INTEGRATED WATER RESOURCE PLANNING

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INTRODUCTION

Integrated Water Resources Planning (IWRP) defines a holistic approach to the management of water systems combining water supply, water demand, water quality, environmental protection and enhancement, rate structures, financial planning, and public participation. IWRP is a subset of the more general Integrated Resource Planning (IRP) methodology. The American Water Works Association (AWWA, 2001) describes the IRP process as follows:

> *IRP is a comprehensive form of planning that encompasses least-cost analyses of demand-side and supply-side management options as well as an open and participatory decision-making process, the development of water resource alternatives that incorporates consideration of a community's quality of life and environmental issues that may be impacted by the ultimate decision, and recognition of the multiple institutions concerned with water resources and the competing policy goals among them. IRP attempts to consider all direct and indirect costs and benefits of demand management, supply management, and supply augmentation by using alternative planning scenarios, analyses across disciplines, community involvement in the planning, decision making, and implementation process, and consideration of other societal and environmental benefits.*
>
> *IRP includes planning methods to identify the most efficient means of achieving the goals while considering the costs of project impacts on other community objectives and environmental management goals. These planning methods specifically require evaluation of all benefits and costs, including avoided costs and life-cycle costs.(AWWA, 2001)*

Another, slightly different definition is contained in a report on IRP (Barakat and Chamberlin, 1994) conducted for the AWWA Research Foundation (AWWARF).

> *IRP is a continuous process that results in the development of a comprehensive water resource management plan. It identifies and gives balanced consideration to supply and demand management planning alternatives. It includes analyses of engineering, economic, societal, and environmental costs and considerations while balancing the needs of competing users and multiple objectives of the use of the resource. It is an open and participatory process involving all stakeholders and striving for consensus, while encompassing least-cost analyses of short- and long-term planning options, and satisfying utility and regulatory policy goals. Finally, IRP explicitly seeks to identify and manage risk and uncertainty and provides for coordination of planning between water and wastewater utilities in a specific region.*

Following this approach, many utility organizations are formally incorporating a broader view of planning into their policies and practices. In this document, reference is made primarily to water resources applications, thus the process will be noted as IWRP.

1. WHY WAS IWRP DEVELOPED?

IWRP evolved from a growing recognition of the interconnection of environmental systems and society's impacts within them (Beecher, 1995). In many areas, increasing populations and water demands have exceeded regionally-minded planning; by sharing resources with neighboring areas, planners have found more cost-effective solutions to water scarcity. Multiple stresses on areas have also necessitated multidisciplinary responses. For example, changing solid waste management practices to improve water quality or evaluating the land use impacts of reservoir development can help maximize the efficiency of overall resource use.

Emphasis on preventative planning compels consideration of not only the immediate cost of an idea, but also externalities and long-term consequences (Reisner, 1993). IWRP provides a platform for the many considerations required to preserve sensitive environments and creatively meet the needs of people both within and outside of traditional water service boundaries.

2. ADVANTAGES OF IWRP

Development of a coordinated resource management plan has clear benefits. The District of Southern California composed an IWRP plan in 1996 that addressed summer water shortages by negotiating a water transfer program with the Central Valley. Review of the program in 2003 found that agricultural interests in the Central Valley now viewed the program as a "good business practice" and Southern California had achieved greater system reliability. (Metropolitan Water District of Southern California, 2004)

Water management has also gained increased cooperation from the public by incorporating the IWRP process. Instead of traditionally viewing public groups as "interveners," IWRP uses the groups' energies as participants (Beecher, 1995). Water managers have found that by effectively involving stakeholders and taking advantage of their unique knowledge, planning process is improved, and there is increased support of the both the planning process and its results. Conservation projects have also been more effective. Often, the needs of traditionally competing groups can be met to a greater extent by working together and pooling resources.

While there are always tradeoffs in resource management, planners have found they can more accurately determine management priorities through incorporating input from more effected parties. For example, a study of residential customers in California found that citizens were wiling to pay $12 to $17 more per month for water to ensure greater system reliability and fund supply-side changes (AWWA, 2001). In other situations, however, modification of demand through conservation programs has also been successful in limiting the need for new water source development. Modifications from both the demand and supply side of water service allow planners more flexibility. Weighing risks rather than traditionally assuming risk to be unacceptable also allows planners to be more creative. Finally, the iterative nature of IWRP allows planners to consistently evaluate risks and uncertainties to more appropriately adapt policies to changing input and needs.

3. HOW CAN IWRP BE USED?

IWRP has been used at municipal, county and state levels and for energy, waste management, and various water managers. The Los Angeles Coastal Plain of California combined surface and groundwater in a conjunctive use system (Viessman, 1997). These systems can offer aquifer storage for use in the summer and then replenish groundwater with water from surface systems. Nebraska and Florida have divided their states into large water districts that manage water operations and have the power to levy property taxes (Viessman, 1997).

Using IWRP planning to support the general planning process allows such management to more equally meet each area's needs. In many areas, energy and water management have developed joint plans weighing the water needs of hydropower or water cooling systems for other power plants with those of the public. Water and waste management have worked together to reduce water contamination and conserve water with wastewater reclamation systems. By combining oversight to simply opening active communication between groups with shared interests, IWRP has been used to lower costs and aid in adapting systems to new demands.

4. IWRP FRAMEWORK

Although there is no complete definition of IWRP, there are a series of characteristics of IWRP that have evolved over time to be typical of the planning process. Figure 1 presents an overview of IWRP. This figure illustrates that IWRP begins with a careful consideration of both supply-side and demand-side planning and that the process is highly interconnected. System reliability is also shown to be a central component of IWRP. The output of the planning process is both a plan and a mechanism to evaluate the plan. The figure also indicates that public input is required. As noted elsewhere in this document, public input is needed at all stages of planning.

Figure 2 highlights one component of the process shown in Figure 1, the formulation of resource strategies. It is the philosophy applied to developing resource strategies and the evaluation of these strategies that distinguish IWRP from other forms of planning. As demonstrated in the figure, IWRP calls upon the study objectives and policy guidelines to frame the analysis and explores a wide range of options when arriving at a strategy for meeting the study goals.

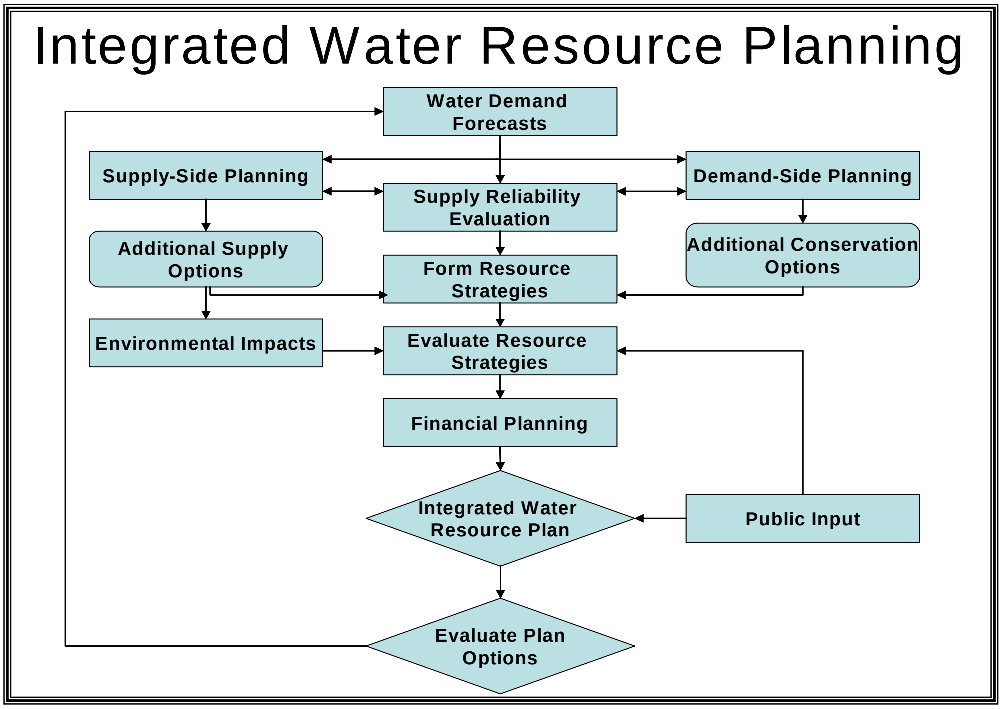

FIGURE 2. INTEGRATED WATER RESOURCES PLANNING (AWWA, 2001)

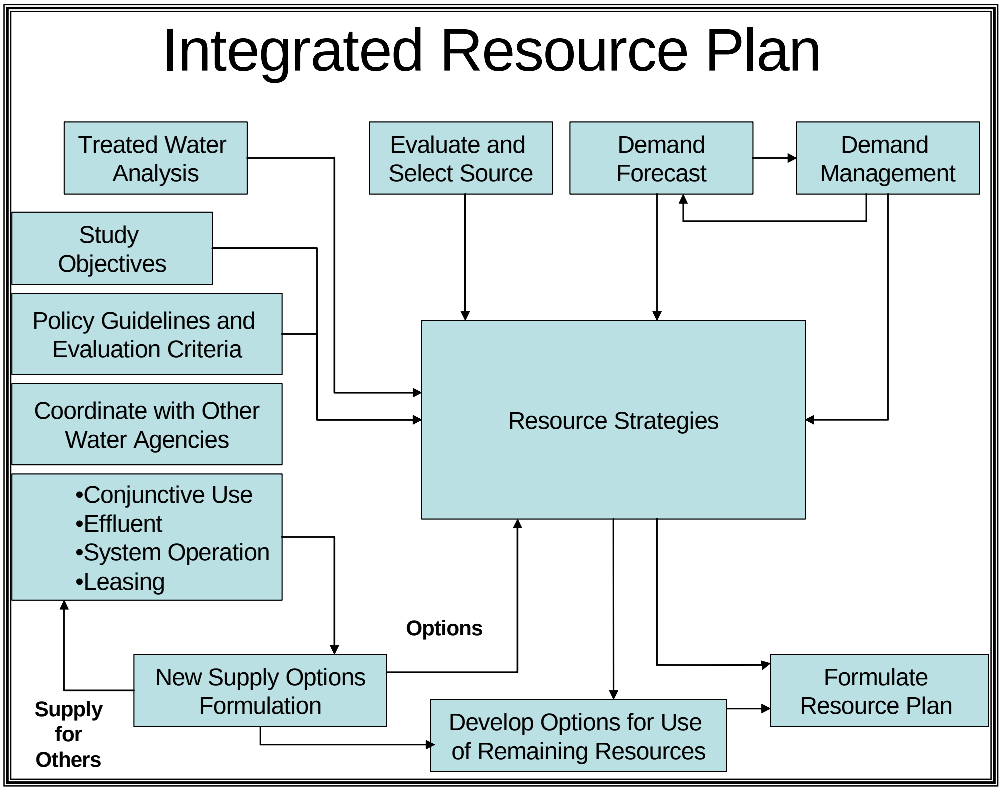

FIGURE 1 - INTEGRATED RESOURCE PLAN (AWWA, 2001)

5. REPORT CONTENT

The purpose of this report is to provide an overview of the IWRP process. Following the introduction to the IWRP process offered in this section, the report presents a summary of a general water resources planning methodology. This summary is presented to provide a context for the IWRP process. The methodology discussed is a disciplined approach that integrates well with IWRP. Following this section, specific characteristics of IWRP are highlighted. Emergency planning is then discussed. Finally, a brief discussion is presented on tools to aid in the IWRP process.

A REVIEW OF WATER RESOURCE PLANNING

1. INTRODUCTION

Planning can be defined simply as a disciplined approach for achieving a desired set of goals. Water resources planning is a specialized discipline of planning that deals with planning for and managing natural and man-made systems that are typically contained within watersheds and which include hydrologic, biological, economic, and political systems. Typically water resources planning includes a wide range of often conflicting objectives. Water resources planning requires integrating a wide range of disciplines to ensure success, including hydrology, hydraulics, water quality evaluation, resource economics, microeconomics, epidemiology, environmental impact assessment, finance, and public policy, and public participation.

There are a number of issues that distinguish water resources planning from other planning processes. Successful water resource plans (or the lack of proper planning) can have extremely significant impacts, as has been demonstrated in the US with conflicts over water in the west (the Columbia River, the Colorado River, and the rivers of California), the South (the Apalachicola-Chattahoochee-Flint/Alabama-Coosa-Tallapoosa River basins), and the mid-west (the Missouri and the Mississippi River basins), to name just a few (Palmer, 1998). Because the environmental, economic, and social impacts are potentially large, there is a very high potential for conflict, complicating the planning process.

Water resource planning must acknowledge the naturally variability of water, creating a need to develop contingency plans and to recognize the uncertainty of water supply. Unlike many resources that are more static in nature, the amount of fresh water available for use and distribution can change radically from year to year, even in systems in which there are reservoirs to store water. Comprehensive water resource planning requires highly technical and data intensive evaluations that must be conveyed to both politicians and the general public in a fashion that sometimes belies that complexity and uncertainty of the analysis.

Perhaps adding most significantly to the complexity of water resources planning is the institutional setting in which planning occurs. Most water resource plans involve participation at many levels of government and the participation of many different stakeholders. This requires coordination, the creation of shared goals, and public scrutiny at all levels of the process. In many studies, the institutional setting is not sufficiently appreciated and can lead to significant challenges in creating successful plans.

2. A BRIEF HISTORY OF WATER RESOURCES PLANNING

Water resources planning has a long and storied history of development. Many of the more formal planning processes have emerged from the federal water planning that occurred in the middle portion of the 20th century. It is difficult to define the beginning of a codified planning process, but the US Fish & Wildlife Coordination Act in 1934 set forth planning procedures. The Federal Flood Control Act of 1936 expanded upon these, and they were further developed into specific procedures in the Proposed Practices for Economic Analysis of River Basin Projects, better known as the "Green Book" (1950). These procedures changed and evolved over time into the Principles and Standards for Planning Water and Related Resources (1973) and the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (1989). These documents provide explicit and often detailed procedures for many technical evaluation procedures.

The environment in which water resources planning is performed has changed dramatically since the earliest procedures were suggested. Initially, planning was performed at a federal level, with a very small role (if any) for local public participation. Since the late 1960s, state and local agencies have assumed a much larger role in the planning process for many projects, and they have assumed a much larger share of the cost of project development and management. Equally important, stakeholders have assumed a more significant role in the planning process, demanding that their interests and concerns be incorporated throughout the planning process. This has required that the planning process be expanded to include more objectives and often more participants.

3. THE AGENTS IN WATER RESOURCES PLANNING

Water resources planning can be considered to be composed of three essential agents: players, processes, and products. Players are those individuals that influence the planning process, and can include individuals; businesses; communities; stake holders; nongovernmental agencies; and local, state, and federal government agencies. The term player is used to highlight the individuality of these agents, implying that simply changing the individual or group engaged in the planning process may well change the planning outcome.

The second agent is the planning process itself, which will be discussed at length in this document. It is important to have a formal, well conceived planning process, one that has shown to be successful in the past. Only in the most limited of planning exercises can planning be successful without a carefully conceived planning process. The planning process must include, at a minimum, the identification of goals, measures of performance, the generation of alternatives, an evaluation of trade-offs, and a plan for implementation.

The final agent is planning products. This can include traditional reports that document the results and conclusions of the planning process, but should also include evaluations of the planning process, the tools used to develop the plan, such as computer models, suggestions for institution improvements, and new communication procedures and networks.

4. CHARACTERISTICS OF WATER RESOURCES PLANNING

There are three basic planning paradigms that are used in water resources planning, regardless of the specific steps or approaches applied in the planning process. These paradigms are the planning iteration, screening, and scoping. These techniques are required; water resource planning is a very broad process and setting the boundaries and constraints of a study are often difficult. Often budget and time limitations help define the breadth of the study that can be performed, but because water resources planning is such an open-ended process, the three paradigms presented here are very useful in guiding the process. Each planning characteristic is discussed below.

A. PLAN ITERATION

Iteration implies doing the same thing more than once. In planning, iteration implies returning to an analysis when more information is available, when a different level of detail is necessary, or when new evaluation techniques have emerged.

The planning process is one that is improved when it is performed more than once. This not only implies that reviews improve evaluations, but that the level of detail of evaluations is likely to change during the planning process. Planning is not a simple linear process. Any process that encourages feedback from stakeholders will naturally require some degree of iteration. Feedback typically creates new information or helps to identify new priorities or areas of increased interest. Incorporating this information improves the quality of a plan if it is considered.

B. SCREENING

Screening is a basic systems engineering concept. Screening is the process of iteratively examining alternatives to select those which will receive further consideration and those that will not. A principal goal of screening is to effectively reduce the quantity of detailed analysis that is necessary, without eliminating alternatives which should be evaluated fully.

Screening does not imply full evaluation and ranking, it implies making use of expertise and sound judgment to use one's time effectively. Without some form of screening, almost any water resource planning effort would become too complex and intricate to accomplish. With screening, promising alternatives are provided an opportunity for full evaluation and inferior alternatives are excluded from further evaluation.

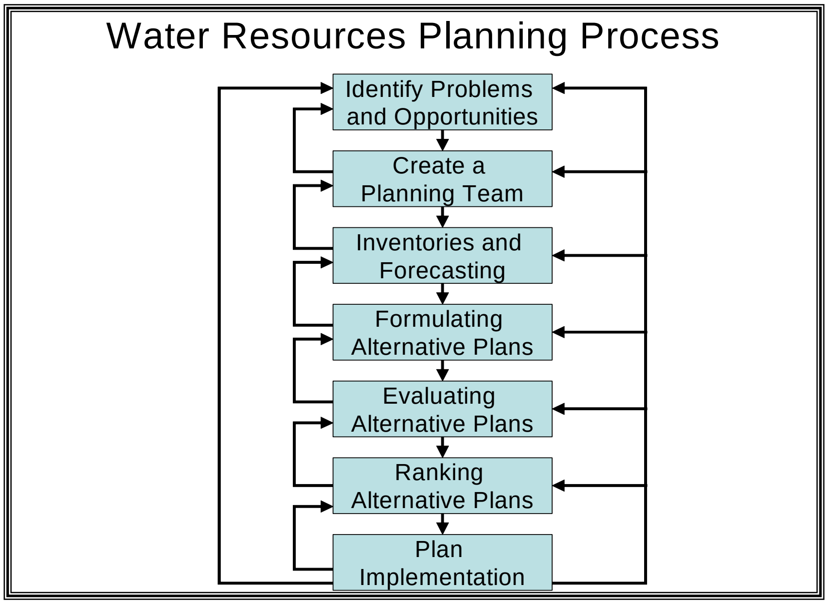

FIGURE 3 - SEVEN STEP WATER RESOURCES PLANNING PROCESS

C. SCOPING

Scoping is also another basic systems engineering concept. Scoping identifies the boundaries of the problem to be addressed and the boundaries of the solutions to be considered. Scoping is particularly important in evaluating water resources planning because the National Environmental Policy Act defines scoping as a required process. In that act, scoping is defined as "an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to a proposed action." Scoping has been used in many studies as a formal procedure to ensure the input of stakeholders in the planning process.

D. THE SEVEN-STEP PLANNING PROCESS

Although there are many ways to organize the planning process, a number of specific procedures with well identified steps have been suggested in the literature (Palmer, 1999; Keyes and Palmer, 1995). The seven step process described here is an example of a "disciplined, iterative process." This implies that all steps must be performed and recognizes the natural feedback that exists between all steps. Figure 3 summarizes the process. The number of steps and their boundaries are less important than the general planning philosophy, that is, good water resources planning involves carefully defining the challenges faced, defining the planning environment and including all those that might impact or be impacted by the plan, creating a comprehensive and creative set of alternatives for addressing the challenges, selecting among those alternatives the one plan that best addresses the objectives and constraints of the challenge, and creating an comprehensive approach to implementing that plan. Each of the seven steps is described below.

i. **Step 1** - *Identify Problems and Opportunities*

One of the most important and most neglected aspects of planning is a careful consideration of the problems presented and the opportunities to address it, and the translation of these into planning objectives. Good planning begins with well defined planning objectives. A planning objective is a concise, formally structured statement that defines what a plan should accomplish, describes the geographic and temporal scope of the plan, and identifies who the plan will impact. Planning objectives are created to focus the study on the problems of greatest concern, ensure that multiple goals are explicitly considered throughout the process, help create a common vision of the process, and allow evaluation of the effectiveness of the plan. Planning objectives help direct study resources (time, dollars, talent) to the challenges and opportunities of greatest importance. Without accurate and well formulated planning objectives the planning process loses its focus, important interests are ignored, important problems are not addressed, effective alternatives are not formulated, plans cannot be evaluated, and implementation becomes impossible.

Initially, it would appear that defining problems and opportunities and translating them into planning objectives should be a simple process. Experience (National Drought Study, XX) suggests that this step is, in fact, very difficult. Many planning objectives in practice have proven to be poorly conceived and a lack of attention has resulted in failed planning efforts.

ii. **Step 2 -** *Create a Planning Team*

No plan can be created without participants, and the participants of a water resources plan will, to a great extent, determine the quality of the plan. Developing an appropriate and effective team to perform planning can be challenging. Team members must possess both individual skills and be able to work effectively in groups. It is important to remember that a diverse perspective broadens the view of the problem and results in better plans. Also, broad stakeholder representation is required if the plan is to be implemented. In addition, good chemistry between team members is invaluable.

When creating a team, it is important to carefully determine who can best contribute to the success of the planning process. This requires not only the area of expertise of the members, but their role in plan implementation. When considering a potential team member, one can ask: Will their endorsement of the plan be required? Will they play a role in enacting the plan? Will they be impacted by the plan? Can they impede the plan? Do they possess skills, expertise, or a perspective that is needed in the planning process?

Although creating a planning team has been listed as the second step of this process, planning teams help create planning objectives. Likewise, it is difficult to assemble an appropriate planning team without knowing the study objectives. These two steps illustrate the type of feedback and iteration that is common in water resources planning.

iii. **Step 3** - *Create Inventories and Forecasts*

This step in the planning process requires a careful definition of the "status quo" and forecasting future conditions. In this setting, the status quo is defined as the existing and anticipated conditions of a water resources system if the planned policies, system configurations, regulations, and management strategies remain unchanged.

The purpose of creating inventories and forecasts is to create a shared and accepted understanding of the physical, technical, regulatory, management, and policy attributes of the system; create a statement of important problems facing the region; identify the uncertainties and discrepancies in information available; and catalog, to the extent possible, the polices governing system operation.

a) Inventories

There are a variety of components in a system inventory, including a facilities inventory, resource inventory, economic inventory, management inventory and demand inventory. Facilities inventories catalog all of the major facilities in a basin including reservoirs, distribution facilities, treatment plants, pumping facilities, diversions and water-related structures, such as boat ramps, docks, and locks.

Resource inventories include all of the natural features in the study and might be characterized as physical features and aquatic/terrestrial features. Physical features include the study area's climate, hydrology, unregulated streamflow, gaging station locations, local flows, precipitation, snow fall, evapotranspiration, and groundwater resources. Aquatic and terrestrial features include all fish and wildlife, threatened and endangered species, water quality, fish needs, and locations of effluent discharge.

Legal inventories include authorized purposes for all existing projects; existing water rights and priorities; instream flow requirements; water quality regulations; and other federal, state, and local law impacting the management of the system.

Management and policy inventories include operating policies for existing or planned facilities, rule curves for reservoirs, triggering mechanisms for management operation, management preferences, societal preferences, and political concerns.

Economic inventories include facility capital and operating costs, recreational benefits, marginal cost of resources, and past benefit/cost analysis.

Demand inventories include explanations of water uses (instream, offstream, consumptive, non-consumptive), current and forecasted demand levels, demand patterns, driving factors, cost of water, conservation strategies, curtailment measures, and revenues generated.

b) Forecasts

Forecasts are necessary to evaluate the effectiveness of water projects in the future. If conditions in a study area are stable, sometime forecasts can be made with great confidence. More often, however, forecasts must be made in rather dynamic conditions knowing that the parameters being forecasted (rate of population growth, future environmental regulations, response of endangered species to increases in instream flows) are based on an artful combination of expert judgment and incomplete information. This does not diminish the value of forecasts, as reasonable forecasts based on sound analysis of limited information are certainly superior to planning with no forecasts. It is important, however, to acknowledge the uncertainty inherent in forecasts and to make every attempt to propagate this uncertainty through any quantitative assessment that is made.

*iv. **Step 4** - Formulate Alternative Plans*

The formulation of innovative solutions to water resource challenges is one of the most difficult and complicated components of the planning process. All too often creative, novel and effective solutions to problems are left undiscovered while inferior and routine alternatives are chosen. A balancing act is required between the cost and time needed to develop a variety of appropriate solutions, recognizing that each potential alternative will require time and resources to evaluate.

A first step in formulating alternative plans is the process of creating measures of performance for evaluating alternatives. (This step could be considered a separate step entirely, as important as the seven steps presented here.) Performance measures must be clearly defined, easily understood, directly related to planning objectives, relevant to decision makers and stakeholders, and capable of addressing risk and uncertainty. There are typically two types of performance measures: performance accounts (describing the overall effect of an alternative in a specific area) or metrics (describing statistical or numerical measure of system performance). For federal projects, four categories of performance measures are used: National Economic Development (NED), Regional Economic Development (RED), Environmental Quality (EQ), and Other Social Effects (OSE - effects that are not reflected in the other three categories). Often defining measures of performance is helpful in beginning the alternative formulation process.

The general alternative formulation process is an iterative one. Alternatives should be presented initially as general concepts or approaches without too much detail. This provides the opportunity to explore alternatives and to adjust and modify them freely before they progress into more formalized concepts.

*v. **Step 5** - Evaluate Alternative Plans*

An alternative plan should be evaluated based upon its success in addressing planning objectives effectively. Infeasible alternatives should be discarded when they are proven to be impossible or impractical. Inferior alternatives should be identified, although not discarded immediately in the early stages of planning, as during the alternative generation process some constraints identified as impinging on an alternative may be later relaxed. Promising alternatives should be noted and analyzed in greater detail as the planning process proceeds.

Typically, a top-down approach is used in the evaluation process that includes iteratively screening and selecting projects for further analysis. This process is applied with increasing concentration on increasing the detail of the analysis and evaluating the project's effectiveness, efficiency, and acceptability.

Plan evaluation involves not only exploring the impacts of a plan, but evaluating how changes in a plan impact its effectiveness. Essentially, the analyst is required to perform trade-offs of both the assumptions of the plan and of the goals of the plan. Within other fields of planning and analysis this analytical process is termed "trade studies" analysis. This suggests parametrically exploring the response of a system to changes in input or transformations. In these studies, it is extremely important to emphasis the life-cycle of the project and to ensure that a consistent period of evaluation is used for comparisons.

*vi. **Step 6** - Rank Alternative Plans*

In the process of ranking alternative plans, the analyst incorporates preferences into the analysis. These preferences reflect the relative importance of the planning objectives of the study and the planning constraints. It is not the role of the analyst to incorporate his/her preferences in the evaluation process, but rather to ensure that the preferences of the decision makers and the stakeholders are incorporated. In addition, a full range of potential preferences should be included to ensure that those making the decisions have identified "Pareto optimal" solutions. When ranking alternative plans, it is important to recognize that both analytical and subjective comparisons are important. In analytical evaluations, quantitative scores based upon how well the alternative can meet a planning objective can be calculated. By their nature, subjective evaluations are less amenable to quantitative analysis, although a variety of quantitative techniques have been used to bring some level of quantitative analysis to subjective evaluations.

Throughout the ranking process, it is important to recognize that the goal of this process is to develop a ranking of alternatives or group of alternatives that can be displayed, debated, adjusted, and in the end adopted. This process involves not only the analytical evaluation of plans, but the process of seeking consensus among those who will eventually implement the plans, the ability to modify plan alternatives to address concerns that arise, the ability to incorporate new information as it becomes available during the planning process, and full recognition of all of the planning objectives and constraints and their relative importance.

The process of ranking alternative plans requires equal portions of communication, cooperation, compromise, and ingenuity among those engaged in the ranking process. It is at this stage in the planning process that deficiencies in all of the previous stages of planning become obvious. Although planning is an iterative process, it is important that the other stages of planning be revisited and more analysis be performed only if this significantly changes the ranking of projects and thus the selection of a different preferred planning alternative.

vii. **Step 7** - Plan Implementation

Once a planning alternative is chosen, the next step is implementation. Implementation is the cornerstone of plan success, as a plan can truly only be successful if it is implemented. It should be noted that a strategy for implementing a planning alternative must be part of the plan. As through all of the planning steps described here, implementation is iterative and interlinked with the other planning steps.

Plan implementation requires a commitment to success, as the process if often long and difficult. Successful plans are technically and politically viable; they contain a clear definition of the roles of agencies and individuals, and have a clear mechanism of formal and informal endorsement. Successful plans also address clear mandates, are not based upon "wishful conditions" that do not reflect reality, include careful interagency coordination, have sufficient resources and have broad based endorsement.

5. SUMMARY

This section has focused on the general water resource planning process and planning characteristics. A water resources planning process is characterized as an iterative process that uses screening and scoping to define that challenges to be addressed and to appropriately define the boundaries of the planning effort. Water resources planning is performed as a six step iterative process involving: 1) Identifying Problems and Opportunities, 2) Creating a Planning Team, 3) Developing Inventories and Forecasts, 4) Formulating Alternative Plans, 5) Evaluating Alternative Plans, 6) Ranking Alternative Plans, and 7) Implementing the Plan.

In the next section, we will focus on those elements of Integrated Water Resources Planning that have been identified as distinguishing it from typical water resources planning. Primary among these is public involvement. The role of public involvement has increased dramatically in US water resources planning since the 1980s. This change has required that the planning procedure adapt. However, IWRP is more than simply increased public involvement, it is an emphasis on "systems thinking" and systems approaches. This implies that careful consideration is given to the natural interaction among components of water resource systems.

ATTRIBUTES OF INTEGRATED WATER RESOURCES PLANNING

As noted previously, six attributes of IWRP have been identified as distinguishing it from traditional planning. These are: 1) Public Involvement, 2) Water Demand Forecasting, 3) Water Supply Forecasting, 4) Reliability Evaluation, 5) Source Strategies, 6) Financial Planning, and Drought Contingency Planning. In the following sections, each of the components of IWRP is discussed.

1. PUBLIC INVOLVEMENT

Public involvement is extremely important in the IWRP process. Five aspects of public involvement are discussed here as related to IWRP: identifying stakeholders, consensus building, early involvement, circles of influence, and closure.

A. IDENTIFYING STAKEHOLDERS

Successful implementation and positive responses to management plans depend on the accurate identification of stakeholders. Planners should strive for representation of different socioeconomic groups, gender balance and equal input from special interests. While traditional meeting areas, such as city halls, may offer good access to some of these groups, attention should be given to how to obtain a more random sampling of stakeholders. Telephone surveys can help to identify those most invested in current plans and to determine the average level of knowledge stakeholders have regarding an issue. Additionally, addressing cultural and gender differences between stakeholders may help planners create a more all-inclusive environment. In an assessment of 121 water projects, the World Bank found that "ensuring women's participation in decision-making positively affected both project quality and sustainability" (IWA, 2002). The AWWA lists possible parties to contact as including: utility managers, elected officials, economic development and business organizations, wholesale water customers, state and federal regulatory agencies, recreation interests, environmental interests, workers, developers, neighborhood associations, large water users and media (AWWA, 2001). By seeking diverse opinions, planners increase their ability to anticipate the use of their plans, make appropriate modifications, and achieve greater public support.

B. EARLY INVOLVEMENT

To maintain stakeholder involvement and eventually reach consensus on important issues, a supportive environment must be established early in the process. First, planners should assess stakeholders' background knowledge regarding plans. Information can then be distributed so that all can choose to be involved in planning based on an equal understanding of the issues. The AWWA suggests (Awwa, 19xx) that position papers may effectively communicate the issues. Once a core group of interested parties assembles, the group should define its major goals. The group, along with planners, should identify the most important issues. With shared priorities, the group can then discuss their opinions. Planners should make an effort to define the role of stakeholder based on their concerns and abilities, so that a clear sense of purpose develops. By allowing stakeholders the opportunity to effectively voice their opinions, but also the structure to come to conclusions, a sense of involvement and progress may be created.

Depending on the desired level of input from stakeholders, utilities planners must identify the most effective forms of communication. The AWWA IRP guidelines suggest that groups of 25 or fewer are most able to make decisions and that perhaps consensus building groups should be limited to stakeholders that need to be included. Larger public meetings may allow an exchange of information and help form a better community relationship with utilities services. The size of such meetings, however, inhibits effective decision making and consensus building. Citizen advisory committees and workshops may allow a range of involvement from the public, including information exchange and possibly consensus building. Task forces and professional or scientific panels generally have a more formal structure and may be formed to make specific recommendations. Finally, mediation and the similar, but binding process of arbitration employ an impartial facilitator to determine a fair compromise among divided parties. Each form of stakeholder engagement demands different commitments from participants and asks for different responses from utilities managers. The appropriate form should be chosen carefully so as to include stakeholders, but not ask them to give input that is not desired from water management.

C. CONSENSUS BUILDING

Despite the best intentions early in the process, creating consensus among different groups can be a challenge. If consensus is desired, planners or a designated facilitator should encourage realistic planning early in the process. By allowing a group sufficient time for discussion and defining concrete steps along a timeline, planners give the group a methodology by which to measure success. The AWWA suggests that policy statements can serve as a working draft of a group's positions which can be revised until consensus is reached. Documenting accomplishments and progress prevents old discussions from recirculating and can bind participants to the issues they have already agreed upon. Stakeholders can also be asked to sign a "memorandum of understanding," pledging to actively take part in a process to reach consensus. Regular reevaluation of goals and timelines can keep the group on task and the process moving. By encouraging commitment to process and giving the group tools to constructively comment on their developing work, planners can help a group reach consensus

D. CIRCLES OF INFLUENCE

One relatively new model for public involvement is the circle of influence approach. This model suggests at least four levels of participation, each including an increasingly broad circle of participants. The process recognizes that not all study participants are able to be equally involved in all levels of planning. Circles of influence identify an inner circle (Circle A) that consists of a multi-agency group of experts. The next concentric circle that surrounds A is Circle B. Circle B generally includes experts as well as one representative from each of the major interest groups found in outer circles. Representatives in Circle B may review or revise proposals drafted by circle A. The next concentric circle that surrounds B is Circle C, which includes a much larger group of representatives from advocacy and management groups. This group may meet twice a year in formal workshop format. The outer circle, "D", expands the group to include regional decision makers such as agency heads and elected officials. These decision makers are informed of the group's progress by representatives. Using this model, participants with more time to invest in the process are employed to coordinate with professional groups that may have less time to devote to the group. By keeping politicians informed, this model also increases the chance that recommendations from the group will be implemented (U.S. Army Corps of Engineers, 1995).

E. CLOSURE

When facilitators sense decreased productivity in the group, it is often appropriate to draw the process to an end. In some cases it is appropriate to end by stating opposing views, what has been addressed, and what could still be addressed. This demonstrates that all parties have been heard and acknowledges what has been accomplished. As important as transparency is in the beginning, it is also important at the end. Special influence from some groups may be inevitable and may be best dealt with by openly recognizing it. For example, the needs of the largest customers may be favored in a decision. Hard feelings on the part of other stakeholders may be decreased by recognizing this decision and management's dependence on large customers' business. While group decision making is trying as compared to traditional high level planning, the results give a much more accurate reading of public sentiment and allow project goals to be balanced more effectively.

2. WATER DEMAND FORECASTING

Accurate water demand forecasting is an essential ingredient in a well executed IWRP exercise. As competition for water has increased over time, more attention has been placed on how best to estimate future water demands and what actions can be implemented to manage demand. In a recent literature review of water demand forecasting techniques Arbués et al. (2003) noted that "there has been a change of approach to water management," one that is less supply-side driven and which focuses on the factors that impact water demand. In their article, citing over 110 refereed publications, Arbués et al. (2003) note that the most important factors influencing water demand include price, income, weather variables, residential population, industrial use, housing characteristics, frequency of billing rates, and indoor versus outdoor water use.

Howe and Linaweaver (1967) first demonstrated that water demand is not simply a function of the number of residential customers and industrial water users. At that time, water pricing in many areas was founded on a declining block structure and water demands were increasing dramatically. Their work, like many other studies, detailed the impacts of price on demand and began the formulization of mathematical approaches to forecast water demands (Carver and Boland, 1980). Since the 1960s, water demand forecasting has emerged as a distinct field, with mathematical models of water demand replacing simple engineering extrapolations of demand over time (Baumann, Boland, and Hanemann, 1997).

Forecasting water demand has been complicated by trends in national water demands. In the US, water usage by thermo-electrical plants, irrigation, and industry has decreased since 1980. Water demand in the US has decreased by approximately 10% since 1980, with significant declines in irrigation and thermo-electrical plant withdrawals, and there has been a 40% decrease in water used by industry since 1970 (USGS, 1995). Per capita fresh water use in the US peaked in 1980 and dropped by more than 20 % by 1995 (Gleick, 2000). Global water use has proven to be significantly below earlier forecasts as well (Gleick (b), 2000). The decreases are due primarily to increases in industrial efficiencies, the increasing price of water, and improved irrigation practices. The decrease in global water consumption comes at a time of increasing total food production and increasing world populations, implying more efficient use of current sources.

Water demand forecasts can be derived from a variety of other forecasts, such as population, individual and industrial water use patterns, future land use characteristics, water price, and the availability of water. In this section, three aspects of water demand forecasting are highlighted that are typical of IWRP: 1) models of water demand forecasting, 2) incorporating conservation and changing water demand priorities, and 3) demand management.

A. MODELS OF WATER DEMAND FORECASTING

In IWRP, water demand forecasting typically has three elements: 1) forecasting a baseline water demand, 2) predicting the impacts of policy intervention, and 3) balancing use and supply. In IWRP, demands are regarded in the context of other factors affecting the water supply system.

A wide variety of approaches exist to create water demand forecasts (Kindler and Russell, 1984; DeKay, 1985). In the past, water demands were typically created by extrapolating past water demand patterns.

This technique is referred to as trending. A second, related technique is the associated with per capita sector projections. This implies defining water use as a function of the number of people to be served. This technique can be extended to defining the type of industries to be served and calculating the industrial portion of the water demand by anticipating future industrial activity. This technique can be refined by more completely dividing service areas into components of similar characteristics for which "per capita" demands can be calculated.

Econometric models attempt to forecast water demand by identifying and quantitatively estimating the effects of specific factors on water use. Factors often used in economic models, in addition to population served, are individual income, fixed price of water, variable price of water, property value, type of industries served, employment level, and weather, among other factors. These models are typically developed to create log-linear relationships between water demand and then explanatory variables.

Since the 1970s, a number of large scale water demand models have been developed. One of the most commonly used models of these is the IWR-Main (Municipal and Industrial Needs), funded originally by the Institute of Water Resources of the US Army Corps of Engineers. This model uses highly disaggregated data to forecast water demands. When using this type of model, water demand typically is divided into a series of customer classes including: Residential Single Family, Residential Duplex, Residential Multi-family, Small Commercial, Large Commercial, Industrial, Irrigation, and Government and Education. For the small commercial, large commercial and industrial categories, use is divided into the predominant types of activities that exist or are predicted to be demanding water in the future. If the region in which the forecast is being made involves purveyors of water, the demand for each water purveyor must also be considered.

For municipal water demands, these models use the following types of water use determinants: water and sewer rates, household income, sector or total employment (all but residential), climate, irrigation precipitation days (residential), the number of households and their characteristics.

B. INCORPORATING CONSERVATION AND CHANGING PRIORITIES

Perceptions of the importance of water conservation and the priorities to which water is placed have changed significantly in the past several decades. Individuals have changed the way they use water, as the full impacts of water use (hydropower production, cooling water, irrigation, municipal and industrial water use) have become more apparent. In much of the US, long-term water conservation programs have proven very effective. Both the introduction of regulations and the subsidy of low flow fixtures (low flow toilets, low pressure shower heads, etc.) have resulted in significant water use reductions in many municipal water supplies. Changes in outdoor water use have also been dramatic. Xeriscaping (a term popularized by Denver-Colorado Water Department from the Greek word Xeros which means dry) implies the use of regionally appropriate landscaping that does not need water in excess of that which occurs naturally.

It has been problematic to incorporate these changes into models of water use. Changing public perception and dramatic changes in personal water use are not concepts that are easily incorporated into models. Typically, such programs are included into water demand forecasts in a rather ad-hoc approach, with demands reduced from those calculated using conventional models. As our understanding of the impact of water conservation on overall water demands improves, this element of forecasting water demands will be better incorporated into the mathematical models of water demand.

C. DEMAND MANAGEMENT

Demand management has taken on new significance in recent years and is normally exhibited in two forms: limiting peak demands and limiting seasonal demands. In some of the fastest growing areas of the US, the ability to meet peak summer demands has been compromised due to lack of peak distribution capacity. This is addressed by limiting the maximum demand during the summer by implementing “even-odd” day outdoor watering or other similar policies. Such peak period restrictions may be implemented during unseasonably dry and/or hot conditions and for longer periods when the infrastructure cannot meet demand during more normal conditions.

Demand management can be used to defer investment needed to create new infrastructure or to allow a system to deal with unusually adverse conditions. It is becoming increasingly obvious that communities are willing to change water use patterns when there are significant savings or when there are clear improvements in environmental quality.

3. WATER SUPPLY RELIABILITY EVALUATION

Often, a principal goal of IWRP is to more carefully and formally define the yield of a water supply system, to calculate the reliability of the system to meet anticipated future demands, and to create alternatives that best combine demand and supply alternatives. In this section, we will address each of these issues.

A. DEFINITION OF SAFE YIELD

The safe yield of a water supply is defined as the maximum quantity of water that can be guaranteed to be available from a system during a critically dry period (AWWA, XXX). For groundwater sources, this definition is often broadened to note that extracting the safe yield from a system should not result in any “undesirable conditions”, such as groundwater mining or negative impacts on hydraulically connected surface water systems. For systems with reservoir storage, safe yield is often calculated by including other commitments placed upon that system, such as providing water for aquatic habitat needs.

Hydrologic information is necessary to calculate the yield of a system. Hydrologic records may be derived from historic streamflow records or from metrological data processed by rainfall/runoff models. The length of the hydrologic record (in years) has a significant impact on the safe yield. If storage facilities are available, in the form of reservoirs, the safe yield is a function of the storage and the set of flows whose combination most limit the amount of water available. Longer historic records provide a greater probability that a significant drought has occurred.

To standardize comparisons of yield, the AWWA has suggested a reliability standard of 98% to define the yield of water supplies. This implies that water supplies be able to meet all demands in 98 out of 100 years. If a utility has 100 years of hydrologic record available for analysis, then 98% reliable yield would be the yield associated with the third worst drought on record. This yield would be calculated by determining the largest quantity of water that could be supplied for the historic record, given that two annual system failures are allowed. If a utility has only 50 years of record available, then the 98% reliable yield would be the largest quantity of water that could be supplied for the historic record, given that one annual system failure is allowed.

This standard initially was suggested when there was less emphasis on cost-effective demand management options and before there was full recognition of the role that peak-demand management can play on extending the yield of water supply systems. In a comprehensive IWRP effort, system yield often is portrayed as a more dynamic concept, one based upon the response taken to periods of drought or low flow. One of the purposes of an IWRP effort is to more fully integrate the concepts of supply and demand and to achieve appropriate levels of reliability, based upon the unique conditions in a community and the community's planning objectives.

B. CONJUNCTIVE MANAGEMENT

Conjunctive management is an important component of IWRP. Conjunctive management implies integrating of all supply resources in a manner as to maximize the yield of a system. Conjunctive management recognizes the synergistic nature of water supplies; that is, the combined yield of several water supply sources is typically greater than the sum of the individual sources. Synergistic gains exist because droughts typically do not occur at exactly the same time for all water supplies and because of operational advantages that can be gained by combining sources of water. For instance, in multi-reservoir water supplies, temporal and spatial differences in the onset and intensity of a drought may result in operational opportunities that emphasize the use of one reservoir over another. In systems that have both groundwater and surface water, groundwater can be reserved for those periods when it best compliments the use of surface water.

When calculating the yield of systems that have the benefit of conjunctive use, it is important to explore the impact of a wide range of operating procedures and to determine the maximum yield that is possible. This is often accomplished by investigating past drought events. It is widely recognized, that although these past events will not reoccur, they may provide valuable insights into the types and magnitude of droughts that will occur in the future. Optimization models can be created to determine the maximum yield that is possible, and then simulation models can be used to develop operating rules that attempt to achieve these maximum yields with the use dynamic operation algorithms.

C. CLIMATE CHANGE

Evaluation of system yield based on past hydrologic events serve the valuable purpose of answering the question of what is the likely yield of a system, given that the hydrologic conditions in the future are similar to those in the past. During the past two decades, the impact of climate change on water supply systems has become an important and active area of research. The most recent finding of the IPCC concludes that there has been a change in climate. Among the many impacts that are expected to occur, those associated with water resources are felt to be among the most important.

There are a variety of ways in which IWRP can incorporate climate change into an evaluation of system yield. These approaches range from very simple to extremely complex. Because most IWRP is long-range in nature, it is extremely important that such plans acknowledge the potential impacts of climate change and develop contingencies for coping with climate change. Four approaches to incorporating climate change into evaluating system yield are provided below. These approaches range from simple modification of historic streamflow records to incorporation of the results of global circulation models (the models used in the atmospheric sciences community to estimate the impact of climate change). Because most climate change models forecast future conditions in the US to be warmer and dryer, it is likely that the impacts of climate change will reduce the yield of water supply systems.

D. EMPHASIZE RECENT DROUGHTS

For many portions of the US, the past decade has had an unusually large number of warm, dry summers. An extremely simple approach to evaluating the yield of a system is to assume these conditions are more representative of the future than a longer historical period and to calculate the reliability of a system based upon these more frequent, severe conditions. Unfortunately, this technique does not provide any insight into the likelihood of climate change, nor its rate of change.

E. ASSUME CHARACTERISTIC CHANGES IN STREAMFLOW

When other information is not available, changes in climate can be estimated by assuming the future streamflows will only be a percentage of those that have occurred in the past. For instance, one might assume that future hydrologic flows during the summer will only be 90% of what they have been in the past. This method has the disadvantage of being rather speculative; however, it does provide simple information and can be used to form the basis of a sensitivity study.

F. ASSUME CHARACTERISTIC CHANGES IN CLIMATE

Many of the more respected climate change models provide consistent forecasts of the predicted change in temperature and reasonably consistent forecasts of the predicted change in precipitation in the future on a global scale. If hydrologic rainfall/runoff models exist for the study region, past meteorological data can be modified to reflect these changes in average future conditions. This approach has the advantage of making use of some of the emerging information concerning climate change, but it is important to recognize that these continental and global changes may not be appropriate for all regional analysis.

G. PERFORM REGIONAL ASSESSMENT OF CLIMATE CHANGE

It is becoming more common to perform regional climate change assessments to calculate more precisely the impacts of climate change on system yield. A full scale regional study typically includes varying assumptions about future greenhouse conditions, evaluation of several different climate change models, sophisticated approaches to downscale the results of climate change models to specific locals, state of the art rainfall/runoff models that make use of climate information, and an extensive calibration/verification process to ensure proper model application. These studies can not be viewed as definitive, as climate change modeling is still a relative young science and will improve in the future. However, regional assessment of climate change is currently the most comprehensive approach at estimating potential, future impacts and will become an important component of IWRP in the future. It is the only appropriate approach when making long-term forecasts of supply availability.

4. SOURCE STRATEGIES

In most planning settings, there is a broad range of potential approaches to meet planning goals. If a planning goal is to increase water supply reliability, this can be accomplished by modifying demand, developing new sources, improving the operation of existing sources, or by changing the definition of system reliability. As noted in the review of fundamental water resource planning, it is extremely important to carefully articulate planning objectives to ensure that the strategies developed are appropriate ones. In the IWRP process, formulation and evaluation of alternatives should emphasize combinations of resources that meet the planning objective.

This section addresses some of the unique issues associated with IWRP that arise during the formulation and evaluation process. Traditional water resources planning might be characterized as being focused on supply options that are under the control of a utility where the primary objective is to minimize cost subject to meeting a pre-specified reliability level. IWRP views the development of source strategies differently and is focused equally on demand and supply options, accepting the role of resource agencies and the public as partners, and incorporating a variety of objectives that include not only minimizing costs but also addressing environmental concerns and the total impacts of the project.

A. WATER SUPPLY OPTIONS

In IWRP, there are a variety of potential sources of water supply. Typically, demand side management is explored, as it is often the most cost efficient source. Long-term conservation is an excellent approach to deal with supply/demand disparities. Long-term conservation can be implemented through changes in water plumbing and landscape codes and regulations, changes in the pricing structure of water, or by subsidizing the purchase of more efficient household appliances. It is common in IWRP to characterize modifications in demand as a source of new water. This recognizes that demands are not fixed but reflect the price and management framework in which water is made available.

On the supply side, IWRP emphasizes the creative use of alternative supplies and the creation of partnerships. Water transfers or exchanges (from one utility to another) offer promise in many areas. Water transfers have often been limited in the past by issues related to water law and water rights. As the need of transferring water between beneficial uses has become more apparent, changes in the administration of water rights has also changed. Water transfer, in many portions of the world, represents an important source of water.

Conjunctive use of sources to enhance supplies or to supply areas not currently served are potential alternatives. Conjunctive use is not limited to better integration of groundwater and surface water sources, but can be applied to how water use is managed between any set of sources. Improved conjunctive use of water supplied by surface water reservoirs has provided more reliable water in many situations. Improved conjunctive use requires not only an assessment of existing resources, but a systematic review of how these resources can be best coordinated.

Increased storage in existing reservoirs or more creative use of existing storage offers water supply opportunities. Increased storage can occur from the construction of new facilities, but it can also result from more aggressive use of storage that currently exists. The common trade-off between flood protection and water supply illustrates the potential for enhancing storage opportunities. Improved metrological and streamflow forecasting provides the opportunity to manage flood storage more aggressively and, in some cases, to provide more storage to water supply purposes. The use of existing "dead" storage in reservoirs is also possible. Dead storage is water in a reservoir that is typically not drafted because of a lack of hydraulic access or because of water quality concerns. Pumping facilities and water treatment can provide this dead storage, often at very cost-effective rates.

Wastewater reclamation offers the opportunity either to directly use water for municipal purposes or to exchange wastewater for municipal systems where such water is beneficial. This option is particularly valuable when large users of reclaimed water exist. Potential users of reclaimed water (those needing a large volume of water in a particular location) include industries, golf courses, and turf growers. Reclaimed water can also be used for municipal water supplies that are destined for outdoor use, or can be returned to streams to contribute to instream flows.

5. DEVELOPING RESOURCE PORTFOLIOS

In today's planning situations, a single supply source or demand management alternative rarely meets all needs. Planners typically seek combinations of solutions or solution portfolios. This approach is useful for several reasons. There are typically many stakeholders engaged in planning, each seeking to address the objectives they find most important. Often planning objectives are sufficiently diverse that several different options are required to address them in their entirety. Also, solution portfolios are valuable because in the initial phases of planning, it is often not obvious which solutions are likely to be implemented and ultimately successful.

Thus, an earmark of most IWRP is a carefully considered portfolio of supply source and demand management options, finely tuned for the plan's precise setting. As noted previously, all good plans are derived from precise planning objectives and quantifiable measures for evaluating alternatives. Evaluating alternatives in an IWRP process uses multiple criteria and is not limited to cost. Some of the more common evaluation metrics in IWRP are cost, risk and reliability, environmental impact, and public acceptability.

A. COST

Cost remains an important criterion in evaluating alternatives. Cost is no less important today than it has been in the past, however, it is now one of several criterion considered in IWRP. Benefit/cost analysis remains the essential means by which projects are evaluated, although as noted elsewhere, financial feasibility and impacts on rate structure are also important. When performing benefit/cost analysis, it is important that appropriate discount rates be chosen and that projects be evaluated over similar project life.

B. SYSTEM RELIABILITY

The concept of system safe yield is less commonly used in IWRP as system reliability has emerged as a more useful and appropriate measure of system performance. Analysis of the type, magnitude, and frequency of system failures that are likely to occur typify IWRP. Such analysis requires the integration of system operating rules during drought and other extreme events into the calculation of system reliability (see also the following section on drought management plans). This process recognizes that the performance of a water resource system is a function of not only the water supply and demand, but the management policies that are in place.

C. ENVIRONMENTAL IMPACTS

IWRP requires that the environmental impacts be carefully considered in selecting preferred alternatives. Environmental impacts of alternatives can be positive (the construction of fish bypass facilities) or negative (the dewatering of a stretch of stream during portion of the year). Direct biological evaluation of impacts can sometimes be difficult, but should be performed whenever possible and appropriate. Often physical surrogates are sought (such as using average streamflows during the summer as a surrogate for fish production). A common result of an IWRP process is recognition for the need for more comprehensive data to access environmental impacts. Often alternatives in the solution portfolio may include strategies to gather and evaluate such information.

D. PUBLIC PARTICIPATION AND PUBLIC ACCEPTANCE

As addressed at length in other portions of this document, public participation is another cornerstone of IWPR. Careful consideration of how public input can be gathered and incorporated very early into the planning process and the alternative evaluation process is essential. Encouraging interaction with the public and all stakeholders is an indispensable feature of IWRP and discounting its importance can result in a planning failure. Careful attention must be paid to how best to incorporate public opinion and acceptance in the evaluation of all alternatives.

E. DESIGNING RATE STRUCTURES AND TARIFFS

As noted previously, the IWRP process recognizes the interactions between water price and water demand. To accurately assess the links between water supply and water demand, an understanding of the impacts of water pricing is necessary. If a plan incorporates a rate structure significantly different than the past rate structure, water demands will change and thus the revenue stream will change also. Alternative rate structures should reflect the planning objectives, but all rate structures have common goals. In general, rate structures are established to encourage economic efficiency, equity, fairness, resource conservation, and revenue stability. They must also be relatively simple and easily understood by the public, and they must generate sufficient revenue to meet system costs. (Boland,).

Setting rate structure is an interactive process, as the impacts of a rate structure must be explored before it is implemented. A rational approach for modifying an existing rate structure in an IWRP process is to adjust the existing structure so as to meet the planning objectives. It is common to consider economic efficiency as a primary planning objective, suggesting that all rate structures should reflect the marginal cost of supplying water. In addition, equity must be addressed, ensuring that equals are treated as equals in the pricing scheme. When demand management is a concern, often common themes occur. Seasonal pricing of water often is identified as an appropriate foundation for a rate structure, as the marginal cost of water. After this objective is met, factors relating to equity should be addresses next. Rate structure has extremely far reaching impacts and should be thoroughly analyzed in IWRP.

6. DROUGHT CONTINGENCY PLANNING

Drought contingency planning is often related to demand management; however, it is limited to dealing with weather conditions. Drought contingency plans are "working" documents that provide clear guidelines on how best to manage the demands and supplies of water during periods of drought. Municipal water supply agencies, in particular, have begun to rely on drought management plans to coordinate the demand and supply of water and have historically not been part of the water planning process. Drought management plans minimize the effects of water shortages on public health, consumer activities, recreation, economic activity, and the environment in the most cost-effective manner possible. Drought plans are created to provide a consistent framework to prepare for and respond to drought events (Shepherd 1998). A drought plan should include drought indicators, drought triggers, expected drought responses, forecasts and monitoring procedures, and enforcement measures (IWR 1994).

Drought indicators are any single observation or combinations of observations that contribute to identifying the onset and/or continuation of a drought. Drought indicators can include measures of streamflow, precipitation, reservoir storage, the Palmer Drought Severity Index which is a function of precipitation, temperature, and the Available Water Content of the soil, and other similar measures (Hayes 2001, Fisher and Palmer 1997). The effectiveness of drought indicators depends on the region and the resources. No single indicator can work for all regions. Often, the degree of infrastructure development in a region may define the most appropriate indicators.

A drought trigger is the specific value of a drought indicator that activates a management response. In a drought contingency plan, trigger levels can be varied to alter the sensitivity of the response and the effectiveness of the plan. Defining drought triggers can be difficult. Trigger levels change over time, that is, an appropriate trigger level for a particular system may change dramatically if that system has an increase in available infrastructure or if water demands change dramatically. Urban water triggers are often quite different from agriculture drought triggers, as the urban infrastructure can often mitigate the impacts of short-term droughts.

Drought responses are predefined management actions that are activated by a trigger. Short-term responses can include the initiation of outdoor water use bans, the increase of the price of water, or the use of printed media to inform the public of water supply problems. Drought management plans for many urban areas are often developed with four to five levels of responses, all of which encourage different levels of demand reduction or supply augmentation. The effectiveness of drought responses is dependent upon the community. An outdoor water ban, for instance, may be effective for an affluent residential community, but not for a heavy industrial community.

Climate forecasts attempt to predict drought conditions for better planning. Organizations, such as the National Oceanic and Atmospheric Administration (NOAA) and the National Drought Mitigation Center (NDMC) use indices to predict droughts. These indices include the Standard Precipitation Index (SPI), which quantifies the precipitation deficit for multiple time scales, and the Palmer Drought Severity Index (PDSI), to monitor and quantify their forecasts (Hayes 2001).

Finally, drought plans must include public education and enforcement measures. A comprehensive public information program should be implemented immediately to achieve more effective results from the plan. Simultaneously, enforcement measures are necessary to encourage the public to abide by the water use restrictions. Enforcement measures traditionally include incentives, such as rebates on low flow showerheads and faucets, and penalties for noncompliance, such as warnings and fines.

Drought plans should be incorporated into IWRP as they have a significant impact on water management and on the impact of extreme events. They require iteratively evaluating proper response to extreme climate conditions, thus are important in evaluating water supply reliability.

EMERGENCY PLANNING

Following September 11th, the security and emergency contingency plans of many public facilities have come under careful scrutiny. Currently, natural disasters still present a much higher probability of threat to water systems than attacks from terrorists. However, interest in emergency planning in the context of IWRP has increased dramatically, and the following discussion of emergency planning procedures summarizes the steps necessary to prepare water management for a wide range of threats, including terrorist attacks .

Security and emergency contingency planning consists of three major steps: 1) assess the vulnerability of the system, 2) create a responsive mitigation plan, and 3) prepare for emergencies. Throughout this process, it is important to clearly assign responsibilities to specific individuals and agencies and to integrate the efforts of all those involved. Proper preparation will help prevent an emergency and, equally important, minimize its impact if one occurs.

1. VULNERABILITY ASSESSMENT

A vulnerability assessment should convene a diverse group of participants to identify possible threats to the water supply system. Frontline personnel, law enforcement, water supply management and other facilities management should participate to provide their practical knowledge. It is important to consider a wide range of threats and the impacts associated with these threats. First, the vulnerability assessment team should inventory the system resources by reviewing blueprints and physical plans of the system. Participants can then outline the major components of the system using the following headings:

- administration and operations
- source water
- transmission system
- treatment facilities
- finished water storage
- distribution system
- supporting infrastructure

Using this description of the system, the assessment team should develop an extensive list of potential threats to the facilities. To identify threats to the system, the assessment team should consider the scenarios causing emergencies. Human threats can be characterized as caused by unintentional error, vandals, "lone wolf" terrorists and terrorist groups. Human error may include accidents caused by water system staff or others, such as a construction crew that breaks a waterline. It is impossible to prevent human error, but there is extensive knowledge concerning the range of accidents that occur due to these errors. Vandals are most likely to commit acts of opportunity without a specific target. Unfortunately, the impacts of some of these acts may be more significant than those anticipated by the vandal. A "lone wolf" terrorist, on the other hand, could directly target any part of a water system and may have the goal of either harming the system or directly harming the systems' customers. While an individual terrorist is unlikely to be capable of contaminating an entire water supply, a terrorist group may have access to the chemicals and equipment necessary for a large scale attack.

Of all these human threats, however, the probability of significant threat may be highest for a disgruntled employee. These "insiders" have the greatest access to information and facilities. Today computer hackers can also access privileged data files or introduce a random virus capable of disabling a water system's entire computer network. The causes and resources associated with each threat require different responses from water management.

Natural disasters are most likely to cause widespread emergencies and can be anticipated according to an area's climate and geography. In areas vulnerable to earthquakes, foundation failure, connection pipe damage and collapse of elevated tanks should be considered. Areas prone to hurricanes should anticipate broken pipelines from uprooted trees and structural damage. Floods, volcanic eruptions and debris from fires can contaminate water supplies. Tabulating the types of hazards faced, their probability of occurrence, and their impacts (for example, see Table 1) provides a useful, initial framework for further analysis. The vulnerability assessment team should consider the immediate effects of a natural disaster and the secondary effects to the defined components of the water system.

In a widespread disaster or attack, the impacts of the event may pose secondary threats. If emergency responders, such as hazardous spill teams, are overwhelmed or debilitated, a problem could quickly escalate. An electricity outage could deactivate pumps, lighting, water temperature control, electronic security systems and computers.

Type of Hazard	Estimated Probability	Estimated Magnitude	Comments
Earthquake	1 in 60 years	7.0 (Richter scale)	
Fault rupture	Medium	2ft	Meridian fault
Ground shaking	High		
Liquification	Medium-low	Vertical and horizontal accelerations	Fill areas
Densification	Medium		Fill areas
Landslide	Medium-high		In slopes of 30 percent
Tsunami and seiche	None		
Hurricane	None		
Wind			
Storm surge			
Flooding			
Tornadoes	Low		
Floods	Low-medium	100-year flood to elevation 1,020 ft	At treatment plant
Forest of brush fires	High		Dry creek watershed
Volcanic eruptions	1 in 300 years	150 miles away	Mount Nueces
Other sever weather			
Snow or ice	None		
Extreme heat	High	100-year drought	Reservoir depleted
Wind	Medium	60-80 mph	Usually in winter
Lightning	Low		
Other			
Waterborne diseases	Low		Cryotosporidiosis
Hazardous-material release			
Chlorine	Medium-high	1-ton containers	Earthquake damage
Other spill	Medium	Tanker car	Dry creek reservoir
Structures fires	Low		
Construction accidents	Medium	Line damage	In older area of system
Transportation accidents			
Road	Low		
Rail	Medium		Rail yard near warehouse
Water	Low		
Air	Low		
Nuclear power plant accidents	Low	Contamination	Lake West reservoir
Nuclear bomb explosions	Low		
Vandalism, terrorism	Medium		Storage tanks
Riots	Low		
Strikes	Low		

TABLE 1. HAZARD SUMMARY FOR A HYPOTHETICAL WATER SYSTEM

Sewer failure could contaminate a water source. Without natural gas, water cooling and heating, as well as backup generation would shut down. Diesel or propane shortages could also prevent backup power generation, transportation and operation of utility vehicles, such as forklifts. Roads could be blocked or flooded and communications could be down. Staff may also be lost either because they cannot be contacted, or because they are debilitated by the emergency. Consideration should also be given to staff's primary responsibility to their families which may distract them if they are not allowed to first resolve these concerns. In worse case scenarios, the psychological effects on stressed personnel might also be considered. Pooling the knowledge of multiple utility heads will help a vulnerability assessment group anticipate all these complications.

2. MITIGATION

The first step in creating a mitigation plan is to agree upon acceptable levels of service in an emergency. The daily goal of the water supply systems is to provide safe, reliable, and inexpensive water. In an emergency, however, bottled water or wells could be used as short-term safe drinking water supplies. In emergencies, it is very important to provide water used for sanitary service and for fire protection. This water may need less treatment than drinking water. On the other hand, priority customers, such as hospitals may require an uninterrupted clean water supply. In is important to develop unique service goals and measures of system reliability and vulnerability that are appropriate for emergency conditions.

Human attacks to the physical system may be prevented according to the principals of detection, delay and response. Improved video surveillance and personnel identification can detect an intruder. To prevent a drive-up attack, delivery companies can be asked to send names and pictures of drivers to a plant before arrival. A break-in can be prevented by implementing regularly changing security codes and not relying on simple key systems. The most cost-effective detection measure may simply be better lighting. Other security measures may not deter, but rather delay a determined perpetrator. Fences, distance between fences and the facility, and visual barriers all allow more time for police to arrive at the scene. To ensure an efficient response, local emergency service providers should be given security codes and keys and should be educated about facilities. Similarly, water system personnel should be trained both to look for security threats and to respond appropriately to different levels of security breaches.

Natural threats to the physical system can be addressed in anticipation of and, in some cases, immediately before the event. Improvements to the mitigation system should be made according to the probability and severity of risk the mitigation system addresses as determined in the vulnerability assessment. Natural disasters, such as hurricanes, may be predicted hours or even days before the event, allowing last minute preparations. In this case, staff can take an inventory of emergency supplies, check communication systems, and move vital records to a safe location. Elevated tanks can be filled and isolated from the distribution system. Pressure reducing valves can be set in manual mode in case of electrical outage. Finally, staff can be encouraged to modify their activities to help mitigate the impacts of threats. Making priority changes to the system, as well as planning last minute security operations, can prepare the physical system for an emergency.

Training and development of secure operation procedures encourages an overall atmosphere of security. Regular training exercises can help staff become comfortable with emergency procedures and eliminate flaws in the system. Staff can also be cross-trained to provide back-up during emergencies. Even if an unexpected emergency occurs, training will most likely help staff to improvise. Other operational security measures may begin and end with increased security in hiring or exit interviews. To avoid predictable routine, operations schedules should be varied. Chemical deliveries to treatment facilities should also be carefully scheduled so that the delivery is expected by personnel, and they can immediately report any unexpected delivery. Investing the time and money in operations security will help ensure a quick, uniform response to emergencies.

Chemical system security procedures focus on prevention. Early warning systems can monitor water temperature, pressure, flow and chemical levels in the distribution system and at the treatment plant. A low cost alternative at the treatment facility is to maintain a tank of native fish. Treated water can be run through the tank and fish monitored. In either case, personnel then need to be informed as to what changes necessitate no action, increased water treatment, emergency service contact, public announcements or system shut down. An established relationship with local laboratories allows staff resources for further analyzing suspicious samples. To reduce the risk associated with the delivery of treatment chemicals, utilities may consider switching to onsite generation of chlorine, use of sodium hypochlorite or use of other disinfectants. Otherwise, onsite chemical analysis of deliveries may be implemented. In case of chemical contamination, mitigation procedures might include an agreement with a nearby water service provider to supply water in case of emergency. Old wells or treatment plants within the system might also be used as back-ups.

Prevention of cyber, SCADA and communications attacks includes improving fire walls, virus protection and categorizing data for appropriate protection. In some states, open record or sunshine codes may make potentially dangerous documents, such as a vulnerability assessment, available to the public. An attorney should be consulted to consider how best to protect information. When sensitive information is made publicly accessible, it may be possible to determine who requested the information and for what purpose. In both this situation and in online data access, a log of activity should be kept and reviewed periodically. Finally, networks should be protected by limiting remote control to onsite terminals and preventing unauthenticated dial-in access to data files. While these steps can be used to improve system security, an information technology professional should be employed to accurately assess a system's vulnerabilities.

3. EMERGENCY RESPONSE PLAN

In the case of an emergency, communication is essential to response coordination. A central incident command center (ICC) is recommended so information can be gathered in one location and key utility staff can gather there to assess and respond to a problem. The emergency preparedness plan, system blue prints, communication equipment and other response resources should all be available at this site. Staff can easily prioritize repairs when managing operations from the ICC. If emergency responders become involved, they could also staff the ICC to support a unified response. With the ICC in place, individual facilities will know whom to contact for information, and clear leadership will be set for an emergency.

A separate communication center and a spokesperson should be identified for media contact. In the case of an emergency, it is best to release accurate information to the public as soon as possible. The spokesperson should make prior contact with media to educate them about the local water system. Press release templates should also be prepared for quick communication. Then, if emergency response is needed from the public, a clear message can be communicated.

Each water system will require a different emergency response plan depending on the needs of the public and the vulnerabilities of the system. The first part of any plan, however, should be a well-defined process to analyze the type and severity of the emergency. Once the degree of emergency is agreed upon, staff should provide assistance to save lives. This might include evacuation of a treatment facility or areas near a dam. Next, actions should be taken to reduce the probability of additional damage. Emergency repairs might first be made to storage and treatment facilities and then to the distribution system. After major problems are addressed, the recovery process can begin. Throughout emergency procedures the response plan should be evaluated both to compare action to the plan and to make note of needed modifications. When regular service has been restored, water management should meet to discuss the efficacy of the plan.

Identifying and addressing risk is an iterative process. Plans continually need to be evaluated, tested and updated. At the same time, risk must always be put in perspective with the costs of prevention and mitigation. For example, the amount of a chemical needed to contaminate a reservoir is most likely prohibitive to all but well funded terrorist groups. Contaminating a small portion of a distribution system is much easier and has the intended effect desired by a terrorist. Accordingly, it might be appropriate to invest more money in monitoring distribution systems than in preventing drive-up attacks. If an emergency preparedness plan is realistic and well outlined, the public is likely to support the cost of additional security. Considering the possible vulnerabilities and solutions offered above, water management should be able to more accurately determine where their efforts should be focused.

MODELING THE IWRP PROCESS

The IWRP process is complex and computer models are an essential ingredient to success. Because the IWRP process includes many steps and components, a wide range of software is often used. No dominant software program has emerged, and those performing IWRP often develop specific in-house software programs to meet their purposes. This software is designed to provide access to information, to facilitate technical analysis for all members of the process, to generate information appropriate to support decision making, and often to serve as a common repository for the study's progress and accomplishments. What is common among these software programs is the implementation of five functions: 1) Knowledge and Database Information Storage, 2) Preprocessors, 3) Analytical Tools, 4) Post processors, and 5) Visualization, Interactive User Interface, and System Help Functions.

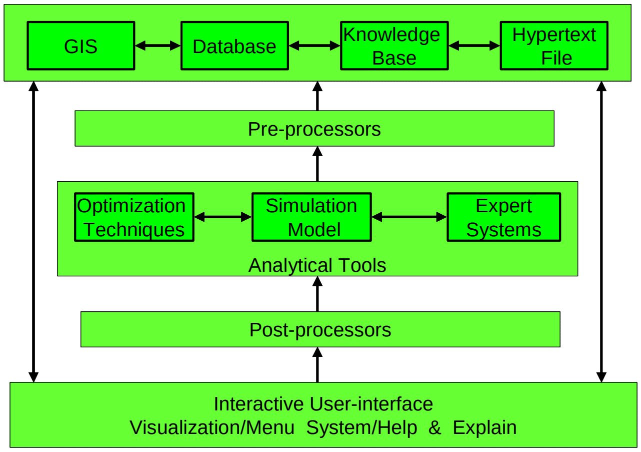

Figure 4. Software Functions for IWRP

Even if specific software is developed to perform specific tasks to support the IWRP process, it should be noted that simple tools like word processors, spreadsheets, and relational data bases also typically contribute to the process. Organizing and managing the information generated in these tools can also present a challenge, because of the dispersed nature of their use. The tracking, cataloging, organization, and retrieval of information generated with simple tools should be carefully considered.

In the remainder of this section, each of the five software functions necessary to support the IWRP process is described (Figure 4).

1. KNOWLEDGE AND DATA INFORMATION STORAGE

The IWRP process requires large quantities of information. This information is available, often, in a variety of forms and in inconsistent formats. A goal of the modeling of IWRP is to provide this information seamlessly to uses in a format appropriate for its intended use. Geographical Information System (GIS) data are becoming essential in IWRP planning. Watershed, land use, vegetation, facility location, pipeline distribution, and demand data are often accessible through GIS databases. This information is essential in developing inventories and creating forecasts of future study conditions.

Another common form of data is in hierarchical and relationship data bases. Billing data, historical water demands, streamflow data, meteorological data, and other essential information is often stored in databases. Software used in IWRP must be able to access, modify, and use these data.

In addition to spatial information and databases, the IWRP process makes extensive use of knowledge about system operation, biological information, and the social and political setting in which the planning is to occur. Much of this data is not quantitative, and is best represented as text, heuristic and/or rules. This information can be stored electronically in the form of hypertext or in the form of expert system rule bases.

2. PREPROCESSORS

Between the raw data used in analysis and the analytical engines used to process this information are the preprocessors. Preprocessor extract storage information and convert it into a format that can be used. Preprocessors may handle very large databases, such as those used in GIS systems, or simply find and retrieve a specific piece of information that is needed by analytical engines.

3. ANALYTICAL ENGINES

Analytical engines are the tools used to calculate and analyze the impacts of various alternatives, assumptions, and management activities. In IWRP, these tools typically evaluate the economic, financial, environmental, and physical impacts on a water resource system. There are four major types of analytical tools used. Optimization models are computer models that can arrive at an optimal solution when the objective and constraints or a problem can be mathematically identified. Optimization models have been applied to water resources management settings for many decades. They are most effective when problems are well-defined. They also have the facility to address multi-objective problems. Simulation models are computer models that attempt to replicate system operation over time. Simulation modeling has also been used in water resources management for many decades and is the most common tool to evaluate alternatives in IWRP. Simulation models must be used in an iterative fashion to arrive at solutions considered "optimal." Typically, simulation models do not have extensive optimization features, and trial and error or simple heuristic searches must be used to seek appropriate management policies. Simulation models can be used for a variety of activities, including demand forecasting, economic analysis, supply analysis, and environmental assessment. Expert systems are used when expertise exists that can prescribe how systems should be operated and when this knowledge needs to be codified for use by others. Rate structure design and system operation are two activities for which expert systems have been applied.

4. POSTPROCESSORS

The purpose of a postprocessor is similar to that of the preprocessor; it is to take the large quantity of data that is generated by the analytical tools, perform specified operation on this data, and then make it available for further analysis. Many of the analytical tools, as exemplified by hydrologic watershed models or system operation models, may produce gigabytes of data. Effective postprocessors convert this large quantity of data into a more useful and compact format.

5. VISUALIZATION, INTERACTIVE USER INTERFACE, AND SYSTEM HELP FUNCTIONS

One of the key features of the IWRP process is the incorporation of stakeholders into the planning process. Many of these stakeholders may not have technical background, thus translating the output of analysis into comprehensible information is extremely important. Unlike the past, stakeholders today expect to be able to work with models to explore their interests and to understand the output of models. Effective data visualization, and development of interactive user interfaces, and on-line and easy to use system help functions contribute significantly to engaging stakeholders and greatly increase likelihood that analytical results will be incorporated into any plan that is formulated.

CONCLUSIONS

Integrated Water Resources Planning (IWRP) is a holistic approach to the management of water systems combining water supply, water demand, water quality, environmental protection and enhancement, rate structures, financial planning, and public participation. IWRP was created because of the growing recognition that water resources planning is a complex activity and that society's needs are changing. IWRP emphasizes consideration of the feedbacks that exist in water resource management, and uses new techniques to cost-effectively balance system side and demand side needs.

There are numerous characteristics of IWRP, but the most important are: 1) Public involvement is emphasized throughout the planning process, 2) water demands are forecasted with care and with attention to the impacts of price, water policy, and water law, 3) water supply is forecasted recognizing the role of synergistic gains and the role that operations play in system yield, 4) reliability is considered a parameter to be evaluated rather than a constraint and management alternatives are considered in defining reliability, 5) source strategies encourages consideration of unique combinations of solutions and careful consideration of planning objectives , 6) financial planning always considers the impacts the rate structure, and 7) drought contingency planning is included as an essential element of the IWRP process.

In addition, the IWRP has begun to include more attention to emergency planning and hazard assessment. Although natural hazards still present the greatest challenge to water systems, risks associated with human attacks must now be considered part of the planning process.

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