequent difference in water use of 1.9 gpd could be taken to be a measure of the reduction in water use due to the retrofit, given that the two groups reacted similarly to other external factors that occurred during the study periods.

EXAMPLE 2

Because the water savings that were derived in Example 1 seemed to be much smaller than expected, and because not all of the households in the participant group actually received conservation kits, a similar analysis was done comparing mean water use of households that received kits to those that did not. The table below shows mean annual household water use (in gpd) for these groups during the pre- and posttest periods; standard deviations are in parentheses.

	Preretrofit 1989	**Postretrofit 1990**	**Difference**
Received kit (n=918)	228.360 (155.743)	190.817 (129.205)	37.543
Did not receive kit (n=385)	241.142 (178.558)	212.422 (148.731)	28.720
Difference	-12.782	-21.605	8.823

The preretrofit t-statistic for the differences in the means was calculated as -1.29. Thus, the hypothesis that the mean water use of the two groups was essentially the same prior to the retrofit could not be rejected at the 0.05 level.

The postretrofit t-statistic was computed to be -2.63 and, thus, fell well outside of the acceptance region for the hypothesis that mean water use in the two groups was essentially the same during the postretrofit period. The results implied a household water savings of approximately 8.8 gpd because of the retrofit program.

APPENDIX D

CASE EXAMPLES OF SIMPLE LINEAR REGRESSION

CASE EXAMPLES OF SIMPLE LINEAR REGRESSION

EXAMPLE 1

The following example is drawn from an analysis of water savings attributable to a retrofit of a community in the Southeast United States. The evaluation of conservation savings followed a treatment/control design.

Average annual water use per account in the posttest period (including both treatment and control groups) was taken to be a function of average annual water use per account in the pretest period and a binary variable representing the differences between the two groups. The binary variable was assigned a value of one if the customer was a member of the treatment group and zero, otherwise. This explicitly captured the effects of the retrofit. Water use in each billing period for each account was averaged across billing periods in both the pre- and posttest periods, yielding 1,726 observations for each test period. Any account that had zero water use for the entire pretest period, the entire posttest period, or both periods was deleted from the data set, reducing the number of observations to 1,721. The model used in the analysis was

$$Q_{POST} = a + bQ_{PRE} + cTRT$$

where

Q_{POST} = average annual water use for each account in the posttest period
Q_{PRE} = average annual water use for each account in the pretest period
TRT = binary variable capturing the effects of the retrofit program

External factors were assumed to affect both the treatment and control groups equally, and were not included in the model. The results of ordinary least squares (OLS) applied to this model are provided in the table below. Water savings due to the retrofit were estimated at 426.1 gallons per billing period per household, or 7.0 gpd per household (based on 60.8 days per billing period), as given by the coefficient on the binary variable intended to capture the effects of the retrofit. This coefficient was found to be statistically significant.

Dependent Variable: Q_{POST} Parameter	Estimate	T for HO Parameter = 0	PR > |T|	Std. Error of Estimate
INTERCEPT	1.3911	7.31	0.0001	0.190
Q_{PRE}	0.8744	76.63	0.000	0.011
TRT	-0.4261	-2.40	0.0163	0.177

R-square = 0.774. Root MSE = 3.67.
F-value = 2942.69. N = 1,721.

Water use expressed in 1,000 gallons per account per billing period.

EXAMPLE 2

This example is drawn from an evaluation of a pilot retrofit program in Tampa, Florida (Kiefer and Davis, 1991). The following simple regression procedure was utilized as the first alternative to the comparison of means method that was shown as an example in Appendix C.

Average annual water use was calculated for the preretrofit (calendar year 1989) and post-retrofit (calendar year 1990) periods for each of 1,363 accounts. Average water use per account in the postretrofit period was then taken to be a function of the average water use in the preretrofit period, and a binary variable that designated each account as a participant or control group member. If an account was part of the participant group, the binary variable received a value of one, otherwise the binary variable was set to zero. Hence, the simple linear model

$$Q_{POST} = a + bQ_{PRE} + cPARTICIPANT$$

where

Q_{POST} = average annual water use for each account in 1990
Q_{PRE} = average annual water use for each account in 1989
PARTICIPANT = binary variable capturing the effects of the retrofit program

The model was estimated using ordinary least squares (OLS). The results are shown in the table below. The parameter estimate for the binary variable implies a water savings of 8.1 gpd per household as a result of the retrofit. However, the estimated coefficient is significant only at about the 0.14 level. This falls outside the customary 0.05 level of acceptability.

Dependent variable: Average annual 1990 water use per account (1,000 gal/month)

Parameter	Estimate	T for HO: Parameter = 0	Pr > | T |	Std. Error of Estimate
INTERCEPT	1.3709	7.88	0.0001	0.1739
AVG Q89	0.6782	51.82	0.0000	0.0131
PARTICIPANT	-0.2421	-1.51	0.1323	0.1608

R - square = 0.6651 Root MSE = 2.3892
F - value = 1350.27 N = 1363

EXAMPLE 3

In order to improve on the results shown in Example 2, above, the same regression procedure was applied to those households that either did or did not receive retrofit kits. Omission of those respondents who did not live in Tampa at the time and those who could not recall receiving a kit, resulted in a set of 1,303 observations for each time period. The table below shows the results of the simple linear regression procedure. The estimated coefficient for the binary variable GETKIT indicates an average annual water savings per household of 391 gallons per month, or 13 gpd. This coefficient is statistically significant at the 0.05 level. As in the previous example, water use in the preretrofit period is a highly significant predictor of water use in the post retrofit period.

Dependent variable: Average annual 1990 water use per account (1,000 gal/month)

Parameter	Estimate	T for HO: Parameter = 0	Pr > | T |	Std. Error of Estimate
INTERCEPT	1.4389	9.43	0.0001	0.1526
AVG Q89	0.6847	52.47	0.0000	0.0130
GETKIT	-0.3910	-2.76	0.0059	0.1416

R - square = 0.6810. Root MSE = 2.3309.
F - value = 1387.35. N = 1,303.

APPENDIX E

CASE EXAMPLES OF MULTIPLE REGRESSION APPLICATIONS

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EXAMPLE 1

As part of an analysis of water use in Tampa, Florida (Kiefer and Davis, 1991), multiple regression was utilized to detect which variables significantly affected average monthly household water use over a 38- month time period between December 1987 and January 1991. Variables for which time series data were available included average daily temperature, average daily maximum temperature, monthly rainfall, and marginal price. Three binary variables were included to capture the effects of three events that had taken place within the study period: a retrofit program, a water conservation surcharge, and daytime watering restrictions. Each of these binary variables was coded as one for each month in which its effects would have been felt, and zero otherwise.

The *stepwise* ordinary least-squares regression technique was used to generate a multiple regression model that best explained changes in average monthly water use from the independent variables available for analysis. The stepwise technique introduces one variable at a time into the regression model (hence, "stepwise") but then omits those independent variables that do not meet a minimum explanatory significance criteria based on the F-statistic. The stepwise technique is available in many commercially available statistical software packages. The table below describes the model that was selected by the stepwise technique. The binary variable for surcharge, maximum daily temperature, and rainfall were found to be the most statistically significant variables for explaining average monthly water use. Unfortunately, the effects of the December 1989 retrofit could not be determined, presumably due to the strong effects of the introduction of the surcharge just one month later. Interpretation of the parameter estimate for the surcharge suggests that, on average, monthly water use dropped 1,534 gallons per household (or 51 gallons per day) as a result of the surcharge. Some of this decline in water use may have been indirectly attributable to the retrofit.

The model R^2 indicates that a significant amount of the variance in average monthly household water use was left unexplained. The inclusion of a variable to detect the seasonal variation in water use, as well as other variables designed to detect underlying trends, might have improved the model results.

Dependent variable: **Average monthly household water use in sample (1,000 gal/month)**

Parameter	Estimate	T for HO: Parameter = 0	Pr > | T |	Std. Error of Estimate
INTERCEPT	2.2431	1.476	0.1491	1.5197
MAXDAY	0.0663	3.422	0.0016	0.0194
RAIN	-0.0897	-2.630	0.0127	0.0341
SURCHARGE	-1.5336	-5.676	0.0001	0.2702

R - square	= 0.5170.	Root MSE	= 0.75403.
F - value	= 12.129.	N	= 38.

EXAMPLE 2

This example continues the examination of techniques used to measure the water conservation savings stemming from a pilot retrofit program of single-family residences in Tampa, Florida. Time series household water use data were "pooled" with cross-sectional results of a mail survey to analyze water use within a multivariate linear regression framework.

Water use of the participant and control groups was examined for the 24-month period spanning January 1989 through December 1990. After adjusting for missing mail survey observations, a total of 27,528 pooled observations were analyzed by the following OLS model

$$Q = a + bRAIN + cMAXDAY + dPOOL + ePEPL + fINCOME +$$

$$gSURCHARGE + hMONTH + iPARTICIPANT$$

where

Q	=	monthly water use per account
RAIN	=	total monthly rainfall (inches)
MAXDAY	=	average maximum daily temperature (degrees fahrenheit)
POOL	=	binary variable assuming a value of 1 if the household has a pool
PEPL	=	number of persons per household
INCOME	=	annual household income (dollars)
SURCHARGE	=	binary variable capturing the effects of the conservation surcharge
MONTH	=	month for which water use in analyzed
PARTICIPANT	=	binary variable capturing the effects of the retrofit on the participant group

Marginal price was not incorporated into the multiple regression framework because of the effects of the city of Tampa's changing water rate schedule. Before October 1989, all households were charged a uniform rate of $2.95 per 1,000 gallons (including sewer charges). For the months of October through December 1989, the marginal price increased to $3.17 per 1,000 gallons, again for *all* households. Therefore, because everyone faced an identical price through the end of 1989, the marginal price for water did not explain any of the variance in water use between households. In January 1990, a water conservation surcharge of $0.48 per 1,000 gallons was imposed on the households inside the city that were using more than 9,724 gallons of water per month. Thus, beginning in this month, the marginal price faced by water consumers became a function of the quantity of water they consumed. The estimation of a model for water use in which all households face the same price, and then suddenly face a higher marginal price because of higher consumption, results in a positive coefficient for the marginal price variable. This, of course, is contrary to economic reasoning. For this reason, the binary variable SURCHARGE was included to pick up the conservation effects of marginal price changes occurring after January 1, 1990.

The table presented below contains the results of the multiple regression model for the participant and control groups. The binary variable PARTICIPANT was designed to detect the effects of the retrofit. Interpretation of the estimated coefficient implies a water savings of approximately 22.3 gpd per account (668.7/30). The coefficient is highly significant. In fact, all of the independent variables included in the model are statistically significant and have the expected signs. The coefficient of the binary variable that captures the effects of the conservation surcharge implies a reduction of 25.1 gpd per household due to the surcharge.

Dependent variable: Monthly water use per account (1,000 gal/month)

Parameter	Estimate	T for HO: Parameter = 0	PR > |T|	Std. Error of Estimate
INTERCEPT	-0.3867	-0.97	0.3334	0.3998
RAIN	-0.0579	-6.77	0.0001	0.0086
MAXDAY	0.0541	11.07	0.0001	0.0049
POOL	1.5825	16.74	0.0001	0.0945
PEPL	0.9485	36.90	0.0001	0.0257
INCOME	0.0001	46.57	0.0000	0.0000
SURCHARGE	-0.7525	-6.27	0.0001	0.1201
MONTH	-0.0403	-4.74	0.0001	0.0085
PARTICIPANT	-0.6687	-9.39	0.0001	0.0712

R - square = 0.1905. Root MSE = 4.7853.
F - value = 809.63. N = 27,528.

The statistical significance of the month variable suggests that there exists a downward trend in water use over the 24-month period that was not explained by the other variables. It was thought that water use restrictions imposed by the Southwest Florida Water Management District would explain part of this downward trend, since restrictions on daytime lawn watering were imposed throughout the study period. In order to explore the possible effects of these restrictions, multiple regression models were estimated using binary variables to capture the effects of the changes in restrictions. The results indicated a weak, but statistically *insignificant*, effect on household water use. Based on the statistical criterion of significance, the restriction variable was omitted from the model described above.

In order to investigate the model's validity, elasticities of water use with respect to the continuous variables in model were calculated. As the following table indicates, the elasticity of water use with respect to each variable was reasonable and found similar to various other studies of water demand. The coefficient for the binary variable POOL seemed reasonable as well, implying an additional water usage of 52.8 gpd for those households having a swimming pool.

DERIVED ELASTICITIES OF MULTIPLE REGRESSION MODEL (PARTICIPANT/CONTROL GROUPS)

Mean Water Use: 6.4980 (1,000 gal/month)

Variable	Mean	Derived Elasticity*	Typical Elasticity
RAIN	4.5442	(-0.0579) x (4.5442/6.498) = -0.04	-0.01 to 0.12
MAXDAY	83.05	(0.0541) x (83.05/6.498) = 0.69	0.50 to 1.50
INCOME	27,851.66	(0.0001) x (27,851.66/6.498) = 0.43	0.30 to 0.60
PEPL	2.2910	(0.9485) x (2.2910/6.498) = 0.33	0.20 to 0.70

*Elasticity can be derived from linear models by using the following general formula

$$\text{(estimated coefficient)} \times \left(\frac{\text{mean of independent variable}}{\text{mean of dependent variable}}\right)$$

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