WATER SUPPLY RELIABILITY IN CALIFORNIA:
HOW MUCH DO WE HAVE?
HOW MUCH DO WE NEED?

Phase 1
Setting the Stage: Defining, Measuring, and Setting Goals for Water Supply Reliability

CALIFORNIA URBAN WATER AGENCIES

January 1992

Prepared by
BARAKAT & CHAMBERLIN, INC.
Oakland California

CALIFORNIA URBAN WATER AGENCIES
WATER SUPPLY RELIABILITY PROJECT
Phase 1

TABLE OF CONTENTS

WATER SUPPLY RELIABILITY IN CALIFORNIA: HOW MUCH DO WE HAVE? HOW MUCH DO WE NEED?

Phase 1

Setting the Stage: Defining, Measuring, and Setting Goals for Water Supply Reliability

I. INTRODUCTION

The ongoing California drought has focused people's attention on the state's water supply crisis. The drought has led to widespread water supply shortfalls in most parts of the state. In many instances, water supply agencies have been forced to impose severe rationing to reduce demands to the level of available supplies. These shortfalls have affected all types of water demands. Landscapes have died, manufacturers have had to live with reduced allocations, fields have gone fallow, and environmental impacts have been severe. Several studies have indicated that the drought has probably affected the state's economy.[1]

Agencies and consumers have responded to the crisis with many creative water management techniques. Several pieces of legislation have been introduced in Sacramento and in the U.S. Congress that could change the basic structure within which

---

[1] See, for example:

- California Urban Water Agencies, "Cost of Industrial Water Shortages". Prepared by Spectrum Economics, Inc. November 1991
- "Urban Values for Reliable Water Supplies". Presentation to Economics Work Group of the State Water Resources Control Board by William W. Wade. October 1991
- California Department of Water Resources, "Department of Water Resources Survey on the Third-Party Impacts of Sales to the State Water Bank". June 1991

water is allocated and managed in the state. Water policy issues are increasingly being addressed by politicians, a variety of water negotiating groups, and the courts. Water has also become a favorite subject for the broadcast and print media.

While many of the actions taken are directly drought-related, many are attempts to address California's longer term water problems, which extend well beyond the current crisis. Forecasts of water supply and demand in the state show that future water shortages to all sectors will occur with increasing frequency. Rapid urban growth in the state, coupled with essentially static or diminishing available water supplies, ensure that water demand is outstripping available supplies. As a result, policymakers and water agency managers are exploring myriad long-term options to bridge this gap, including supply-side and demand-side alternatives.

It is generally recognized that one outcome of the current and forecasted supply shortfalls is a degradation of water supply reliability to all sectors. As a result, discussions about California's water crisis increasingly include references to water supply reliability. There is, however, no consensus on what "water supply reliability" means, how to measure it, how much of it we have, and how much of it we *should* have.

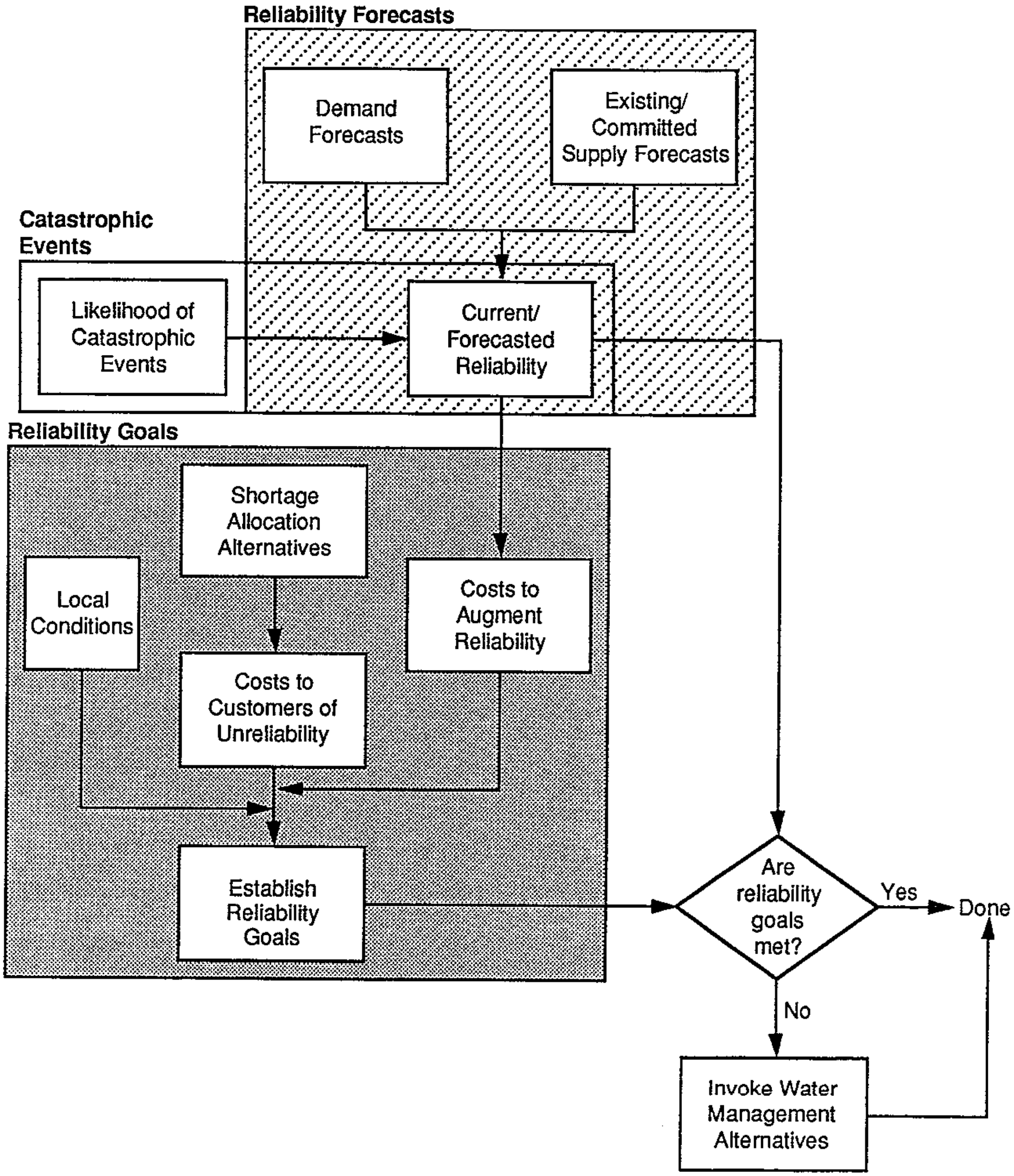
California Urban Water Agencies (CUWA) has recognized for some time the critical nature of those questions. In January 1991, CUWA, in association with the California Municipal Utilities Association and the Water Education Foundation, sponsored a conference on water supply reliability.[2] The conference began a process of systematizing the way in which California water suppliers and policymakers look at reliability. Partly as a result of that conference and partly as a result of the increasingly critical nature of water reliability issues in the state, CUWA has undertaken this study of urban water supply reliability in the state.

The project will focus on issues that are of statewide and regional interest, rather than those that are more local concerns. For example, it will exclude the questions of distribution system reliability, including distribution storage, which are critical to water purveyors. Moreover, local conditions differ and it is likely that reliability goals and the

---

[2] For a discussion of the conference, see "Water Supply Reliability" in Western Water, March/April 1991.

Figure I-1
A Generic Reliability Planning Framework



1411.CUWA.ap

specific processes used to derive them will also differ among local agencies. Thus, the project will not prescribe a particular approach that state or local agencies should use to conduct reliability planning. Instead, it will develop a framework that is adaptable to local circumstances.

The importance of urban water supply reliability extends well beyond the state's urban areas. The level of urban reliability not only affects urban residential, commercial, and industrial water customers, but also agriculture and the non-urban environment. It is also becoming linked to statewide growth management issues. Recognizing the importance of the issue, CUWA has established a broadly representative Project Advisory Committee to oversee this project. The breadth of the group will ensure maximally useful products from the effort. (The members of the Committee are listed in Appendix A.)

Figure I-1 presents a general utility reliability planning framework. This framework applies equally well to water supply and other "infrastructure" utility services. As Chapter II will discuss, there is substantial variation in the way that local water agencies incorporate reliability concerns into their planning processes. Agencies may undertake the steps depicted in Figure I-1 in a more or less explicit fashion. However, a sound planning process will compare supply and demand forecasts to derive estimates of system reliability. These estimates will then be compared to some reliability goal and, if the goal is not forecast to be met, some least-cost combination of supply-side and demand-side alternatives will be developed to achieve the desired level of reliability.

As indicated by the shaded portions of Figure I-1, the initial phase of this project focuses on two particular portions of the planning process:

- Measuring current and forecasted reliability as it is affected by supply/demand relationships; and
- Setting reliability goals.

This project may address planning for the risks of catastrophic events in a subsequent phase.

The study is being done in several phases; this document reports the results of Phase 1, which sets the stage for the remaining work by developing a sound conceptual base. The specific objectives of Phase 1 are to:

- Define water supply reliability and related concepts.
- Discuss the applicability to water utilities of the way energy utilities define, measure and optimize reliability.
- Develop meaningful and consistent indices to measure water supply reliability.
- Set forth a framework within which to determine urban water supply reliability goals.
- Explore how shortage management techniques are related to reliability planning.

Phase 2 will begin the process of developing tools and data upon which conclusions and recommendations regarding state urban water supply reliability can be based. The contents of Phase 2 are described in detail in Chapter VIII.

II. HOW CALIFORNIA URBAN SUPPLIERS DEAL WITH RELIABILITY

To better understand how urban suppliers currently deal with the issue of supply reliability, we administered a brief survey to CUWA members. The survey was designed to evaluate how water supply reliability is defined, measured, and incorporated into current agency planning and communications. (The questionnaire is included as Appendix B). Not surprisingly, the survey reveals that agencies do not define or measure water supply reliability in a uniform manner. Survey responses revealed three distinctly different ways that water supply reliability is defined and measured:

- **Reliability to meet short-duration local emergencies.** The critical index here is the quantity of local storage available to meet sudden, localized catastrophes, such as a distribution system failure or a fire. Reliability goals for agencies that defined reliability in this fashion range from 12 hours to 10 days of locally stored water. (As discussed in Chapter I, this is not the thrust of Phase 1 of this study.)

- **Reliability to meet medium-duration delivery system emergencies.** Some respondents strive to maintain local storage to serve demand over a more extended period during which imported supplies might be unavailable due, for example, to seismic or other disruptions. Goals ranged from 2 months to 7 months of storage, and may be based on an assumed reduction (e.g. 25%) in demand. (This is also not the focus of Phase 1.)

- **Reliability to meet long-term demands.** Here, the concern is the long-term relationships between supply and demand. Quantified goals included "100% reliability in dry year periods," "maximum 20-25% shortage," and "25% shortage in worst-case drought." One respondent quantified the acceptable shortage in terms of long-term average and critical year shortage magnitudes. Others presented more qualitative indices, such as "meeting water needs during critical periods" and "[providing] reliable supply over long-term average hydrologic conditions." One respondent discussed expressing reliability in terms of long-term probabilities of particular shortage magnitudes.

Respondents split fairly evenly between those who mentioned planning for catastrophic events vs. long-term supply planning. They mentioned planning for dry periods more often than they mentioned average year planning. They were divided evenly on whether they view reliability in terms of components of the supply system (e.g. transmission or distribution lines) or in customer impact terms.

When asked about the most serious customer impacts resulting from a potential future lack of reliability, the major concerns cited were the impacts on business stability and growth. More specifically, this includes production losses, employment losses, possible commercial and industrial relocation, and reductions in tourism. For residential customers, loss of landscaping and inconvenience were most often mentioned. Property values tied to landscaping were also of concern. For all customer classes, respondents were also concerned about diminished confidence in the water system. Also mentioned was diminished fire protection capabilities, and threats to human health and safety.

When shortages occur, responding agencies generally manage them by increasingly severe levels of rationing. In many instances, required rationing levels vary among customer classes (e.g. requirements for industrial rationing may be less severe than those imposed on residential customers). In some cases, specific uses (e.g. outdoor watering) are limited or curtailed. At least one respondent makes an optional interruptible water supply available at lower cost in exchange for higher levels of rationing during times of shortage.

The discussions in succeeding chapters will address many of the issues raised by survey respondents. The survey responses indicate that the definition and measurement of water supply reliability and the manner in which reliability is incorporated into planning vary considerably among local suppliers. Not only is this not surprising, but it is as it should be. Local conditions and needs differ, so no single approach will work in all situations. It bears repeating that the goal of this project is to develop a framework that will assist state and local agencies to address the reliability issue in a more systematic fashion, but will also be able to accommodate local variation.

III. DEFINITIONS OF TERMS

A prerequisite to reasoned discussion of water supply reliability is a common language. Many terms are used, often interchangeably, and occasionally erroneously, to define the various activities and concepts that relate to water supply reliability. The following set of definitions is logical and internally consistent, and sets the stage for the remainder of this project. It is hoped that these definitions can be adopted as a standard among water policymakers and managers in the state to avoid the language barriers endemic to this type of endeavor.

The recommended definitions are as follows:

Full-Service Demand. The total demand for water under the conditions existing in a particular period without mandatory rationing or other short-term water-use reductions, but reflecting the results of Demand-Reducing Measures.

Demand-Reducing Measure. Any long-term measure intended to reduce the consumer demand for potable or non-potable water. Water reclamation may be considered a demand-reducing measure; alternatively, it may be considered as a portion of the "available supply" (see following definition).

Available [Urban/Agricultural/Environmental] Supply. The total volume of water expected to be available in a particular period for [urban/agricultural/environmental] uses from statewide, regional, and local sources. This may include reclaimed water; alternatively, such water may be considered as a reduction in demand.

Water Supply Reliability. The degree to which water consumers receive their Full-Service Demand within acceptable quality and service standards. [NOTE: Initially, this project will focus on <u>quantity</u> issues and assume that water quality and service are within acceptable standards.]

Reliability Goal. The optimum level of water supply reliability, as defined by reliability planners. Formalized or codified goals are often termed "standards".

Reliability Planning. A process to develop supply and demand forecasts and resulting forecasts of reliability, to define reliability goals, and to specify the combination of actions necessary to achieve these goals.

Shortage. A situation, due to drought or other causes, in which some or all consumers do not receive their Full-Service Demand over some extended period of time.

Outage. A situation in which, due to an unpredictable natural or man-caused event, some or all consumers do not receive *any* water over some period of time.

Shortage Management Planning. A process to develop policies and procedures to be utilized in the event of future shortages.

Outage Management Planning. The development of policies and procedures to be utilized in the event of unpredictable sudden supply disruptions arising from natural or man-caused events.

Contingency Planning. An umbrella term that includes shortage planning and outage planning.

IV. ENERGY UTILITY APPROACHES TO RELIABILITY

It is instructive to examine how energy utilities measure and plan for supply reliability. Energy utilities, particularly electric utilities, have been systematically dealing with the issue for some time. Water suppliers can learn much from the energy experience. However, there are some critical differences among natural gas, electric, and water reliability. Care is therefore called for.

Since the major goal of reliability planners is to avoid episodes of "unreliability," a clear understanding of water supply reliability (or, for that matter, reliability of any utility service) requires an understanding of these episodes. When viewed in that fashion, it is clear that water supply reliability is qualitatively different from reliability for other utility services. Indices to measure the level of water supply reliability must reflect those differences.

For example, the type of event that electric utility planners strive to avoid is a total outage (or "blackout"), in which customers experience a complete absence of electric service for some period of time.[3] Water customers rarely experience such an outage, other than as a result of some catastrophic event or local distribution system problem. As will become clear in subsequent chapters, this study focuses on measuring and setting appropriate goals for water shortages, in which customers do not receive their Full-Service Demand.

Following are brief discussions of key reliability issues for three types of energy utilities.

Thermal Electric Utilities

Electric utilities that rely primarily on thermal generation seek to avoid outages that are generally due to capacity constraints and the resulting inability of the generation system to meet peak demands. Since electricity generally cannot be stored, these outages occur

---

[3] Such outages may be immediately preceded (and hopefully avoided) by the imposition of rotating brownouts (voltage reductions) or blackouts, which are a form of real-time forced rationing.

in real-time and typically cannot be forestalled by prior curtailments or other demand-side management techniques. Water shortages, on the other hand, can normally be forecasted well in advance and therefore do not have the immediacy of electric outages. They can at least be mitigated by various water management techniques.

The indices that thermal electric utilities have historically used to measure reliability reflect these characteristics. "Loss of load probability" (LOLP) measures the frequency with which a peak-demand-related outage as described above will occur.[4] Since electric outages are either "on or off", resource planners require an index that measures the expected frequency of such an event. LOLP is such an index.

Natural Gas Utilities

Natural gas is similar in many ways to water:

- Both are fluids which can be stored.
- System reliability is closely related to the weather. In the case of natural gas, the key weather variable is temperature (which influences demand); water supply reliability is, of course, most affected by the impact of precipitation on water supply.
- Demand is highly seasonal.

There are also some important differences:

- Natural gas utility reliability planning must be concerned with the public safety issues related to residential outages and relighting of pilot lights.
- Natural gas storage volumes are typically not carried over from year to year.
- As is the case with thermal electric systems, natural gas outages in California are almost always due to capacity constraints (related to peak loading). Constraints on water are almost always related to lack of supply.

---

[4] As will be discussed in Chapter V, LOLP is a poor measure of reliability as viewed by the customer.

- Quality is a much more critical issue for water suppliers than for natural gas suppliers.

Therefore, gas "unreliability events" have some of the characteristics of electric outages and some of the characteristics of water shortages. They have more immediacy and occur more in real-time than do water shortages, but the availability of storage enables system operators to anticipate problems and, to some extent, spread their impact over time.

A typical gas utility might therefore have multiple reliability indices that reflect this duality. These could, for instance, estimate the expected unserved demand on the coldest anticipated "design" day, the expected peak year (or season) and the average year. In addition, because of the enhanced ability of gas utilities to manage shortages and direct their impacts to different customers, gas utilities have for many years distinguished between "core" (firm) and "noncore" (non-firm) customers. Core customers are those that have few if any alternatives to natural gas service (e.g. residential customers). These customers have highly reliable service for which they pay higher prices. Noncore customers include customers who do have alternatives and who therefore pay lower prices for less reliable service.

Hydroelectric Utilities

Hydroelectric and water supply utilities have much in common. Both are very sensitive to precipitation and both depend to a large extent on stored water. Moreover, the planning and operation of both must consider a variety of environmental impacts. Both types of systems are typically volume (energy) constrained, rather than capacity constrained.

Reliability planning for most hydroelectric utilities is based on **critical periods.** Under this model, reliability is measured by the ability to serve demand during a period that resembles some past "worst" period.

Critical period planning depends crucially on how the "critical period" is defined. Since the basic thrust of this approach is deterministic rather than probabilistic, most hydroelectric utilities are generally not concerned about the question of how frequently an event at least as severe as the "critical period" is likely to occur. In addition, since historical weather data is often limited, rigorous statistical studies have rarely been performed. One exception is a study done recently in the Pacific Northwest which concluded that a period worse than the designated "critical period" used in that region would occur approximately once every 45 years.

V. MEASURING WATER SUPPLY RELIABILITY

The following discussion adopts the fundamental premise that **water supply reliability should be viewed from the customers' side of the meter** (i.e. to what extent do customers receive their Full Service Demand?). This premise shapes the manner in which we propose to measure reliability. We will develop indices that measure the level of reliability as seen by customers, focusing on the direct and indirect customer impacts that result from a lack of water reliability.

Interestingly, the primary reliability index that is used by electric utilities does not assume this viewpoint. Loss of Load Probability measures the performance of the generation system. It has little to do with customer service reliability. From the customer's vantage point, this index is of limited use for at least two reasons:

- Between 80% and 90% of "unreliability episodes" actually experienced by customers are related to the distribution system. Transformer failures, cars colliding with poles, falling tree limbs, and storm damage are much more common than generation system failures. (This is not the case for large water supply systems, where most such episodes are due to supply shortfalls.)

- Even when there is a generation system failure, the close interconnection of most systems with neighboring systems almost always prevents outages, particularly for firm customers. Such backup capability has been markedly enhanced since the 1965 New York City blackout.

In fact, actual outages experienced by electric customers in California average from one to four hours per year. In other parts of the country, the experience ranges from two to eight hours. Electric service in this country is extremely reliable.

A complete description of water supply reliability in a region requires a specification of the manner in which future shortages are expected to occur. In other words, given the expected supply and demand characteristics of the system, what is the likelihood of shortages of various magnitudes? A convenient way to answer this question is through the use of probability distributions or, more precisely, **cumulative frequency distributions** (CFDs).

Figure V-1 illustrates one such distribution for a hypothetical system in a particular future year. The horizontal axis reflects increasingly severe levels of shortage (percentage unserved demand); the figures on the vertical axis represent the probability that a shortage will exceed particular levels. Thus, the height of the curve at any particular shortage level is the probability that the annual shortage in that future year will exceed that level. For example, the probability of an annual shortage exceeding 10% for this hypothetical system is about 40%.

We can embellish this framework by focusing on any subset of rainfall conditions. If, for example, we designate a particular set of years as "dry", we can display the cumulative frequency distribution for those years. Not surprisingly, as Figure V-2 illustrates, the likelihood of shortages increases in those years. Thus, for our hypothetical system, the probability of a shortage greater than 10% rises to approximately 85% in dry years.

The information embodied in such probability distributions describes the reliability of a water supply system as it is affected by supply/demand relationships. This is the type of information that water system planners need to do their jobs. Indeed, electric system planners utilize very complex probabilistic computer models that develop and manipulate similar types of information. However, probability distributions are difficult to explain and are not easily adapted to the public policy arena. Therefore, just as has been the case for other types of utilities, *summary indices are needed.* Water suppliers must define indices that summarize reliability characteristics in a fashion that is useful and easily communicated.

With that understanding, let us consider three possible water supply reliability indices:

1. **Probability of Shortage (POS).** The expected percentage of years in which full-service demand will exceed available supply (i.e. the probability of a shortage of <u>any</u> magnitude.)

2. **Probability of Designated Shortage (PODS).** The expected percentage of years in which the shortage will be greater than a particular percentage of

Figure V-1

Example of System Reliability Cumulative Frequency Distribution for a Specific Future Year

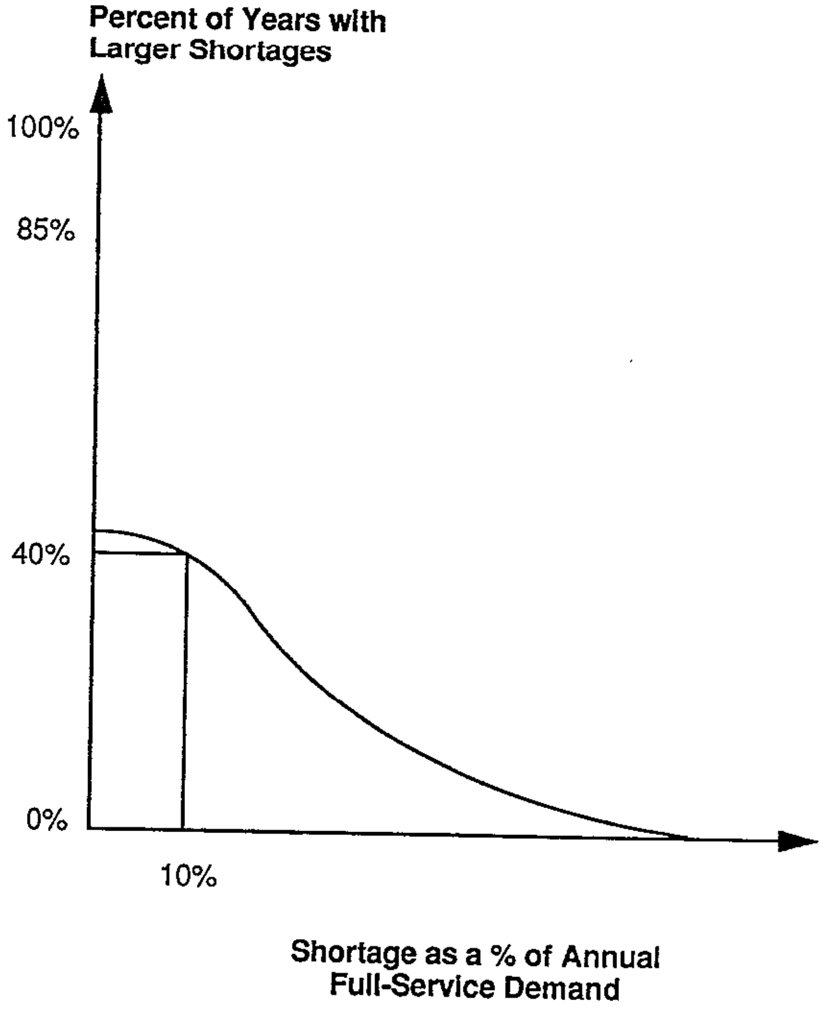
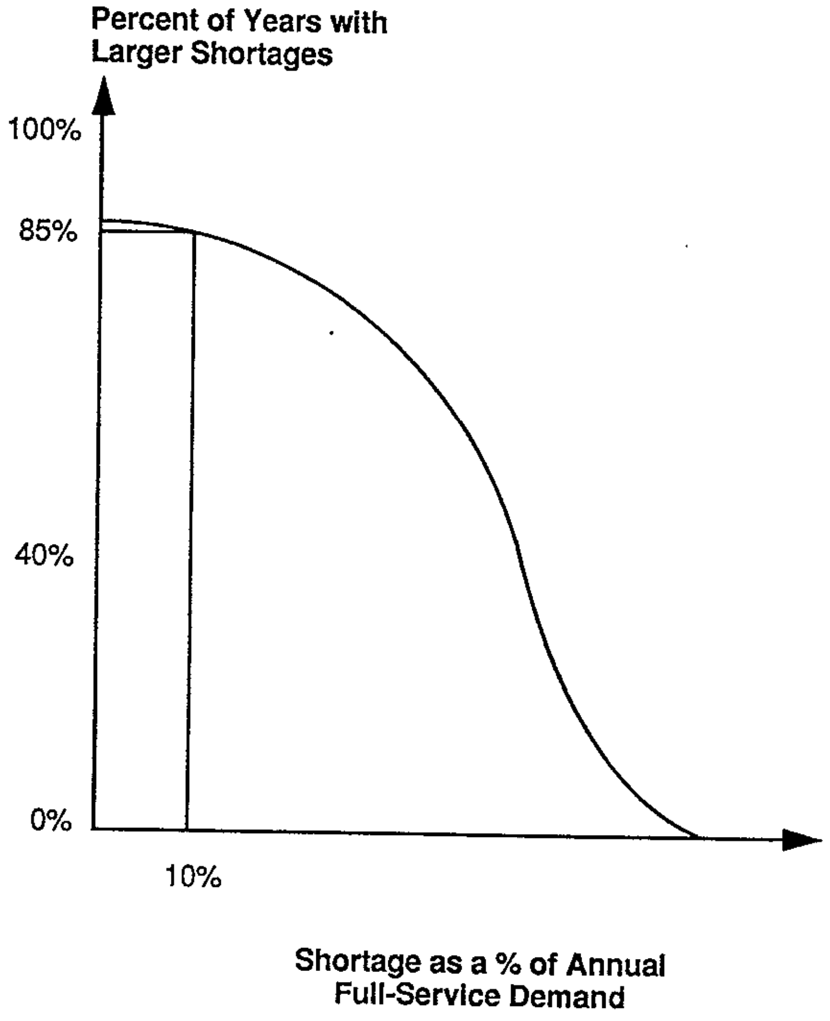


Figure V-2

Example of System Reliability Cumulative Frequency Distribution for a Specific Future Year Assuming Dry Conditions



1411.CUWA.sp

full-service demand. The previous index (POS) is a special case of this index, in which the designated shortage magnitude is zero.

3. **Expected Unserved Demand (EUD).** The expected percentage of full-service demand not served.

Each of these indices is stated for a particular current or future period. Each can be computed for any randomly selected rainfall condition or, as described above, for a subset of precipitation conditions. The magnitude of the indices and the shape and height of the CFD will depend critically on how these subsets are defined. For example, "dry years" may be defined as the lowest 10% of runoff years; alternatively, the lowest 25% of the years may be designated as "dry". The frequency distribution and the associated indices in the former case will be higher than in the latter case (i.e. the driest 10% of the years will have higher shortage probabilities than the driest 25%). Unless there is a common definition of "dry years", these curves can be misleading.

Of course, "dry years" are not the only subset of years that can be defined. Cumulative shortage frequency distributions can be presented for "wet years", "average years", "years after dry years", etc. In all of these cases, the subset of years for which reliability information is being presented must be clearly defined. Any such information may be useful to planners and other audiences as they attempt to better understand system reliability characteristics.

Discussion of Alternative Indices

Appendix C presents a simple example that illustrates the derivation of and relationships among these indices. For the simple example illustrated in Appendix C, only four or five points are needed to completely specify each of the CFDs. The specification of the reliability characteristics of a real-world system is considerably more complex and might depend on historic and/or synthetic hydrologic data, as well as population and economic growth forecasts (which themselves might be uncertain). Moreover, since supply and demand are likely not independent, the computation of shortage probabilities becomes more difficult. In any event, *there exists no single index which can convey the level of* *information that is conveyed by the entire distribution*. The question therefore boils down to which of these admittedly imperfect indices deserve our attention.

Unfortunately, there is no simple answer to that question. The answer will, in fact, vary with the use to which the index will be put. Statistically, the "expected value" index (EUD) has the property of conveying the most information on the distribution. This is because it does the best job of reflecting the dimensions of frequency ("how often do shortages occur?") and magnitude ("how big are they?"). EUD is also, in many ways, most amenable to setting reliability goals.

However, other indices are also useful. For example, POS (the likelihood of *any* shortage) is a simple way to show the magnitude of the problem. (In our hypothetical, the fact that there is a 30% likelihood of a shortage in any year may serve to drive home the seriousness of the situation.) Local conditions may dictate that a particular reliability threshold(s) is (are) critical, so that particular PODS indices may be important.

As long as one is mindful of the limitations discussed above, the dry-year indices provide potentially useful "worst case" information. They convey information about "how bad it can get". Thus, as long as the definition of "dry year" for our hypothetical system is clearly understood, the facts that the system will experience some shortage in *all* dry years and that, on average, close to one-fifth of the demand will be unmet in those years, are revealing.[5]

In short, all of these indices are potentially useful, depending on the context within which they are used. That there is no single index that can meet all analytical and informational needs is not surprising.

Nor are these indices the only possible ones that could be used and useful. Many others could be created and, indeed, may be required to communicate particular information. These, however, have the critical properties of conveying much of the information contained in the cumulative frequency distribution while not being overly arcane.

---

[5] This is not to say that water supply reliability planning should be based on dry years. Given the magnitude of anticipated shortages in California, it would be a mistake to cast the problem as a "dry-year problem" and to therefore seek "dry year solutions."

VI. THE "RIGHT" LEVEL OF RELIABILITY

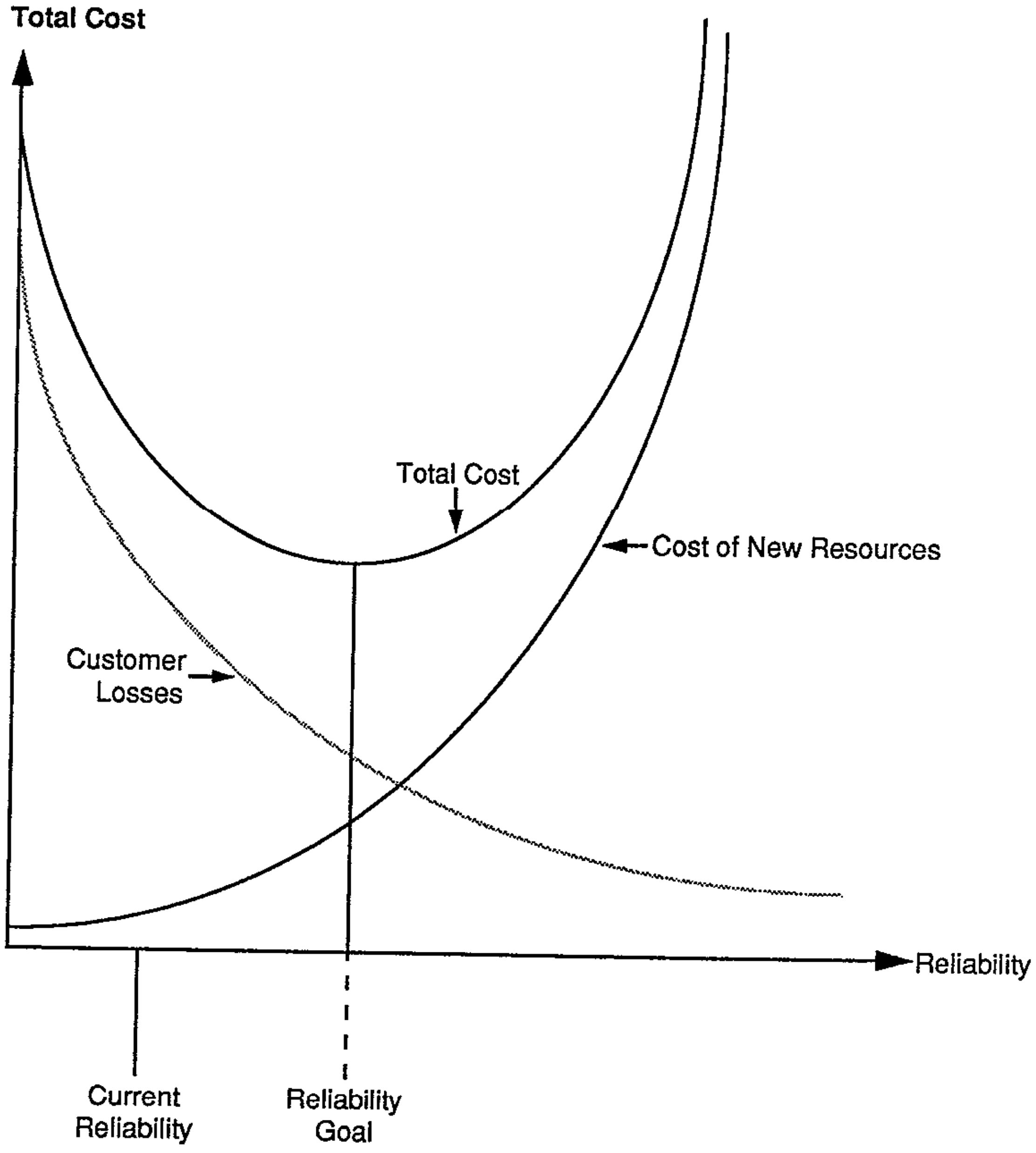
With these indices in mind, the next step is to develop a framework to determine the "right" level of reliability (i.e. appropriate reliability goals). Each supplier must ultimately make this determination based on local conditions. However, the basic notion that should govern these decisions is a balancing of the costs (monetary and otherwise) to customers of "unreliability" with the capital, operating, and other costs of enhancing reliability. In a sense, this extends the traditional concept of "least cost planning", which generally connotes an analytical structure to identify the least costly mix of supply-side and demand-side resources to achieve a particular level of reliability. Now, the least-cost notion is being extended to determine exactly what that level of reliability should be. Again it is instructive to draw on the experience of electric utilities. As pointed out above, the LOLP index measures the reliability of the generation system. Utilities and regulators have adopted standards on which planning and investment decisions are made. In California, the Energy Commission adheres to a standard of a one-day-in-ten-year LOLP. This standard is *not* based on any explicit notion of cost minimization. Rather, it is a "rule of thumb" that has developed over the years.

As pointed out above, California electric customers typically experience one to four outage hours annually. This level of service results from the many investment, operating and maintenance decisions made by electric utilities. Again, these practices have generally not resulted from a systematic attempt at cost minimization.

Figure VI-1 illustrates a least-cost reliability planning approach that can be used by water suppliers to identify the appropriate level of reliability (regardless of the particular reliability index we use). At each level of reliability, it costs something to "buy" an increment of improved reliability. As Figure VI-1 shows, the *total* cost increases at an increasing rate as system reliability increases (see curve labeled "cost of new

Figure VI-1

Determining the Water Supply Reliability Goal



1411.CUWA.sp

resources").[6] This is because resources are added in order of increasing cost. (Note that these new resources can be on the supply-side or the demand-side (e.g. conservation).)

At the same time, at any level of reliability, an improvement to that reliability is worth something to customers. The total cost of unreliability ("shortage cost") to customers will likely decrease at a decreasing rate as reliability increases (see curve labeled "customer losses"). This is another way of saying that, as service becomes more reliable, further reliability improvements add less to customers' "value of service".[7]

The appropriate reliability goal is that level that minimizes the sum of customer and supply costs. Thus, for the hypothetical system depicted in Figure VI-1, the "right" level of reliability is greater than its current level. This indicates that investments in reliability improvements should be made.

Chapter V pointed out that reliability can be measured in a variety of ways. The foregoing discussion has not been tied to any particular index of reliability. The cost-minimization approach described above applies regardless of which index is chosen. Put another way, the approach applies no matter what functional forms are used to specify customer losses and supply costs. However, the manner in which these functions are specified affects the complexity of the analysis, the collection of data, and, perhaps, the usefulness of the results to decisionmakers.

For example, losses and supply costs could be expressed as single-dimensional functions of Expected Unserved Demand (EUD) or of one of the designated shortage probabilities (PODS). Alternatively, customer losses and supply costs could be assumed to depend on

---

[6] Economists' presentations are often made in terms of "marginal" costs, rather than total costs. In that type of presentation, the optimal level of reliability would occur at the intersection of the marginal supply and loss curves. The two types of presentation are completely equivalent; the marginal cost curves are simply the first derivatives of the total cost curves. The optimal level of reliability is unaffected by the chosen form of presentation.

[7] Of course, different customer classes, and different customers within a class, will have different values of service. Also, as pointed out above, the manner in which shortages are managed (i.e. on which customers the burden falls) will affect the customer loss function. These issues will be addressed in Chapter VII.

both shortage frequency *and* magnitude. This latter specification is more complex and more difficult to estimate, but it has the potential of enabling system planners to better understand which of these dimensions (frequency or magnitude) is more important to customers; resource decisions can then be made accordingly.

Estimating Customer Value of Service

In many ways, the most difficult portion of conducting the type of analysis described above is the estimation of customers' value of service. This is because water supply reliability is not a commodity that is traded in an unregulated marketplace. Typically, sophisticated survey methods are used to collect this data.

Survey methods include **direct costing** and **contingent valuation.** Direct costing methods (sometimes referred to as "worksheet" methods) attempt to systematically identify different types of impacts associated with shortages and assign costs to them through use of a worksheet. This approach is more applicable to commercial and industrial customers than to residential customers, since a greater portion of commercial and industrial costs is quantifiable. This approach is more consistent with in-person interviews than with telephone administration, thereby making its implementation considerably more expensive.

Contingent valuation is a well-developed technique that is used by market researchers and economists to place a value on goods or services for which no market-based pricing mechanism exists. For example, it has been used quite frequently to value environmental amenities such as clean air or water, or health benefits, such as reduced cancer risks. More recently, electric utilities have begun to use contingent valuation as a technique to assess their customers' value of service.[8] A 1987 study by Carson and Mitchell was an

---

[8] For a good discussion of the uses of contingent valuation methods, see Electric Power Research Institute, "Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs." April 1990

initial attempt to use contingent valuation to assess California residential water customers' value of service.[9]

In a contingent valuation survey, respondents are asked in a very structured way how much they are willing to pay to avoid certain types of "unreliability events". (Alternatively, they are asked how much they would be willing to accept in exchange for tolerating various such events.) Through careful instrument design and sample selection, the customer loss function(s) can be estimated. Of course, the manner in which these functions are specified will greatly affect the design of the survey. The functional form must therefore be specified in advance of the design.

Even well-designed contingent valuation surveys suffer from the fundamental handicap of dealing with hypothetical situations. Asking residential customers to "bid" on hypothetical shortage situations is inherently difficult. As a result, many believe that such surveys tend to overstate reliability values; this has been confirmed when researchers have had the opportunity to compare these results to customer responses to more "real" shortage situations. When such surveys are tied to real shortages, they are likely to produce more valid results. The recent shortages that many customers have experienced as a result of the drought may provide an opportunity to use contingent valuation methods to obtain some valid and defensible estimates of customers' value of service. As memories of these episodes fade, the results of such surveys will become less accurate.

Incorporating Environmental Impacts

The framework described above to specify appropriate reliability goals attempts to minimize the sum of supply costs and customer shortage costs. The questions that must be asked are "which supply costs?" and "which customer shortage costs?". We could focus exclusively on direct costs (i.e. capital and operating costs) of new supplies and direct impacts on customers. It is likely, however, that any reliability planning process in California will also need to consider various external impacts. For example, some supply-

---

[9] QED Research, Inc. "Economic Value of Reliable Water Supplies for Residential Water Users in the State Water Project Service Area." Prepared for the Metropolitan Water District of Southern California, by Richard T. Carson and Robert C. Mitchell. 1987

side resources may have significant impacts on the environment. These impacts can be thought of as increasing the total costs of some resources. As illustrated in Figure VI-2, this may well *reduce the optimal level of reliability*.

The issue of when and how to consider these costs is a critical policy question. Beyond that, the measurement of these costs presents a vexing estimation problem. Local water customers' values for environmental preservation can be addressed as part of the contingent valuation survey instrument.[10] However, since it is likely that environmental impacts associated with new sources of supply go beyond local customers, other methods and data sources for valuing those impacts will have to be relied upon.

Is the Least-Cost Reliability Level the "Right" Level?

On occasion, the real world can be unkind to economic theory. The limitations of political and institutional feasibility and some serious measurement difficulties will probably combine to result in an answer that differs from the economically correct solution. In all likelihood, available information will be insufficient to determine what this solution really is. Moreover, as already pointed out, there may well be local conditions that cannot be easily incorporated into the cost-minimization framework.

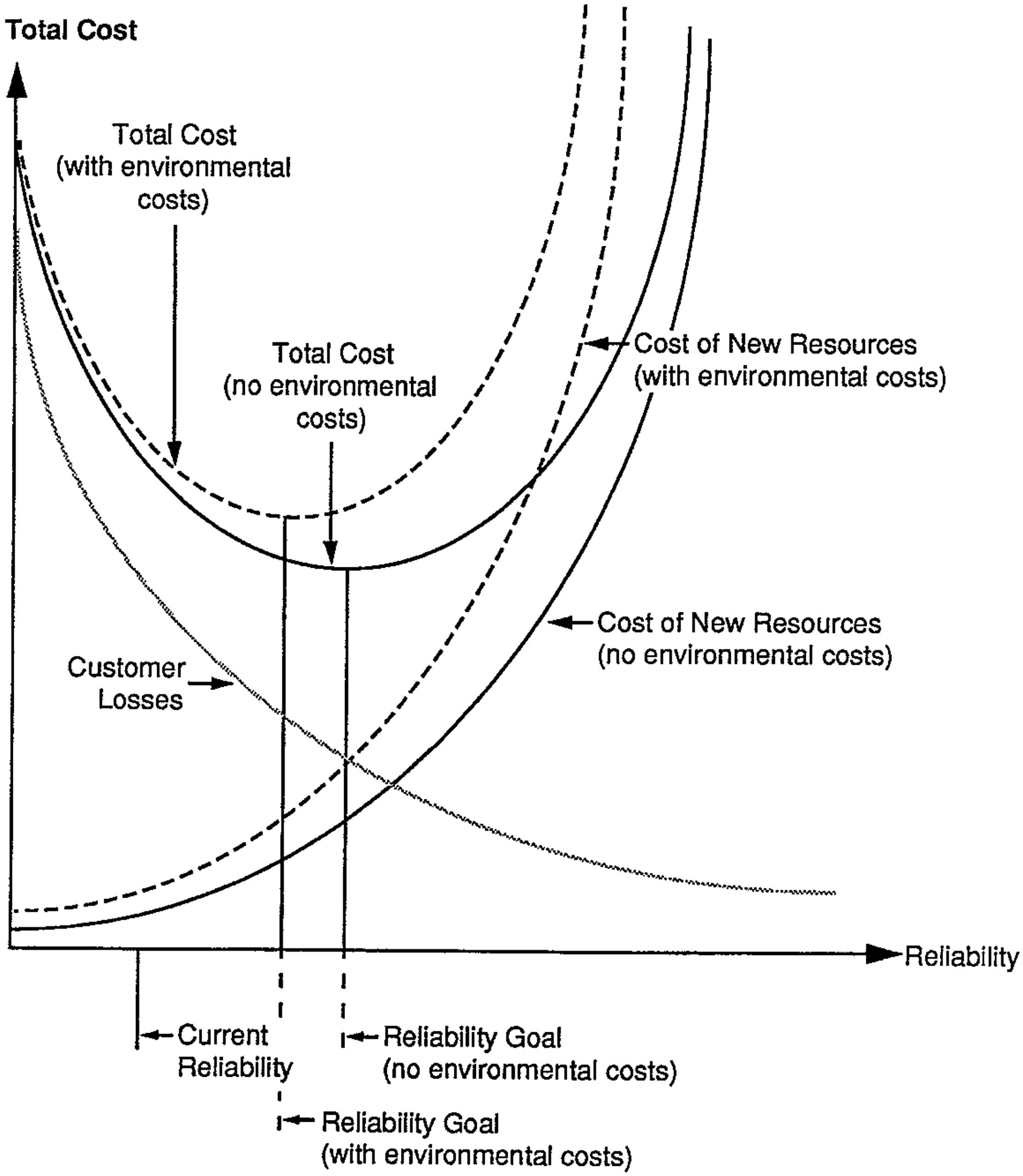
This does *not* say that the framework set forth above is not useful. On the contrary, it is needed to assess alternative solutions and to provide a starting point from which to incorporate non-economic factors. The economic framework will serve to focus the discussion, which we believe to be an invaluable contribution.

---

[10] Conceptually, this portion of the survey will estimate how much respondents' willingness to pay to avoid unreliability will be reduced as a result of potential environmental damage. The resulting environmental values can then either be expressed as additions to resource costs OR reductions to customer losses.

Figure VI-2

The Effect of Environmental Costs on Water Supply Reliability



1411.CUWA.sp

VII. SHORTAGE MANAGEMENT: ALLOCATING THE PAIN

If shortages do arise, utility managers must decide how to manage them, that is, how to spread the shortfall across customers. However, the appropriate reliability goal is itself partly a function of **how shortages will be managed and allocated.** Different customer classes and, indeed, individual customers value water service differently. Therefore, the relevant value of service and the resulting appropriate reliability level will depend on how the overall shortage is spread among customers. For example, if shortages are managed to only affect residential customers, then the appropriate level of reliability is only a function of those customers' reliability values.

Policymakers and utility managers must decide the best way to distribute the shortage among customer groups. This choice can be viewed as another application of least-cost planning principles. There are many demand-side management and pricing techniques that can help distribute shortages in an equitable and economically efficient manner.

Many energy utilities distinguish between **core** and **non-core** customers. Core customers are those that value their water use more highly than do non-core customers. When a shortage does occur, noncore customers are the first to be curtailed. This means that, in order to achieve particular overall usage reductions, required noncore reductions may be disproportionately high. Service to core customers is maintained until the shortage becomes quite severe. Core customers pay higher prices for this higher quality service.

Water suppliers must decide whether the core/noncore distinction is applicable to allocating water supplies in times of shortage. If so, they must then carefully think through the manner in which the core and noncore classes should be defined. Among other things, they should consider the direct and indirect impacts of lower quality service to the noncore. Other issues to be resolved include:

- How equitable is the designation?
- Should a core designation be contingent on the customer having taken particular conservation actions?

- Should portions of customers' usage be considered core, with the remainder noncore?

- How much choice should customers be given in determining their classification?

- How should core and noncore service be priced?

VIII. NEXT STEPS

This report has described the results of Phase 1 of CUWA's effort to study urban water supply reliability. The goal of Phase 1 has been to develop a clear conceptual base on which further work could build. Phase 2 will begin the process of developing tools and data upon which conclusions and recommendations regarding state urban water supply reliability can be based.

The reliability planning framework depicted in Figure I-1 requires various types of information. With one major exception, this information exists in some form. Most water suppliers develop demand and supply forecasts; most estimate prices of new supply-side and demand-side resources; many have explicit shortage management policies. However, while the recent CUWA study of industrial water shortages[11] provides a good basis for measuring industrial customers' value of service, there remains a great need for valid and reliable current data on residential value of service. As described above, the current drought provides an excellent opportunity to gather such data. Thus, one of the objectives of Phase 2 will be to begin the process of generating valid and reliable residential value of service data from which customer loss functions can be derived.

The other major task of Phase 2 will be to develop a prototype spreadsheet model that is specifically designed to produce the types of probability distributions, indices, and reliability goals described in Phase 1. This tool will be tested on some sample water agencies and will be compared to results of adapting an existing, considerably more complex and detailed model that has been developed by the Department of Water Resources.

Phase 2 will set the stage for the next phase of the project, in which analytical tools and data will be refined for statewide use and implementation issues will be examined.

One of the important lessons that we have learned in Phase 1 that will guide the work in subsequent phases is that this project cannot *prescribe* a detailed methodology to be used by all urban suppliers to measure and optimize reliability. The many differences among

---

[11] California Urban Water Agencies, op. cit.

agencies in terms of planning processes, constituencies, data availability, and other constraints preclude such a prescription. However, this project can add significant value by developing a generally-applicable framework as well as data and tools that can, when necessary, be adapted to local conditions.

With that in mind, the specific elements of Phase 2 will be as follows:

- **Value of Service.** As discussed above, there is a serious gap in our knowledge of the manner in which residential customers value water supply reliability. To plug this gap, we must carefully design an appropriate contingent valuation survey instrument. Phase 2 will include an intensive effort to design a survey that will generate customer loss functions and take advantage of customers' recent experience with the drought. This information will be invaluable to state and local reliability planning efforts.

  The Phase 2 product will be a survey instrument that is ready to be administered statewide. The generation of this instrument will require various pretests, customer focus groups, administration of pilots, and ongoing consultation with a subcommittee of the CUWA Project Advisory Committee. This process will be intended to precisely define the critical issues that the survey must address and design an instrument that clearly and unambiguously addresses those issues.

  The Phase 2 work will also enable us to answer sampling and survey administration questions. The size and composition of the survey sample will depend in large part on the extent to which significant local or regional value of service differences are anticipated. The focus groups, interviews, and pretests will help make that determination and thereby inform the sample design. It will also help each CUWA member determine if agency-specific questions should be appended to the surveys that are administered within its service area. We will also base the appropriate combination of telephone and mail survey administration on the Phase 2 results.

  We will, where possible, coordinate this contingent valuation analysis with CUWA's contemplated drought impact study. The Phase 2 process will help us determine which portions, if any, of the survey should be administered as part of the drought study.

For nonresidential customers, Phase 2 will also make use of the recent CUWA-sponsored study by Spectrum Economics[12] to obtain preliminary estimates of nonresidential value of service.

- **Development of Prototype PC-based Spreadsheet.** This model will perform the Reliability Forecasting and Reliability Goals portions of Figure I-1. While most water purveyors forecast demand and supply, many do not combine these forecasts to produce the cumulative frequency distributions and the reliability indices described in this report. Similarly, most purveyors estimate costs of new supply-side and demand-side alternatives. Many also have explicit shortage management policies. Few, however, combine this information with customer value of service assumptions to develop reliability goals in the manner that this report has described.

  This spreadsheet will serve as the linchpin that brings together these existing bits of information in order to develop an understanding of reliability consistent with the framework developed in Phase 1. The model will be generic in the sense that it will not attempt to perform the potentially complex hydrologic, operational, or econometric modeling necessary to produce supply and demand forecasts; nor will it internally forecast supply or conservation costs or estimate customer value of service.

  Instead, the spreadsheet will assume that individual purveyors will provide this information. Based on these inputs, the spreadsheet will develop cumulative frequency distributions of unserved demand, reliability indices, and cost-minimizing reliability goals.

  With their concurrence, we will illustrate the application of this model to the Metropolitan Water District of Southern California and the East Bay

---

[12] California Urban Water Agencies, "Cost of Industrial Water Shortages." Prepared by Spectrum Economics, Inc. November 1991.

Municipal Utility District. As described below, we will also compare the results and usefulness of this model to the DWR Economic Risk Model to determine the contexts in which either tool may be most useful.

- **Application of DWR Economic Risk Model.** The Economic Analysis Section of the Department of Water Resources has developed an Economic Risk Model (ERM). This model was not specifically designed to measure reliability as we have defined it in Phase 1, or to determine its appropriate level. Moreover, the model currently focuses solely on the South Coast region of the state. However, preliminary indications are that this existing tool may be able to be adapted to help describe current and projected reliability levels and determine reliability goals.

  Phase 2 will include an effort to apply the ERM to MWD and to adapt the model for application to EBMUD. We will attempt to make this analysis as consistent as possible with the cases to be analyzed by the Lotus 123 spreadsheet described above. We will compare the results obtained from these two tools and draw conclusions regarding the strengths and weaknesses of each.

APPENDIX A

CUWA WATER SUPPLY RELIABILITY PROJECT ADVISORY COMMITTEE PARTICIPANTS

Alameda County Water District

Barakat & Chamberlin, Inc.

California Municipal Utilities Association

California Department of Water Resources

California Water Service Company

Contra Costa Water District

California Department of Water Resources

Council for a Green Environment

East Bay Municipal Utilities District

Los Angeles Department of Water & Power

Metropolitan Water District of Southern California

Municipal Water District of Orange County

Natural Resources Defense Council

Peter Vorster, Consultant

San Francisco Water Department

San Diego County Water Authority

San Diego Water Utilities Department

Santa Clara Valley Water District

Santa Clara County Manufacturers Group

Sierra Club

California Water Resources Control Board

California Department of Health Services

University of California

Unocal Corporation

US Bureau of Reclamation

APPENDIX B

CALIFORNIA URBAN WATER AGENCIES
SURVEY ON WATER SUPPLY RELIABILITY

1. How does your agency define **water supply reliability**? Is the primary focus on supply/demand relationships, on local distribution system problems, or on catastrophic events? Or is the focus on something else?

_____ Supply/Demand

_____ Local Distribution System

_____ Catastrophic Events

_____ Other (Please specify and discuss)

2. Is water supply reliability an important component of your agency's planning process?

_____ Yes _____ No

IF YES:

2a. Please describe the manner in which your agency integrates notions of reliability into its planning. (Use additional space or attach additional pages as necessary and include reports or reference materials that would be helpful.)

3. For planning purposes, how does your agency measure reliability? If possible, please describe specific reliability indices. (These indices might, for example, relate to the expected frequency or magnitude of shortages, the number of days of local storage reserve, the anticipated percentage by which demand might exceed supply, etc.)

4. Using your preferred reliability indices, what is the current reliability of your system? What is the projected reliability in the year 2000? the year 2010?

Current:

2000:

2010:

5. Do your communications with policymakers, elected officials, and customers routinely include information on current or projected supply reliability?

_____ Yes _____ No

IF YES:

5a. What indicators do you use with these audiences to portray the state of water supply reliability in your service area?

(These indicators might be similar or identical to those described in your response to question 3 above. It may, however, be the case that your communications with these groups require different ways to express the notion of reliability.)

6. Does your agency have any quantified reliability goals, criteria, or standards?

_____ Yes _____ No

IF YES:

6a. Please describe them.

6b. Are these goals or standards "rules of thumb" or do they have a more formal basis?

_____ "Rules of thumb"

_____ More formal (Please describe)

7. Has your agency developed or used any information on the value of service reliability to your customers?

_____ Yes _____ No

IF YES:

7a. Please describe this information and how it was used.

8. What do you view as the most serious impacts on your customers of a future lack of reliability? (Please be as specific as possible. If necessary, distinguish between impacts on residential, commercial, and industrial customers.)

9. Has your agency adopted a method of directing the impacts of shortages to particular customer classes (e.g. interruptible rates, differential rationing, etc.)?

____ Yes ____ No

IF YES:

9a. Please describe these shortage management techniques.

THANK YOU FOR YOUR HELP!

10/24/91

APPENDIX C

ILLUSTRATION OF RELIABILITY MEASUREMENT: A SIMPLE EXAMPLE

Reliability indices are best understood through the use of an example. Figure C-1 describes a hypothetical system that has only three possible levels of demand and three possible levels of supply for a particular future year. Each level of demand and supply is assumed to occur with a particular probability, with supply being determined by precipitation. (For the sake of simplicity, we assume that demand is independent of rainfall.) It is a relatively simple matter to compute the probabilities of particular designated shortage levels either for unconstrained or dry precipitation conditions. (For this case, we define "dry years" as those with an available supply of 700.)

For example, the probability of any shortage (POS) is the probability that full-service demand exceeds available supply. If demand is 1,000 (probability 10%), then demand will exceed supply if supply is either 900 or 700 (probability 50%+25% or 75%). If demand is 900 or 800 (probability 50%+40% or 90%), then demand will exceed supply only if supply is 700 (probability 25%). The probability of shortage (POS) is calculated by adding the products of these probabilities, as follows:

$$\text{POS} = (.10)(.50+.25) + (.50+.40)(.25) = 30\%.$$

In dry years (available supply of 700), demand will always exceed supply; thus, dry year POS is 100%.

To illustrate the calculation of probabilities of designated shortages (PODS), we will consider a 12.5% shortage level. We seek the probability that a shortage will exceed 12.5%. If demand is 1,000 (probability 10%), a shortage greater than 12.5% will only occur if supply is 700 (probability 25%). If demand is 900 (probability 50%), a shortage greater than 12.5% will again only occur if supply is 700 (probability 25%). If demand is 800 (probability 40%), a shortage greater than 12.5% cannot occur. The calculation is therefore as follows:

$$\text{PODS}(12.5\%) = (.10)(.25) + (.50)(.25) + (.40)(0) = 15\%.$$

In dry years (supply of 700), a shortage exceeding 12.5% will occur only if demand is either 1,000 or 900 (probability 10%+50%). Therefore:

$$\text{Dry Year PODS } (12.5\%) = 10\% + 50\% = 60\%.$$

Figure C-2 presents the cumulative probability distributions for all years and for "dry years". Figure C-2 also shows how some of the key reliability indices can be read from the graphs.

Figure C-1
RELIABILITY MEASURES FOR A HYPOTHETICAL WATER SUPPLY SYSTEM

ASSUMPTIONS

Full-Service Demand	
Level	Probability
1,000	10%
900	50%
800	40%

Available Supply		
Level	Probability	Rainfall
1,200	25%	Wet
900	50%	Average
700	25%	Dry

MEASURES OF RELIABILITY

Probability of Shortage (POS)

All Years	*Dry Years*
$POS = (.10)(.75) + (.90)(.25) = 30\%$	$POS = 100\%$

Figure C-1
(Continued)

Probability of Designated Shortage (PODS)

All Years	
Designated Shortage	PODS
0	30%
10%	25%
12.5%	15%
22.2%	2.5%
30%	0

Dry Years	
Designated Shortage	PODS
0	100%
12.5%	60%
22.2%	10%
30%	0

Expected Unserved Demand (EUD)

All Years

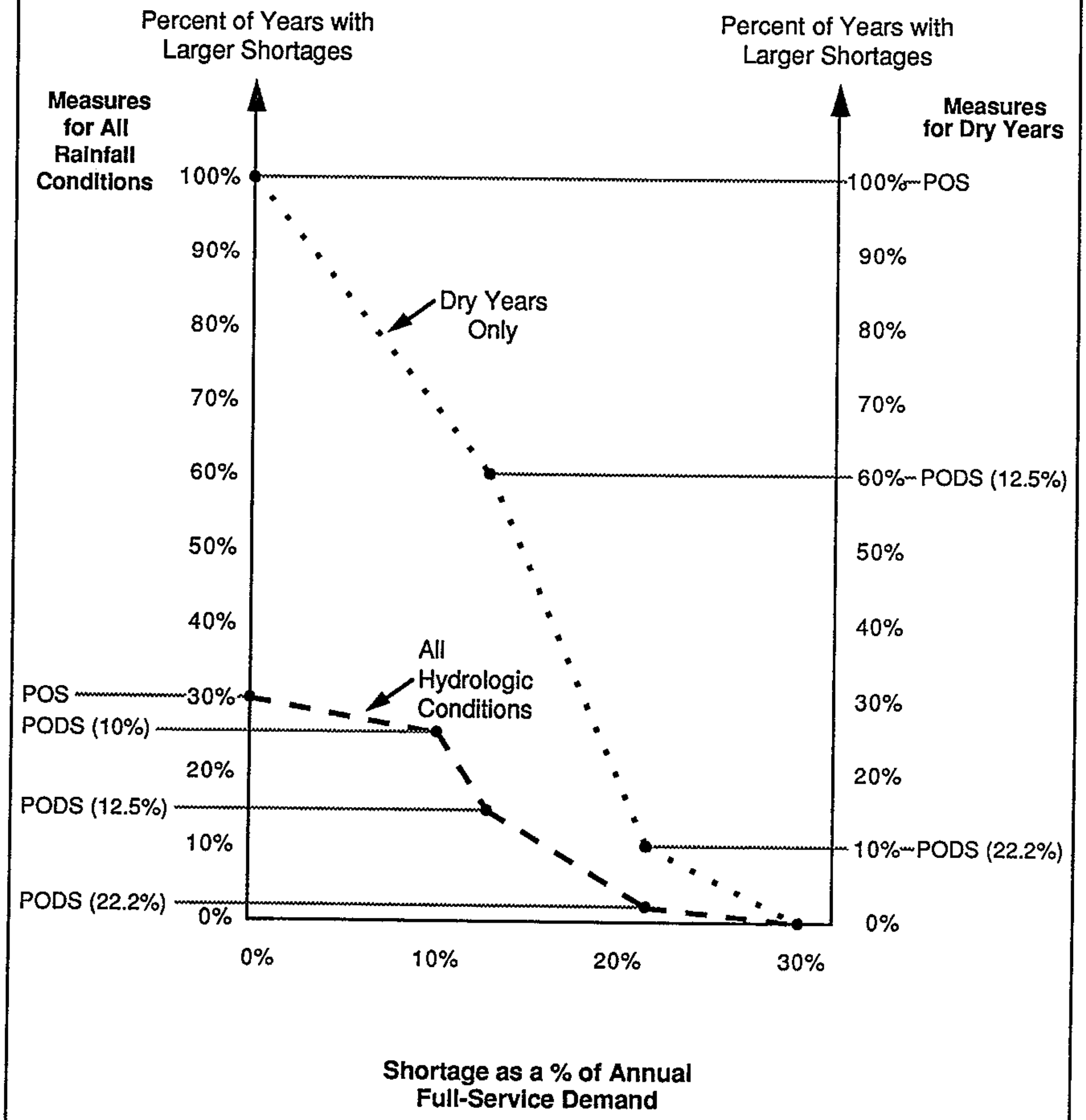
$$EUD = (.10)(.50) \times \frac{100}{1{,}000} + (.10)(.25) \times \frac{300}{1{,}000} + (.50)(.25) \times \frac{200}{900} + (.40)(.25) \times \frac{100}{800} = 5.3\%$$

Dry Years

$$EUD = (.10) \times \frac{300}{1{,}000} + (.50) \times \frac{200}{900} + (.40) \times \frac{100}{800} = 19.1\%$$

Figure C-2

Cumulative Frequency Distributions for Reliability of Hypothetical Water Supply System



1411.CUWA.sp