Order Number 1348488

Evaluating water management policy options for the Upper San Pedro Basin of Arizona

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The University of Arizona, 1992

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EVALUATING WATER MANAGEMENT POLICY OPTIONS FOR THE UPPER SAN PEDRO BASIN OF ARIZONA

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF HYDROLOGY AND WATER RESOURCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN WATER RESOURCES ADMINISTRATION

In the Graduate College

THE UNIVERSITY OF ARIZONA

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ACKNOWLEDGEMENTS

I am indebted to the members of my Committee, Edella Schlager, Assistant Professor, School of Public Administration and Policy; Michael Bradley, Professor, Department of Hydrology and Water Resources; and particularly, the chairman of my Committee, William B. Lord, Professor, Department of Hydrology and Water Resources. I am also thankful to Mary G. Wallace for her encouragement and guidance, and also to the people of the San Pedro River basin, specifically those who participated in this study. Finally, I would like to thank my parents, Norm and Kay Henrich, for their love and support.

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ABSTRACT

This study examines future water management options for the Upper San Pedro Basin. It is an effort to better understand the water related social values present within the basin and how they might be used to formulate sound water resource policy. To this end, techniques based upon decision analysis were employed to elicit and analyze the judgements of a sample of basin residents regarding water management. Relevant social values for the management of water were identified and then the Multi-Attribute Tradeoff System (MATS) program was utilized to rank available water management policy options. No option was found upon which all groups agreed, but directions can be provided for the development of future policies.

CHAPTER I. Water Management in an Arid Environment

Purpose

Introduction

This study explores future water management options for the Upper San Pedro River Basin (USPB), located in southeastern Arizona. The residents of the Upper San Pedro Basin face decisions regarding future water supplies, a situation typical of many communities in the arid southwest. Current supplies are derived from a small surface water supply and more extensively from underground reserves. While estimates of available groundwater in storage are large, this groundwater is being utilized at a rate greater than it is being replenished each year. Prospects for securing additional water from sources outside the basin are limited.

Water management in the arid regions of the United States, where dependable, sustainable water supplies are finite and where populations are expanding, is the subject of many studies focusing on the development of appropriate water management policies (Martin, et. al., 1984; Riesner, M., 1986; Riesner and Bates, 1990). Further, in these studies, there is an increasing emphasis on institutional solutions, in addition to technical solutions to water management problems. Finally, there has also been an increasing awareness of the need to account for the broader societal preferences in water management decisions, not simply the narrower interests of specific water users (Lord, 1986).

These developments are indicative of changing perceptions on the part of society regarding water resources. There is an ever growing emphasis on understanding "the social and environmental aspects of how water is used and misused, rather than solely technical issues of hydrologic systems" (Viessman and Schilling, 1986). Water has symbolic and aesthetic values as well as the more traditional values of production and consumption (Martin, Ingram et al., 1979: 4). These different values of water lead inevitably to differences of opinion and conflict over what is the "best" use of limited supplies.

One purpose of this study is to better understand how the residents of the Upper San Pedro Basin community feel about questions of basin water use. A thorough understanding of the preferences of basin residents and their points of conflict is prerequisite to the design of policy options capable of achieving a broadly based and lasting consensus, especially given the nature of water as a common pool resource.

The Common Pool Resources Problem

Water-related decisions affect everyone because of the common pool nature of the resource. In his 1968 article, "The Tragedy of the Commons," Garrett Hardin identified a class of problems facing humanity without technological solution, instead requiring a shift in social values and morality (Hardin, 1970: 31). This class includes problems related to the utilization and management of common pool resources such as groundwater, streams, lakes, wildlife, and the atmosphere (Ostrom, 1969: 157). According to Hardin, the absence of an answer to problems associated with common pool resources is "tragic" because the "remorseless working of things" (Hardin, 1970: 31) leads individuals, acting in their own best interest, to produce joint consequences that are not in their long-term interest (Ostrom, 1977: 173).

In Hardin's example, we are asked to imagine a pasture, open to all for livestock grazing (Hardin, 1970: p.36). Area herdsmen raise animals there. Each herdsman is assumed to maximize his own gain. So long as the carrying capacity of the pasture is not exceeded, each herdsman can continue to add to his herd without adversely affecting the grazing of animals already there. However, once the carrying capacity of the pasture is breached, a tragedy of the commons is set in motion.

Deciding whether to add an additional animal, each herdsman faces a gain and a loss. The gain is in the additional animal, a gain which accrues exclusively to the owner of the herd to which it is added. The loss is in the decreased yield of every animal kept at the pasture as a result of overgrazing. This loss is shared by all herdsmen utilizing the common pasture however, reducing its impact. Thus, the benefit to the herdsman adding an additional animal is greater than his loss. This situation applies to all herdsmen at the pasture, and this same reasoning supports the addition of more and more animals by all. The result is a tragedy because while individually each herdsman seeks to maximize his gain, in the end, everyone is worse off than they had been before exceeding the carrying capacity of the pasture.

Problems in the utilization and management of common pool resources occur for the following reasons: 1) ownership of the resource is held in common; 2) a large number of users have independent rights to the use of the resource; 3) no one user can control the activities of other users or, conversely, voluntary agreement or willing consent of every user is required in joint action involving the community of users; 4) total use or demand upon the resource exceeds the supply (Ostrom, 1977: 157).

The water resources of the Upper San Pedro Basin can be conceptualized as a common pool, much the same as the pasture in Hardin's example. Basin water resources conform to the four criteria outlined by Ostrom. There are a large number of water users with independent rights to the use of a common resource, a resource in which no user can control others without their willing consent. Under these conditions, the central problem facing the residents of the San Pedro River Basin and other western communities in the management of their water resources is the tragedy of the commons.

<u>The Collective Action Problem</u>

A secure water supply is an elementary task of community organization (Martin et al, 1979: 3). Throughout the West, a stable supply of a water has been a primary task facing communities. Many of the major populations centers in arid regions have centered around the limited surface supplies of water.

However, agreement over the best ways to use and manage water are not always easy to achieve because of a problem commonly referred to as "the collective action problem", or "the group decision making problem." The central notion of this concept is that "rational egoists are unlikely to succeed in cooperating to promote their common interests" (Taylor, 1987: 4). Common pool resources provide fine examples of collective action problems; among them Hardin's pasture and the Upper San Pedro Basin.

Mancur Olson (1965) succinctly identified a "Logic of Collective Action", arguing that "unless the number of individuals is quite small, or unless there is coercion or some other special device to make individuals act in their common interest, **rational, self-interested individuals will not act to achieve their common or group interests** (Olson, 1965: 2, as quoted in Ostrom, 1990: 6). Olson characterizes the key problem facing common pool resource appropriators as one of organizing their interests. The solution lies in the ability of people "to change the situation from one in which appropriators act independently to one in which they adopt coordinated strategies to obtain higher joint benefits or reduce their joint harm." (Ostrom, 1990: 39).

This organization, from independent to coordinated, or collective action, is one approach for the management of common pool resources (Ostrom, 1990: 40). Ostrom notes three conditions under which suitable collective arrangements for the management of common pool problems are more likely to occur: 1) "a high level of accurate information is provided to all affected individuals; 2) considerable freedom to enter in a wide variety of social arrangements exists; and 3) individuals can devise social arrangements that will induce individuals to take into account the social costs of their individual action in regard to any particular common pool" (Ostrom, 1977: 180).

Illuminating the preferences of the residents of the basin regarding water resources can facilitate the beginning of cooperative agreements to begin the process of organization of interests from the individual to the collective. We expect differences and conflicts, where compromise solutions must be sought.

This research follows from these perspectives - the water of the Upper San Pedro Basin is conceptualized as being a common pool resource with the associated problems related to use and management of this type of resource, including the problem of collective action. The purpose here is to provide an impetus for the development of meaningful and equitable collective action arrangements among basin residents to avert a tragedy of the commons.

Method

This water management study was undertaken through an agreement between The Cochise County Flood Control District and the Water Resources Research Center, University of Arizona. It is an effort to better understand the water related social values present within the basin and how they might be used to formulate sound water resource policy. To this end, techniques based upon decision analysis were employed to elicit and analyze the judgements of a sample of basin residents regarding water management. Relevant social values for the management of water were identified and then the Multi-Attribute Tradeoff System (MATS) program was utilized to rank available water management policy options.

The first stage of this portion of the study involved the identification of pertinent social objectives to guide the management of basin water resources. A list of possible underlying social values were generated and disseminated to a sample of basin residents for comment and suggestion. Based upon this review, a total of four social values were selected. A total of seven attributes were chosen to represent these social values in the analysis.

These seven social value attributes, or factors as they are termed in MATS, were presented to a selected group of basin residents through a series of field interviews. The factors were subsequently revised and further field interviews were conducted until a total of thirty basin residents were sampled. Two types of information was elicited: A relative weighting of the importance of each of the seven cues; and also a utility function, or function form, for each attribute.

The results of the field interviews were then analyzed to provide useful information in the context of basin water management. The results of the weighting portion of the field interviews were subjected to a cluster analysis in order to identify possible basin stakeholder groups. Three such groups were subsequently identified.

Additionally, a set of general water management policy options were generated and using a technique of the MATS program which employed both portions of the basin resident interviews (weights and function forms), a ranking of options in order of desirability was produced for each stakeholder group. Finally, the rankings of the three stakeholder groups were compared to discern the existence of an alternative highly desirable to all stakeholder groups.

No option was found which all groups agreed upon, which is hardly surprising given the likely conflicts over water use and the very general nature of the policy options. This study does yield information useful in the early stages of policy development.

Chapter II. The Upper San Pedro Basin

Study Location

The Upper San Pedro Basin is located in southeastern Arizona within a classic basin and range geologic province (Figure 1). The basin is comprised of a broad alluvial valley ringed by jagged, localized mountain ranges of crystalline and sedimentary rock. The basin extends areally over 4,400 square miles, including approximately 700 square miles in Mexico. Elevations range from between 3500 and 4500 feet above sea level at the valley floor, to over 9,000 feet in the Huachuca Mountain range along the western boundary of the watershed. The valley floor is underlain by between 500 and 1200 feet of consolidated and unconsolidated alluvium, with valley boundaries effectively coinciding with those of the watershed basin (Roeske and Werrell, 1973).

The basin is commonly divided into the Upper San Pedro basin and the Lower San Pedro Basin, with the dividing line drawn at "the narrows" about 10 miles north of the community of Benson, Arizona. The narrows is an area of bedrock outcropping that constricts flow in the river valley. The Arizona Department of Water Resources (ADWR) has further

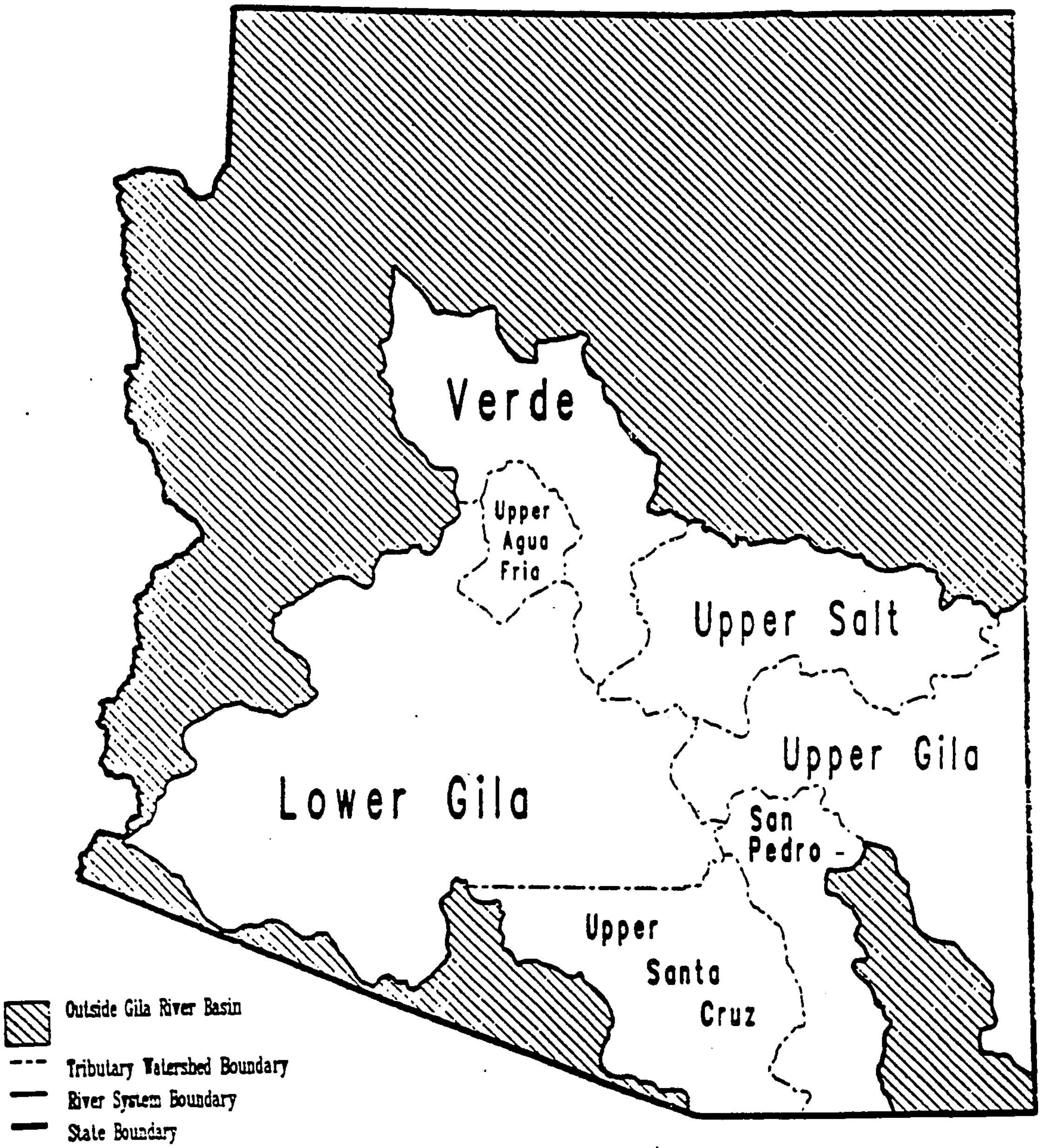


Figure 1. State of Arizona showing the Gila River System (Source: ADWR,1990).

divided the basin into a total of five sub-basins, two in the upper portion and three in the lower (Figure 2). The upper portion of the basin, which lies between "the narrows" and the international border just south of Palominas, Arizona (the Sierra Vista sub-watershed and the Benson sub-watershed) is the focus of this study. The climate of the region is characterized by very warm summers and cool winters. Average annual precipitation ranges from approximately 15 inches on the valley floor to 25 inches in mountain front areas.

Socio-economic Profile

Population in the Upper San Pedro Basin is concentrated in four areas: 1) Benson; 2) St. David/Pomerene; 3) Tombstone; and 4) Sierra Vista, with the largest concentration by far in the Sierra Vista area. Total population of the basin is estimated at 60,000 with some 35,000 living in the Sierra Vista area alone (ADWR, 1990: 39). Population is expected to grow at a moderate rate from both an urbanizing economy and in-migration from 1990 - 2005 (ADWR, 1990: 38). Higher rates of growth are forecast for the Sierra Vista area because Ft. Huachuca with 12,000 employees and another 11,200 military members, makes up about 66% of the metropolitan Sierra Vista population (ADWR, 1990: 40).

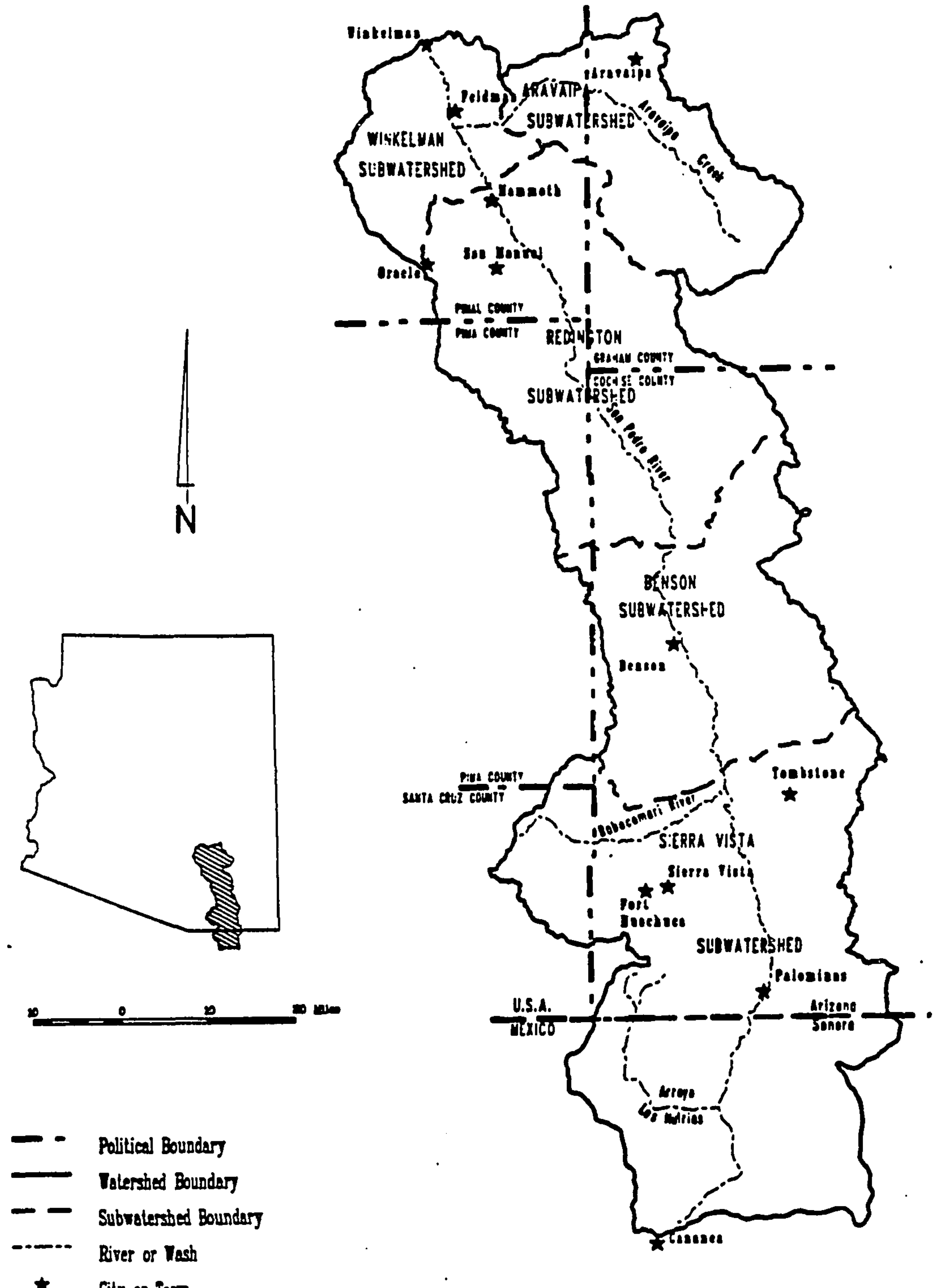


Figure 2. San Pedro River watershed (Source: ADWR, 1990).

The following percentages indicate the approximate distribution of land ownership within the basin: State of Arizona, 49%; federal government, 25%; private ownership, 25%; and Native American lands, 1%. The majority of land is utilized for agriculture and livestock ranching.

Average annual household income is estimated at $14,000 (de Gennaro, 1990: 152). The largest employer is federal, state, and local governments, responsible for nearly one in every three jobs (de Gennaro, 1990: 124). Of special note is Fort Huachuca, an Army base adjacent to Sierra Vista, which employs some 12,000 civilians in addition to a sizable military detachment. The balance of basin employment consists of service industries, trade, and to a lesser extent manufacturing, agriculture, and construction.

The overall economic climate is typical of many communities in the southwest. Agriculture and mining were historically the mainstay of local economies, and while their importance continues and is paramount in some segments, these industries no longer account for the majority of economic activity within the basin. In fact, the future of Fort Huachuca and its impact on service-related industries is a much bigger factor in the current economy.

Basin Hydrology

Surface Water

The San Pedro River, from which the basin takes its name, flows northward along the valley floor. The river originates near Cananea, Sonora, Mexico some thirty miles south of the international border and flows north 170 miles to its confluence with the Gila River near the town of Winkleman, Arizona. River flow is perennial for only 31 of these miles, and intermittent for the rest of its length (ADWR, 1990: 79). Streamflow also varies widely with seasonal weather conditions, with highest levels generally occurring in the summer months of July and August and lowest levels usually in the spring during April and May.

Streamflow in the San Pedro River has two components: runoff, the streamflow resulting from rainfall events and some snow melt, and baseflow, the discharge of groundwater to the stream (Putnam, 1987: 28). The baseflow is relatively constant and provides much of the streamflow during dry periods. The runoff is highest during the summer months with the onset of the summer monsoon season. Long-term annual flow of the San Pedro River entering the United States at Mexico is estimated at 23,420 acre-feet per year (ADWR, 1990: 260).

Regional Aquifer

Vast alluvial deposits provide excellent underground water storage. The regional aquifer is the largest source of groundwater in the San Pedro basin; it provides high quality potable water to basin residents. The areal extent of the regional aquifer is estimated at 862,971 acres (ADWR, 1990). Current estimates of the amount of groundwater in storage to a depth of 1200 feet in the Sierra Vista and Benson subwatersheds are 31.9 million acre-feet and 27.2 million acre-feet for a total of 59.1 million acre-feet (ADWR, 1990: 64), enough to support current consumption levels for several hundred years.

Groundwater overdraft conditions occur when groundwater pumping exceeds the annual recharge rate, resulting in a decline in the water in storage within the aquifer (Putnam, 1987: 17). In the San Pedro River Basin, overdraft conditions in the regional aquifer have been identified in the Sierra Vista-Fort Huachuca area (ADWR, 1990: 65).

Recharge to the regional aquifer occurs along the mountain fronts surrounding the basin during precipitation events, and from stream channel infiltration along the San Pedro River. The ADWR estimates total groundwater recharge in the Sierra Vista and Benson subwatersheds at 25,620 acre-feet per year (ADWR, 1990: 240).

The total estimated change in regional aquifer storage in the Sierra Vista subwatershed is -18,560 acre-feet per year, while no significant overdraft has yet been detected in the Benson sub-watershed. (ADWR, 1990: 240). The decline is relatively small and localized, with average water table declines of about 1.4 feet per year in the Sierra Vista area, and historically only .3 to .5 feet per year in the remainder of the basin (Putnam, 1987: 17).

As a result of concentrated pumpage in the Sierra Vista - Fort Huachuca area, a localized cone of depression in the water table exists. Estimates of the size of the cone range from 5 square miles (Konieczki, 1980) to 7.5 square miles (Putnam, et. al, 1987).

Floodplain Aquifer

The San Pedro River is linked with a smaller, much more localized "floodplain aquifer". These two aquifer systems and the river are conceptualized in Figure 3. The floodplain aquifer runs in a narrow band on either side of the river. The width of this aquifer ranges from a few hundred yards to

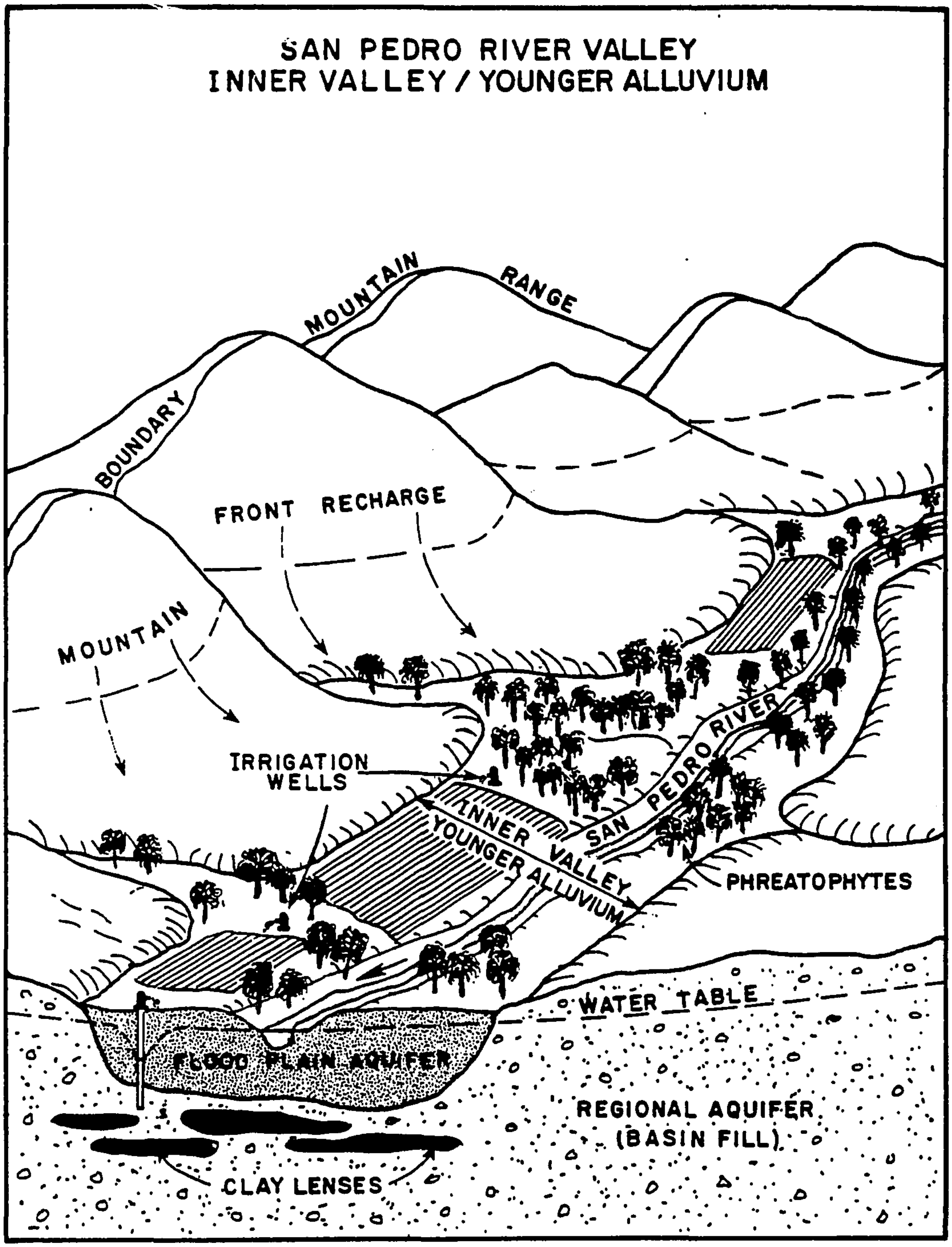


Figure 3. Schematic of the younger alluvium of the San Pedro River watershed. (Source: ADWR, 1990.)

several miles (Putnam, et. al, 1987: 23). The estimated amount of water in storage in the floodplain aquifer in the Upper San Pedro Basin is 283,290 acre-feet (ADWR, 1990).

The floodplain aquifer is important because it is the main mechanism for interaction between the regional aquifer and the surface water system within the basin (ADWR, 1990: 68). Additionally, this aquifer provides water for the phreatophytes in the riparian area and also is the main source of water for agricultural uses in the basin (ADWR, 1990: 68).

The floodplain alluvium is recharged by streamflow, by inflows from the regional aquifer, by percolation from agricultural areas, and by underflow from Mexico (ADWR, 1990: 68). This underflow is estimated at between 700 to 3,400 acre-feet per year (Freethey, 1982). Water levels in the floodplain fluctuate with seasonal variations and pumpage, but floodflows refill the aquifer to capacity each year (ADWR, 1990: 68). As of yet, no longterm declines in the floodplain aquifer water levels have been detected (ADWR, 1990: 69).

<u>Water Sources and Water Use</u>

Present water supplies for the basin population consist of the estimated 23,420 acre-feet of surface water available in the San Pedro River, the estimated 283,290 acre-feet of water stored in the localized San Pedro River floodplain aquifer, and the estimated 59.1 million acre-feet of water stored in the regional aquifer system underlying the basin. Additionally, approximately 2 million gallons per day (2,240 acre-feet per year) of effluent is produced in the basin, but the only present use is alfalfa cultivation (Felix, 1990: 36).

The San Pedro River surface flows provide a limited water supply to agricultural water users in the upper basin through two major diversions, The St. David Ditch and the Pomerene Canal. Both are used to divert water for irrigating farmland in and near the floodplain, with diversions totalling approximately 7000 acre-ft per year (Putnam, 1987: 83). The entire flow of the river is effectively diverted at times during the growing season by these two irrigation projects. The flow of the river is highly dependent on seasonal weather however.

Over the past century, groundwater pumpage gradually supplanted surface flows as the major water source for agriculture within the basin. A total of 6,490 acres of irrigated land is under cultivation throughout the Sierra Vista subwatershed, with most of this land irrigated by groundwater, and another 6,206 acres is irrigated with both surface and groundwater in the Benson subwatershed, where St. David and Pomerene are located. (ADWR, 1990: 119-121).

Nearly all the irrigated farmland within the basin is along the floodplain aquifer adjacent to the San Pedro River from which most of the supplemental groundwater is pumped. For example, of the roughly 1200 acres presently under irrigation in the vicinity of St. David, only 300 acres are supplied entirely through San Pedro River surface flows, with the balance supplied by pumpage (Putnam, 1987).

By far the largest water source available is that of the regional aquifer system. All major domestic, municipal, and industrial demand centers within the upper basin, including the communities of Sierra Vista and Benson rely on wells tapping the regional system for water supply.

The total amount of water consumed in the Upper San Pedro basin is estimated at 43,390 acre-feet per year for all human activities and another 34,690 acre-feet per year for natural depletions, for a total of 78,125 acre-feet per year. Natural uses include phreatophyte consumption and open channel evaporation. Approximately 30,380 acre-feet of water, about 70% of all human uses, is utilized by agriculture whereas the total amount of water used by the municipalities in the basin is estimated at 8,800 acre-feet per year, representing about 20% of total human uses.

The following table lists estimates for water use for the Upper San Pedro Basin:

Table 1: Water Uses in the Upper San Pedro Basin (acre-feet per year)

	Sierra Vista	Benson
Anthropogenic Uses:		
Irrigation	13,540	16,840
Domestic	450	250
Municipal	7,850	910
Stockpond	1,750	910
Reservoirs	150	310
Mining	0	0
Industrial	50	380
Total	**23,790**	**19,600**
Natural Uses		
Channel Evaporation	910	670
Phreatophytes	14,510	18,600
Total	**15,420**	**19,270**
Total Use	**39,280**	**38,840**

Source: Arizona Department of Water Resources, 1990.

Arizona Water Law

Modern Arizona water law has been shaped by physical characteristics and by a history shared with other western states. Aridity is the central physical reality; seasonal and annual variability in supply and also scarcity led to the granting of property interests in water. (Gregg, 1990: 1). The prior appropriation doctrine, under which a water right is "first in time, first in right," became a cornerstone of water law in the Western United States, including Arizona. Since statehood in 1912, Arizona has gradually increased regulation of both surface water and groundwater use and treats each resource separately under the law.

Surface Water

As in other Western States, surface water in Arizona is allocated according to the doctrine of prior appropriation. Under this principle, a right to use water is acquired when water is diverted and put to a beneficial use. The priority date assigned to that right is the date water is first put to use. Therefore, the surface water right has two components; seniority and quantity. In times of shortage, junior users must forego water use if necessary to ensure that a full supply is available to those holding senior rights.

In Arizona, surface water is defined as "the waters of all sources, flowing in streams, canyons, ravines or other natural channels, or in definite underground channels" (ARS 45-141(A)). Since 1919, a permit has been required to appropriate surface water for use in Arizona.

Groundwater

For most of Arizona's history, there was little or no regulation of groundwater. Landowners, under the American rule of reasonable use, could pump groundwater from beneath their land. Essentially, there were no restrictions on use other than that it be a reasonable and beneficial use. This is the case in the San Pedro River area and throughout much of the state.

However, in 1980, the Arizona Groundwater Management Act was enacted, both creating the Arizona Department of Water Resources (ADWR) and initiating groundwater regulation in the most populous areas of the state including Phoenix and Tucson. In these areas, and in Prescott and Pinal County, the Act established Active Management Areas (AMA) in which all groundwater uses are restricted.

The Act also mandates mandatory conservation measures for the municipal, agricultural and industrial sectors. In Tucson and Phoenix, the intent is to gradually reduce groundwater pumping until safe-yield (a condition where pumping equals the amount of all water recharged - natural, incidental, and deliberate - each year) is reached, with a target date of 2025.

The Groundwater Management Act (GMA) does not apply to the San Pedro Basin. A proposal to create an AMA there was considered and rejected by the Arizona Department of Water Resources. While current hydrologic conditions and water use patterns within the San Pedro Basin may not warrant the type of Active Management Area already in place in other areas of the state, the existence of GMA makes possible the creation of an AMA tailored to the specific needs of the San Pedro Basin, an option discussed in the last chapter.

Gila River Adjudication

An institutional consideration overshadowing current water management efforts throughout the state is the Gila River Adjudication. Compelled by a series of lawsuits filed by various water rights holders throughout the state, the state court system has undertaken a general adjudication of water rights throughout the entire Gila River watershed, of which the Upper San Pedro Basin is a part (ADWR, 1990).

This proceeding will settle the water rights claims of all surface water users in the San Pedro River Basin, along with all other surface water users in the Gila River watershed. When concluded, all surface water users will know how much water they are entitled to use and the priority date of their claim. However, these proceedings will probably take several years to complete.

A central issue in the adjudication is how the interconnection between groundwater and surface water will be handled by the court. In many places in Arizona, pumping from the sub-surface - water that is directly connected to the streamflow - has been ongoing for years. However, it is water that has never been deemed appropriable under the State surface water code.

In 1988, the presiding judge, Stanley Z. Goodfarb, issued a pre-trial order that defined appropriable ground water as water pumped by wells in the younger alluvium and meeting a 50%/90 day rule. Under this rule, water pumped from wells where the reduction in the volume of streamflow reaches 50% or more of the total volume pumped within a 90 day period is appropriable. If the ruling stands, it will affect wells located close to the San Pedro river in the floodplain aquifer.

San Pedro Riparian National Conservation Area

The federal government has designated the nation's first national conservation area - the San Pedro Riparian National Conservation Area (SPRNCA) - in the region of concentrated perennial flow just north of the international border. Created because of its unique character, it is one of the few perennial flow streams with mature riparian vegetation remaining in Arizona (USDI, 1987).

Administered by the BLM, The SPRNCA covers the riparian corridor along the river from the U.S. - Mexico border north to the St. David irrigation diversion ditch, a distance of some 37 miles and covering 56,431 acres (USDI, 1987). The BLM is currently seeking an instream flow right for surface water for the purpose of maintaining the riparian vegetation. A primary concern of the BLM is a possible reduction in baseflow that may occur as a result of pumping patterns within the basin, particularly: 1) the agricultural withdrawals from the floodplain aquifer; and 2) increased pumpage in the Sierra Vista from municipal growth.

Chapter III: Decision Analysis

Introduction

Decision analysis is concerned with improving the way decisions are made. As applied to the San Pedro, this includes determine the relevant social values and objectives as these relate to water. However, there is often confusion over what these terms mean. To help define these terms, this chapter opens with a brief discussion of social values, objectives, and attributes, and a discussion of water management objectives, particularly as they relate to the San Pedro basin. It then introduces decision analysis. The chapter closes with a discussion of the Multi-Attribute Tradeoff System.

Social Values, Objectives, and Attributes

A necessary step in successful water management planning is the development of relevant planning objectives (Viessman and Schilling, 1986). These objectives are derived from the underlying social values of the community. **Social values** can best be described as "those widely shared yet vaguely articulated notions of what is good and desirable . . . that characterize a culture" (Lord, 1986: 3). Social values help "organize and guide preferences" for society, for the family, for and the individual (von Winterfeldt and Edwards, 1986:

38). They are the foundation for interests and needs (Priscoli, 1990: 5).

A **social objective** is in turn a transformation of a social value that is formalized and operationalized for analytical purposes (Lord, 1986: 5). An objective "generally indicates the direction in which we should strive to do better" (Keeney and Raiffa, 1976: 34). In contrast to the social values from which they are derived, objectives are articulated straightforwardly, providing both direction and guidance for the balance of the planning process, and also, a means of evaluating plan performance, to the extent they are achieved.

An **attribute** represents a value dimension (Edwards and Newman, 1986: 18) and is a measurable indicator of an underlying social value (Keeney and Raiffa, 1976: 34). Attributes are even more specific social value representations than objectives. They provide cardinal number scales for the numerical operations of comparison and evaluation. Value attributes also serve as cues in making tradeoffs between competing values.

A simple example involving the Postal Service should help to clarify the terms **social value, social objective, and attribute.** First, let us assume that the U. S. Postal Service, as well as society, espouses the ideal that individuals should always put forth their best effort when performing tasks. The exact origin of this social value is rooted in a number of historical antecedents, including the protestant work ethic. Let us refer to this broad social value as "Diligence." A corresponding Postal Service objective derived from the social value "Diligence" could be to "minimize the transit time for parcels and letters." This objective is easily enunciated and provides a constant direction for achievement.

An attribute for measuring the degree to which the underlying social value is achieved could be "time in days from sender to receiver." Here, the attribute scale is number of days, with the smallest number representing the best achievement of both the social value "diligence", and also its representative objective "minimize transit time for parcels and letters."

Water Management Objectives

Nearly all decisions involve multiple objectives. When these multiple objectives are in agreement, decisions are simple. Difficult decisions arise when "within the set of options you have, doing well on one objective requires that you do poorly on another" (von Winterfeldt and Edwards, 1986: 5).

Decisions regarding public policy, including water management, are further complicated because doing well or poorly means different things to different people. As Keeney and Raiffa note, "It is almost a categorical truism that decision problems in the public domain are very complex" (Keeney and Raiffa, 1976: 12). Often the norm is that multiple decision makers are involved. Social objectives for the management of water must reflect the existence of multiple objectives and also decision-makers, or stakeholders.

Stakeholders are individuals or groups who care about a decision and can impact the decision process. They are the source of value attributes for the decision (Edwards and Newman, 1982, 23). In this study, the stakeholders are the residents of the Upper San Pedro Basin.

An example concerning multiple objectives can be drawn from the Upper San Pedro Basin. First, there is a strong commitment among some basin residents to preserve the existing perennial flow regime within the San Pedro Riparian Conservation Area, a federal preserve occupying most of the river's perennial reach in the upper basin. However, nearby development, primarily in the Sierra Vista area, is placing increasing demands on the water supply. In light of limited future water supplies, these two desires, to maintain the flow of the river and to sustain development in the Sierra Vista area, may result in conflicting water management objectives.

Conflicting objectives are indicative of conflicting values. Value conflicts, where one value directly competes with another, are a primary source of environmental conflicts (Priscoli, 1988: 5). To arrive at a solution of conflicts of this type will often necessitate tradeoffs among these values.

These tradeoffs are judgements. Tradeoffs are personal, with no objective or universal rules for making them (von Winterfeldt and Edwards, 1986: 11). However, decision analysis techniques can be developed to assist decision-makers when making tradeoffs. Decision analysis is especially concerned with multiple competing objectives (von Winterfeldt and Edwards, 1986: 5).

Decision Analysis

Decision analysis is a specialized field of research, having developed in the latter half of this century as an off-shoot of economics. In "Theory of Games and Economic Behavior", von Neumann and Morgenstern used mathematical techniques to further the idea that decision-makers either do or should choose the option that maximizes utility, applying it also to decisions in risky situations (von Winterfeldt and Edwards, 1986). Simply put, the authors hoped to help people make difficult decisions well, or as well as possible for as von Winterfeldt and Edwards argue, "the quality of decisions really means the quality of the processes by which they are made" (von Winterfeldt and Edwards, 1986: 2).

Decision analysis is specifically designed to help individuals and organizations make wise inferences and decisions. It is a "well-established method for dealing with complex problems" (Sisson, et. al:, 1990: 355). Decision analysis synthesizes ideas from economics, statistics, psychology, operations research, and other disciplines (von Winterfeldt and Edwards, 1986).

Decision analysis relies on formal models and other techniques to help people be rational in making inferences and decisions (von Winterfeldt and Edwards, 1986: 3). As von Winterfeldt and Edwards note, the notion of rationality is prescriptive - it is rational not in the sense that goals or required courses of action can be specified but instead that "ways of thinking and acting can be selected to serve your ends or objectives or moral imperatives, whatever they may be, as well as the environment permits" (von Winterfeldt and Edwards, 1986: 2). Decision analysis requires the clarification of the values of the decision-maker before decisions are made and also assumes that decision-makers will and should seek to maximize the expected utility based upon these values.

Decision analysis has been applied in a wide range of human choice problems and in various stages of the decision-making process (Arkes and Hammond, 1990; Brown, 1984; Sisson, et. al; McNeil, et. al.). Decision analysis can be used to inform an individual about the consequences of particular actions and about his/her own values and how they can be used to make better decisions (Zalkind, D. and R. Schactman, 1990: 369). Decision analysis is intended to simplify these difficult decisions by adding structure through the use of models and other techniques (Arkes, H. and K. Hammond, 1986: 10).

While decision analysis cannot solve problems, it can assist in the journey towards a solution. As Herbert Simon noted, "We see that reason is wholly instrumental. It cannot tell us where to go; at best it can tell us how to get there. It is a gun for hire that can be employed in the service of whatever objectives we have, good or bad." (Simon, H. A., 1983: 7).

Decision analysis can be useful in the pre-decision phase, because it can help identify values, which can then be considered during policy formulation (Priscoli, 1990). Policies formulated according to value based compromise create the possibility of consensus (Priscoli, 1990: 6). This is a multi-step process, for values and objectives must be identified and understood before substantive interaction and resolution can occur.

Multi-Attribute Tradeoff System

The Multi-Attribute Tradeoff System (MATS) is an analytical tool designed to aid in the implementation of decision analysis concepts in complex choice situations. Developed by the Bureau of Reclamation, MATS is a formal model and as its name implies, is specifically designed to aid decision-making in instances where tradeoffs between competing objectives are necessary (Brown, et. al., 1986).

It should be noted that the definition of relevant social values and applicable value dimensions for the decision, perhaps the most important phase of a decision analysis of this kind, must be completed before any substantive interaction with MATS is possible. The value of MATS lies not in the original generation of appropriate social values and representative attributes (the user does that), but in providing analytic structure where deficiencies in value representation and definition can be identified and easily changed.

A primary feature of MATS is that it can help define the decision-maker's preferences or values relevant to the alternatives being considered and also to record the implications of each decision option for each of the values (Brown, Stinson, and Grant, 1986). MATS provides a means to use the decision-maker's values (called factors in the MATS language) to evaluate alternatives by incorporating technical information with these values to produce a ranking of options (called plans in the MATS language).

Decision makers interact with the MATS program interrogatively, comparing each of several hypothetical levels of attainment of each factor, and also weighting factors relative to one another. The results are then presented as a function form for each factor or attribute and a set ofweights for all the factors. Taken together, these weights and function forms permit calculation of an overall value index, called utility. MATS then computes the total utility which would beprovided by each decision option, if it were to be chosen and implemented.

MATS facilitates the weighting of value attributes by presenting them along with visual and interrogative aids to assist decision makers in making necessary tradeoffs. Through weighting, the value attributes (factors) are ranked relative to one another according to each of the participants individual preferences.

The technique employed by MATS is represented below in Figure 4. This produces a cardinal number score for each option based on the respondent's preferences, as expressed in the weights and function forms.

Figure 4: Technique employed by MATS

$$\text{Plan Score}(K) = \sum_{nfac}^{i=1} (wgt(i) * util(i,k))$$

Where:

k = plan
nfac = number of factors in project
wgt(i) = standardized weight of factor i

$$wgt(i) = \frac{wgt(i)}{\sum_{nfac}^{j=i} wgt(j)}$$

Hence:

$$\sum_{nfac}^{i=1} wgt(i) = 1.0$$

util(i,k) = the value of the utility function of factor i, at impact k.

MATS structures a decision through the use of five components: Factors, Weights, Function Forms, Plans, and Impacts. These are briefly summarized below.

<u>Factors</u>

Factors are attributes, and are measurable representations of the values upon which the evaluation of alternatives will be based. Numeric scales are used to quantify the factors, and thereby provide the "value dimensions" discussed previously. For example, in the San Pedro Basin, factors could include the price of water, the preservation of the agricultural segment of the local economy, and/or future economic growth.

Social values are complex, ambiguous, and multi-dimensional, and factors can only hope to capture part of this richness. As a result, factors must be selected carefully, and in some cases more than one factor is necessary to adequately represent a social value. The identification of appropriate factors is extremely important, and in the case of some social values, very difficult.

Weights

Weights rank the factors relative to one another according to each decision-maker's preferences. Because factors are representative of underlying social values, weighting thus ranks relevant social values relative to one another. For example, an environmentalist might attach more weight to factors representing preservation of riparian habitat and less to those indicative of economic rate of growth. A strong proponent of economic growth and development might reverse those emphases. This weighting function is a significant feature of MATS. MATS facilitates the weighting of value attributes by presenting them as factors and employing visual and interrogative aids to assist decision makers in making necessary tradeoffs.

Function Forms

Function forms describe how the utility derived from a factor changes as the quantity of the factor changes. This is achieved through the creation of a function form, or utility function, for each scaled value attribute, or factor, based on the decision makers personal preferences. Function forms are created by the decision-maker and the MATS program interrogatively. The decision-maker is asked to specify his or her preferences across the entire range of the value attributes (factors). Function forms can be positive linear, meaning more is better; negative linear, meaning less is better; or they can have a "best" value somewhere between the attribute endpoints.

Plans

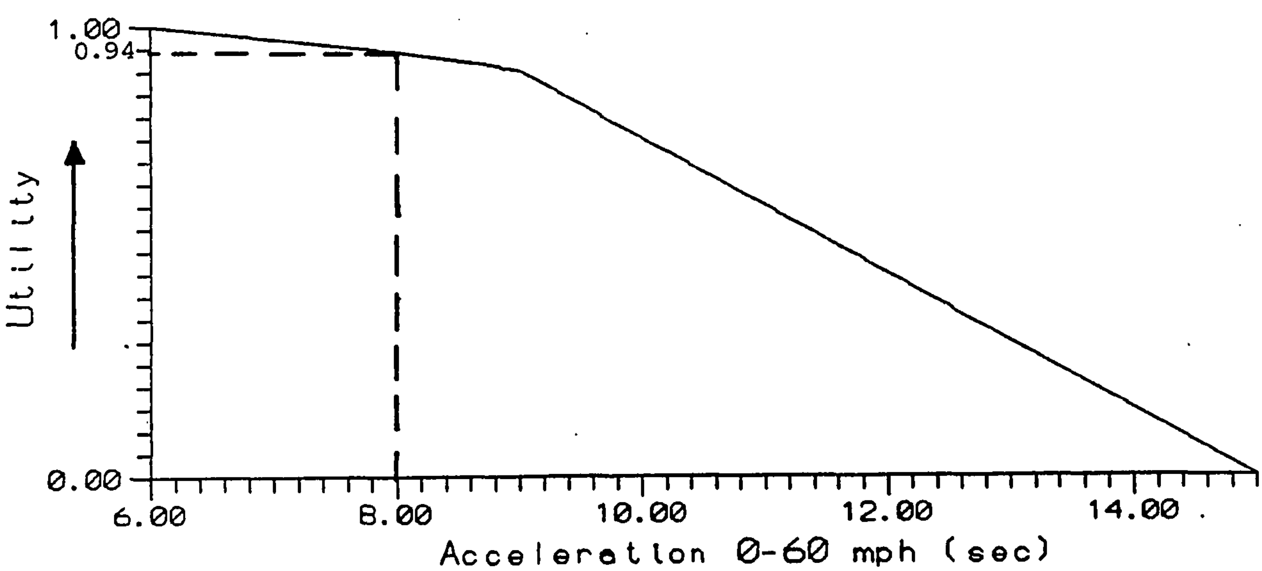
Plans are simply the options that a decision-maker may choose. They are the object of evaluation. Plans for use in this study were generated by University of Arizona researchers working on a related project. A total of ten policy options, including the status quo, were identified for use in the MATS study and are explained in the next chapter.

Impacts

The **Impacts** of a plan are the changes in factor values that result from the implementation of a particular plan. Impacts are developed by estimating how each plan affects the factor set. These impacts are quantitative; plan impacts must fall between the endpoints of the numeric ranges developed for each factor.

Figure 5 below illustrates the translation of an objective impact into a subjective score using function form.

Figure 5



In this example, the decision-maker is a prospective car buyer, and the alternatives under consideration are various cars. This function form was created for the attribute "acceleration" (0-60 mph), which has a range from 6 to 15 seconds, and is essentially negative linear in accordance with the decision-makers' apparent desire for a car with rapid acceleration. In this figure, it is illustrated how a car with an acceleration value of 8 seconds has a subjective score of .933 for this decision-maker.

Once all these components have been entered, an evaluation that combines the values of the decision-makers and the plans' impacts can be made to produce a ranking of the options. This ranking is accomplished through the conversion of function forms and weights into scores, with the scores providing a numeric representation of the total utility that plan would provide to that decision-maker (its desirability).

CHAPTER IV - APPLICATION TO THE UPPER SAN PEDRO BASIN

Introduction

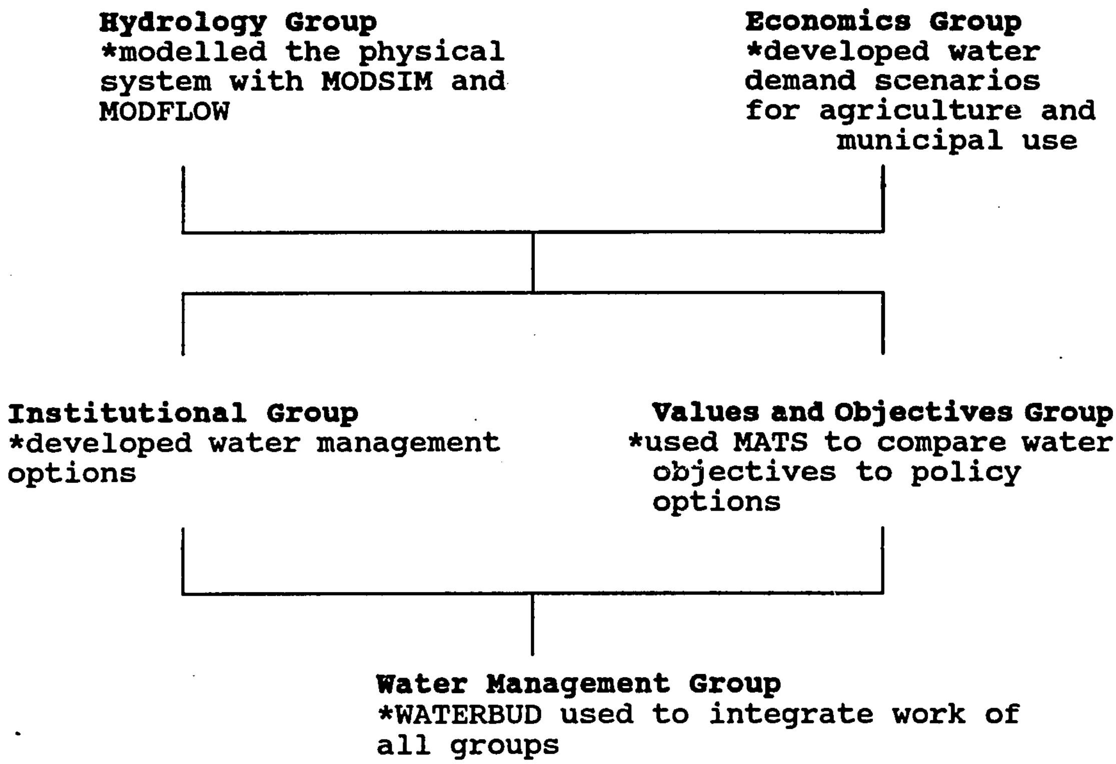
This Study was accomplished as part of a larger study commissioned by the Cochise County Flood Control District in the Fall of 1990 and Spring of 1991. A university team of six professors and twelve graduate students was formed to to assess the water resources situation of the basin and to provide some analytical support to the San Pedro Water Management Council, a local water interests organization. This study was part of that larger effort.

The university study utilized a linked model approach in which four separate models, including MATS, were used to examine the hydrologic conditions of the basin and also to evaluate water management options. The students involved were divided into five separate work groups: 1) a hydrology group; 2) an economics group; 3) an institutional alternatives group; 4) a management group; and 5) a values and objectives group. These groups spent several months collecting and analyzing information relevant to their group assignments. Then four models were chosen for use in the study as analytical aids in evaluating various water management options.

The first, a revised version of MODFLOW, modeled the aquifers near the Sierra Vista area to provide information regarding pumpage and its relation to streamflow. The second, MODSIM, modelled the aquifers and also the river and the water allocation institutions through a network optimization process. The third model, WATERBUD, was constructed specifically for this study. It utilizes a spreadsheet format written for use with the LOTUS 1-2-3 Release 3 software. This models allows the user to examine how varying hydrologic, socioeconomic, and climatic conditions, coupled with various water management policies, affect the water resources within the basin over the next twenty years.

The relationship of these models and the work groups are represented in the following figure:

Figure 6: Overview of Linked Models Approach



<u>Previous Efforts</u>

Previous to this study, residents of the San Pedro Basin have made attempts to specify goals and objectives for the management of local water resources. For example, in 1985, the San Pedro Water Resources Association was formed by a resolution of the Cochise County Board of Supervisors. Specifically, this group was charged "to investigate water issues, short-term and long-term, affecting the Upper San Pedro Basin, and to issue recommendations to the Board of Supervisors and to cities within the basin" (SPWRA, 1985).

One of the first efforts of this group was to specify goals for basin water management. The listings in this table illustrate the difficulty in differentiating between goals, objectives, and means with a mix of all three listed above. These goals are summarized in Table 2 below:

Table 2: Goals of the San Pedro Water Resources Association

* To insure rational decisions are made regarding basin water resources;
* To develop a means so that water resource decisions are made at a local level;
* To develop a water management plan to ensure adequate water supplies for present and future needs;
* To foster a spirit of cooperation and compromise among water users;
* To preserve the riparian habitat of the San Pedro River;
* To better understand legal issues surrounding Basin water use;
* To protect the quality and quantity of water resources in the basin;
* To collect and compile all data relevant to basin water resources (SPWRA, 1985).

Another effort was undertaken in 1990. In June 1990, the ADWR as part of a statewide water planning effort held a meeting in Sierra Vista to solicit public opinion regarding water resources issues in the San Pedro River Basin area. One focus of the state water plan and a discussion topic at the meeting was "what is the management structure in the state on a local basis and how those governmental and institutional structures are taking us into our futures" (Steve Olson, 1991: 2).

As part of this discussion, a basin resident stated two objectives: 1) to preserve the San Pedro Riparian Conservation Area and maintain the flow of streamwater in the river; and 2) to ensure the accommodation of economic growth and possible limitations related to water supply, both in the context of the Gila River Adjudication (Cooper, 1991: 7).

Finally, one other meeting sponsored by the San Pedro River Basin Water Management Council was held that also revealed basin preferences toward objectives. The Council, the successor to the San Pedro Water Resources Association, sponsored a public meeting for basin residents. Assisted by outside facilitator, the purpose of the meeting was to provide a forum for basin residents to "explore and clarify the objectives of the water management plans" under consideration by the university study (Dorrance, 1990: 1).

A technique known as Nominal Group Process, which has been employed in many settings including the determination of federal water planning goals (See Bolton, et. al, 1983) was used to elicit objectives. A very broad question - "What types of activities, factors, or controls should be included in the management plan for the San Pedro Basin? - was posed to basin residents. A wide range of responses (fifty-eight in total) were elicited running the gamut from objectives to means to goals (A full listing of these responses is included in Appendix A). Based upon the earlier efforts of basin residents and this listing of responses, the university team identified the following objectives (Dorrance, 1991). :

Table 3: Water Management Objectives for the Basin

1) To maintain and enhance water dependant riparian ecosystems, especially the San Pedro Riparian National Conservation Area;

2) To satisfy the reasonable water demands of current residents of the basin, with reasonability interpreted to imply no radical changes in lifestyle;

3) To support new development and growth within the basin, with the proviso that equity be established in the distribution of costs and benefits;

4) To maintain a water-dependant irrigated agricultural sector for so long as the substantial water requirements of that sector neither foreclose additional urban growth nor threaten critical riparian habitat;

5) To manage water cooperatively with non-basin entities such as Mexico or the Gila River Adjudication.

Application of MATS

Identification of Study Participants

The first stage of this portion of this study involved gathering a pool of possible study participants. Every member of the San Pedro Water Management Council was asked to list at least five people who he/she felt were knowledgeable and/or interested in water issues in the basin. Every person's name appearing on these lists was then also asked to list at least five people they felt were knowledgeable and/or interested in basin water issues. This process continued, with additional mailings sent out as needed, until no new names were identified by those returning lists.

This "snowball" technique yielded a total of over 150 names of people knowledgeable about water from throughout the basin and from surrounding areas. All local communities, including Pomerene, St. David, Tombstone, Sierra Vista, Hereford, Huachuca City, were represented and representatives of local governmental entities such as the Arizona Department of Water Resources and Bureau of Land Management, agricultural interests, and also local environmental groups such as the Nature Conservancy, the Sierra Club, and the Audubon Society were also included.

Identification of Social Values

This next stage of the study involved identification of pertinent social values to be considered when designing future water management strategies for the basin. The challenge at this stage is twofold; all relevant social values relating to water management in the basin should be addressed, while still keeping the resulting number of attributes as manageable (small) as possible.

The values and their attributes must be related to water management and should represent what is important when making water-related decisions. Also, these values are admittedly complex and arriving at attributes which adequately represent them is difficult. Ideally, one attribute should sufficiently capture the essence of the value it describes. In some instances however, more than one measure is required for each value.

An attempt should be made to keep the number of value attributes as small as possible because as the number of values and their associated measures grows, the analysis becomes more complex and difficult to manage (Keeney and Raiffa, 1976: 52) (for both the subject and the analyst). Additionally, as the number of attributes increases the difficulties in quantifying multiattribute preferences increase greatly (Keeney and Raiffa, 1976: 52).

Based upon the objectives identified above, a team of researchers associated with the University study generated a list of four possible values and associated attributes. These values and their attributes were then circulated to all 150 persons identified through the use of the snowball technique.

Each participant was informed that she/he had been identified as a person who is knowledgeable and concerned about water-related issues in the basin by other basin residents. They were then asked to evaluate the values and attributes for our water resources planning simulation. The respondents were asked for ideas or reactions to either the value or the method of measure (attribute).

Four social values with seven corresponding attributes were presented to the respondents. The first, Economic Well-Being, is defined as the economic prosperity and viability of the basin community and its members. The attribute chosen for this value was Median Annual Household Income in Dollars.

The second value, Amenity/Environmental Quality, refers to the quality of life aspects such as the condition of the environment and other aesthetic concerns. This value also refers to living within a desirable and healthy environment. Two attributes were necessary to capture this value: 1) the Length of Riparian Ecosystem in Miles - the longer this ecosystem in miles, the higher the environmental value; and 2) the Percentage of people living outside incorporated areas

- the value of the rural lifestyle as compared to that afforded by towns and cities.

The third social value is Risk/ Security/ Autonomy. This value refers to how much control basin residents have over water management decisions. It also deals with the assurance of present and future water supplies. Having adequate supplies of high quality potable water and control over these supplies is perceived as an important value within the basin community. The attribute presented is the Percent Chance of a Water Shortage resulting in a 25% cut in availability. A water shortage is defined as the inability to deliver as much water as is requested.

The fourth social value chosen is defined as Distribution of Economic Impacts/Equity, which addresses the perceived fairness in the distribution of water supply benefits and costs. This value concerns how these costs and benefits are distributed. It addresses the question of equitable development of water supplies in the basin. The development and increased use of water resources within the basin affects all basin community members because the public may be asked to finance this development to some extent. The attribute presented is the Percentage of new development cost to be shouldered by the public versus the percentage of new development costs to be shouldered by direct beneficiaries.

Direct beneficiaries are those who benefit from the increased assurance of supply that water development creates.

Selection of Final Values and Attributes

A number of responses, both written and verbal, were received to this survey of values. A meeting for basin residents was subsequently convened to provide a full forum for consideration. As a result of this meeting, all four values were chosen for use in the study. However, changes were made to the attributes chosen to represent the values.

As noted earlier, attributes are measurable representations of the social values. Selection of attributes that fully and accurately capture the richness of underlying social values is perhaps the most difficult phase of the study. Choosing attributes which are appropriate often requires more than one attempt, with continual revision.

Seven attributes were originally chosen but after an initial round of interviews, two were dropped. One, the amount of irrigated acreage, was dropped because it proved to be unsatisfactory in representing the relevant underlying social value, Amenity/Environmental Quality. The other, the stability of basin water table conditions, created judgmental dependencies that affected the entire factor set.

For the first value, Economic Well-Being, two factors were chosen to measure the social value of economic well-being. The first, median annual household income (in dollars), is a measure of the economic prosperity and viability of the basin community and its members as a whole in dollars. An additional attribute was added for this value, median annual household income in rural areas, designed to measure the economic viability of non-urban areas of the basin.

The second social value, Amenity/Environmental Quality, also has two attributes, or factors. Two changes were made. First, the attribute measure of the riparian area was changed from length in miles to total acreage. Secondly, the level of urban population in the basin was used instead of the number of people living in unincorporated areas for the second attribute. Both of these attributes are intended to measure aspects of the environment.

The third social value Risk/Security/Autonomy was changed to reflect only the social value Autonomy. No adequate attributes of risk and security could be could be specified within the constructs of this study. The new social value Autonomy now represents whether control over water should reside with local residents, or at a higher level, i.e., the state or federal level, thus only addressing the Autonomy value. This attribute was represented by a subjective scale, ranging from 1 to 3, with 1 representing local control, 2 representing state control and 3 representing federal control over water resources management.

Following the initial round of sampling, the scale of this attribute was again revised; in subsequent sampling the range of this attribute was presented in dichotomous form. This limited the question to simply whether or not local water management is desirable.

The fourth social value Distribution of Economic Impacts/ Equity, this value represents the preferences for how costs of water management should be distributed between the recipients of new water development and basin residents generally. This attribute also required the creation of a subjective scale. Ranging from 0% to 100%, participants were asked to what extent new water management costs should be shouldered by direct beneficiaries. It was represented through the use of two dichotomous statements: 1) Additional water management benefits everyone and therefore water management costs should be paid by everyone; 2) Additional water management benefits those creating its need and therefore they should pay its cost. Basin respondents were asked to characterize their personal preferences somewhere between these two statements, with statement #1 representing 0 and statement #2 representing 100 on the MATS factor range scale.

The four social values and their representative attributes or factors, are summarized through the use of a value tree in Figure 7:

Figure 7: Value Tree of Social Values and Attributes

UNDERLYING SOCIAL VALUES	MEASURABLE ATTRIBUTES (FACTORS)
Economic Well-Being	Median Annual Household Income ($)
Amenity/Environmental Quality	Urban Population within the basin
	Riparian Acreage within the basin
Autonomy	Level of Basin Water Management
Economic Impacts/Equity	Statement Characterization

This value tree is useful in depicting the relationships between the underlying social values and the decision attributes.

Numerical ranges were also developed for each of the attributes based upon current basin conditions. These ranges were developed through the use of Census data, the Hydrographic Survey Report prepared for the Gila River adjudication by the ADWR, and through the use of WATERBUD, a model developed for use in the larger University study. The ranges are used to specify the function forms and impacts that together with the relative weighting of the attributes provide the subjective scores of the evaluation.

These ranges are summarized in Table 4:

Table 4: Numeric Ranges of Attributes

Value	Attribute	Numerical Range
Economic Well-Being	Median Household Income	$13,000 - 15,000
	Median Rural Income	$13,000 - 15,000
Amenity/Env. Quality	Riparian Acreage (acres)	0 - 45,000
	Urban population	25,000 - 150,000
Autonomy	Basin Control	0 - presence of local 1 - absence of local
Equity	Distribution of Water Costs	0 - all pay 1 - some pay

For the value of economic well-being, the numerical range chosen for the attributes median household and rural income is the 1989 census figure. The numerical range for the attribute riparian acreage is from 0 to 45,000 acres. The range for urban population is 25,000 to 150,000 people. The range for basin control is expressed as 1 for local presence, and 2 for absence of local control. The numerical range for the distribution of water costs is expressed as 1 for all residents share the cost of new development and 2 for only those residents who benefit directly pay.

Basin Interviews

With the specification of the MATS model complete, interviews were then conducted with basin residents selected from the sample drawn previously. Participants were chosen to represent the community at large, with representatives from the major communities, all sectors of the economy, and also environmental groups.

Two separate rounds of interviews were conducted in the Spring of 1990. The people interviewed were asked, using the calibrated MATS program, to give their preferences regarding the attributes as a set by weighting them relative to one another, as well as independently, in order to produce the needed function forms. The interrogative feature of the MATS program allowed the basin residents to express their preferences about each of the social values.

Thirty basin residents completed the MATS exercise in the two rounds of sampling. Because the attributes underwent revision between rounds, only those common to both rounds of sampling were analyzed further. Those four common factors are Median Annual Household Income, Riparian Acreage, Urban Population, and Level of Basin Water Management.

Cluster Analysis

Cluster analysis techniques were utilized to search for and identify possible water management interest groups in the basin based upon the weighting of the value attributes by the study participants. The attribute weights and the function forms which characterized each respondent were analyzed in order to identify natural grouping tendencies and thus possible water management stakeholder group divisions within the basin.

A statistical technique known as cluster analysis was employed in order to identify natural groupings. Clustering is defined as the "grouping of similar objects" (Hartigan, 1976: 1). Cluster analysis seeks to classify a set of objects into subgroups although neither the number nor the members of the subgroups is known (Wilkinson, 1990: 19) For this study, a group is any number of study participants who share similar attitudes towards the attributes presented. The word clustering is most synonymous with classification. Properly executed it is a formal, planned, purposeful, or scientific classification (Hartigan, 1975).

A Clustering algorithm is used to search through the set of all possible clusters to find related groupings. There are several widely used algorithms, or methods available to analyze data for clusters, and the Kmeans algorithm was chosen for use in this study, the algorithm used by SYSTAT. SYSTAT is a computer software statistical package that performs a number of data analyses, including clustering.

For this study, the attribute weighting was chosen as the criterion for clustering because the standardized weights provide a representative of the relative importance of the underlying social values relevant to the decision. The function forms were used to characterize the utility of the identified clusters.

The weighting portion of the MATS field surveys, where the thirty study participants ranked the attributes in relative importance was subjected to the Kmeans clustering algorithm. To produce partitioned clusters via the KMEANS algorithm, you must decide how many clusters you want. KMEANS then searches for the best way to divide your objects into different sections so that they are separated as well as possible.

KMEANS begins by picking "seed" cases, one for each cluster, which are spread apart from the center of all the cases as much as possible. Then it assigns all the cases to the nearest seed. Next, it attempts to reassign each case to a different cluster in order to reduce the within-group sum of squares. KMEANS continues to reassign cases until the within-groups sum of squares can no longer be reduced. Because it focuses on reducing within-group sums of squares, KMEANS is like a multivariate analysis of variance in which the groups are not known in advance (Wilkinson, 1990: 26)

KMEANS clustering splits a set of objects into a selected number of groups by maximizing between-relative to within-cluster variation. The number of iterations, or passes KMEANS used to reallocate cases in this study is 50.

Three distinct clusters emerged, one large and two small. These three clusters comprise only 19 of the original 30 study participants, with the other 11 failing to cluster discriminately. This indicates the existence of extensive, dispersed opinion on the attributes within the basin. Table 5 summarizes the results.

TABLE 5: RESULTS OF CLUSTER ANALYSIS

Clusters	Number of Cases	Attribute	Mean Weight
One	5	**Income**	**0.65**
		Population	0.14
		Riparian	0.11
		Basin Control	0.10
Two	3	Income	0.13
		Population	0.29
		Riparian	0.11
		Basin Control	**0.48**
Three	11	Income	0.17
		Population	0.23
		Riparian	**0.43**
		Basin Control	0.17

The table above indicates the number of respondents in each cluster and also the mean value assigned to each attribute by all the participants in that cluster. The attribute weighted the highest by each cluster is in bold. For example, the members of Cluster One place a high emphasis on "Income" with a mean value of 0.65. These mean values indicate the relative importance of the different attributes as assigned by the MATS program.

Analyses of the function forms indicates similarities and differences both within and between clusters. The function forms for two attributes, "Riparian Acreage" and "Urban Population", provided the greatest opportunity for constructive analysis. The function forms for the other two attributes are less interesting. The function form for the attribute "Income" was, as expected, monotonically increasing over its entire range for each cluster. The "Basin Water Management" attribute, representing the social value Autonomy, was presented successfully only in dichotomous form; whether or not water management efforts should occur at the local, ie basin level (thus, no function forms are possible). Once again, strong preference was shown in favor of local level water management efforts regardless of cluster membership.

Stakeholder Groups

The cluster analysis indicates the presence of at least three distinct water management interest groups in the basin. These three interest groups are defined as 1) fiscal conservatives, 2) controlled growth and development, and 3) traditional environmental. While these interest group definitions are arbitrary, they will be useful in later discussion.

Cluster One: Cluster one mean values indicate a high concern for income, to the exclusion of the other attributes. This cluster is defined as representing a **fiscally conservative** stakeholder group.

The function forms for "Riparian Acreage" indicate preference among part of this group for a decrease in the current level, but most expressed preference for current conditions with certainly no expansion. The function forms for "Urban Population" show the highest preference for current levels, with some limited preference shown for a high increase in population in the basin.

Cluster Two: Cluster two mean attribute values showed a primary concern for "Basin Control" and to a lesser extent for "Urban Population". This cluster is defined as representing an stakeholder group espousing **controlled growth and development** in the basin.

The function forms for "Riparian Acreage" show a preference for current conditions to a slight increase, but no decrease. For "Urban Population" levels, this group unanimously preferred a constant and steady increase in population.

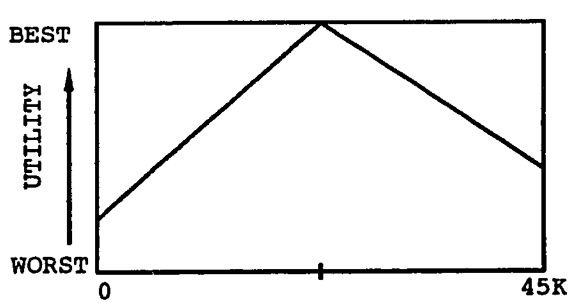
Cluster Three: Cluster three mean attribute values indicate the most concern for "Riparian Acreage". This cluster is representative of a stakeholder group with **traditional environmentalist** sentiments.

The function forms for "Riparian Acreage" show a high preference for an increase in acreage. In contrast, function forms for "Urban Population" indicate preference for current conditions, with little support for substantial increases. Figure 8 shows the mean function forms for the attributes by cluster.

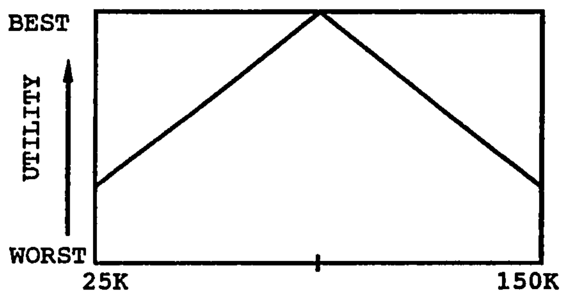
Figure 8: Illustration of Function Forms

Cluster One: Fiscal Conservatives

Riparian Acreage

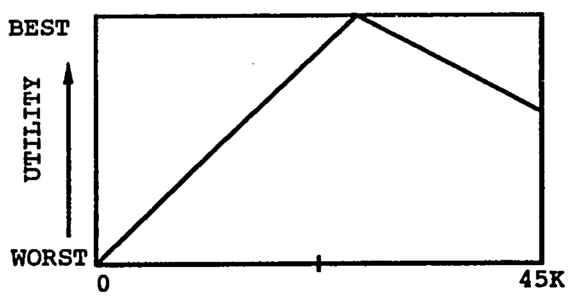


Urban Population

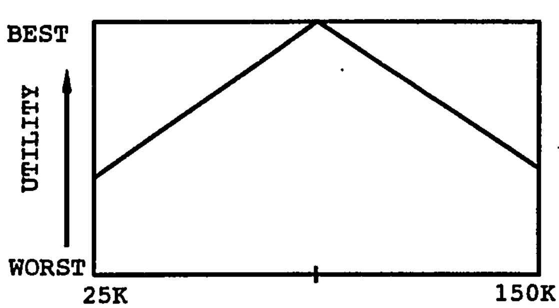


Cluster Two: Controlled-Growth and Development

Riparian Acreage

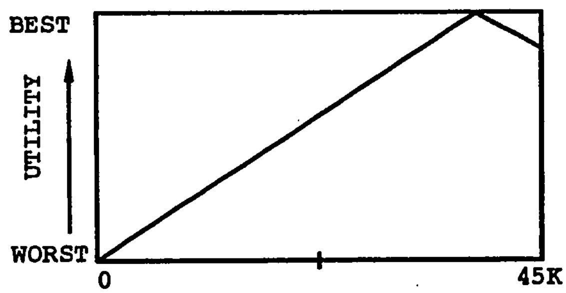


Urban Population

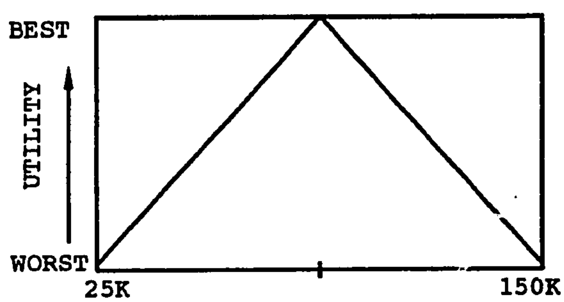


Cluster Three: Traditional Environmentalist

Riparian Acreage



Urban Population



Water Management Policy Options

The second level of analysis involved the ranking of ten water management policy options. For this study, the Institutional Alternatives subgroup of the university study developed five policy options, with some variants for a total of eleven plans, including the status quo. In developing these options, the sub-group reviewed the current institutional arrangements in Arizona and in the basin

(Collins, 1990; Gillilan and Collins, 1990). These options were chosen to "illustrate the nature and magnitude of impacts on the water resources of the basin which can be affected through the use of public policies" (Gillilan and Collins, 1990: 2).

These options are not intended to be specific policy recommendation but rather intended to represent a range of policy options from which basin residents can choose including regulatory types of policies and others. These options are summarized below:

Policy Options:

Policy 1 - Status Quo - This option assumes that no changes will be made to the current methods of water management in the basin, including no new laws, institutions, or regulations. Water use will continue to be based upon individual initiative, as permitted under the Arizona Water Law.

Policy 2-1 - Active Management Area (AMA) - This policy option and the two following it are all variants of the type of state coordinated water management in place in Phoenix, Tucson, and Prescott described in Chapter II. The stated goal of this type of AMA is to reach "safe yield", a condition in which annual water consumption is equal to annual recharge. Limits on domestic consumption are achieved through gallons-per-capita-per-day (gpcd) restrictions, and agriculture is required to increase water use efficiency. The restrictions on domestic consumption and the agricultural efficiencies are gradually increased until safe-yield is reached.

Policy 2-1 forces a 150 gpcd maximum limit on all domestic users within water service areas, and also requires an 85% efficiency level on all irrigated agriculture within the upper basin. **Policy 2-2** - is identical to 2-1, except 50% of current irrigated agriculture within the upper basin is immediately retired.

Policy 2-3 - This policy is also identical to 2-1, except 100% of current irrigated agriculture within the upper basin is immediately retired.

Policy 3-1 - AMA variant - This policy option and the three that follow are also active management areas, but differ from those already in place in Arizona. For these options, domestic consumption and agricultural water use are limited through the use of pricing, rather than the regulatory use of gpcd or irrigation efficiency standards. This pricing strategy is enacted through a surcharge assessed on domestic users and a pump tax assessed on irrigation wells. Also, under this set of options, authority for water management remains within the basin community, as opposed to the state sponsorship associated with current active management areas. **Policy 3-1** calls for a $1.00 per 1000 gallons increase to current charges. **Policy 3-2** is the same as 3-1, except there is $2.00 per 1000 gallons increase in the surcharge. **Policy 3-5** is the same as 3-1, except there is $5.00 per 1000 gallons increase. **Policy 3-10** is the same as 3-1, except there is $10.00 per 1000 gallons increase.

Policy 4 - Supply Enhancement consists of maximum attempts to increase available basin water supplies. In the case of the Upper San Pedro Basin, supply augmentation opportunities are limited to effluent reuse and possibly cloud seeding. This option calls for 100 % recharge of effluent.

Policy 5 - Conservation calls for maximum conservation efforts as a solution to limited future water supplies. Under this option, through a variety of conservation measures, domestic consumption is reduced 25% and agricultural efficiency is increased to 85% throughout the upper basin.

MATS Evaluation of Plans

These policy options were evaluated from the perspective of the value-based clusters using the MATS program. It is this synthesis of the decision-maker's values as measured through the use of attributes, with the available options to create a ranking that forms the final step of the simulation.

Impacts were computed for each of the policy options based upon estimates supplied by WATERBUD, a model developed for use by the study team in formulating policy options (See Appendix A) These impacts were entered into the MATS program and a final ranking produced. The following table summarizes the results:

TABLE 6: PLAN ANALYSIS

Policy*	Cluster One		Cluster Two		Cluster Three	
	Score	Rank	Score	Rank	Score	Rank
1	.612	1	.830	1	.704	2
2-1	.507	10	.351	10	.541	10
2-2	.510	9	.351	9	.544	9
2-3	.513	8	.352	8	.547	8
3-1	.597	4	.827	4	.706	1
3-2	.586	5	.825	5	.703	3
3-5	.556	6	.819	6	.696	6
3-10	.516	7	.810	7	.687	7
4	.609	2	.829	2	.702	5
5	.604	3	.828	3	.703	3

*Policy summaries:
1 - Status Quo; 2-1 - Conventional AMA, 150 gpcd, 85% Irrigation Efficiency; 2-2 - Conventional AMA, 150 gpcd, 50% Ag retirement; 2-3 - Conventional AMA, 150 gpcd, 100% ag retirement; 3-1 - AMA, $1.00 per 1000 gal surcharge; 3-2 - Special AMA, $2.00 per 1000 gal surcharge; 3-5 - AMA, $5.00 per 1000 gal surcharge; 3-10 - AMA, $10.00 per 1000 gal surcharge; 4 - Augmentation; 5 - Conservation.

A number of conclusions can be drawn from the table. First, the status quo, i.e., no new management, fares the best of all the options, ranking first for two clusters and second for the third. However, it should be noted that the status quo policy option enjoys some obvious advantages over the other plans. Perhaps most notable is the fact that this study was limited to a twenty year horizon, and the adverse impacts of retaining status quo management conditions are minimal over this relatively short period of time. Adherence to the status quo in water management affairs may indeed lead to major impacts in the future; however, the attributes chosen and the 20 year forecasting horizon do not support this.

Another advantage enjoyed by the status quo became apparent after the original list of seven attributes underwent revision. While removing the "Water Table Stability" attribute eliminated unwanted overlapping amongst the attributes, it also eliminated a key indicator of basin resident's values in regard to current water conditions. Throughout the first round of sampling, "Water Table Stability" ranked consistently among the most important attributes, indicating a great deal of concern for current hydrologic conditions within the basin.

Second, it becomes very apparent that basin residents would not support the creation of an Active Management Area (AMA) modelled after those already existing in Pima, Maricopa, and Pinal Counties. This is clearly illustrated by the uniformly low plan scores of options 2-1, 2-2, and 2-3 regardless of cluster. This is directly attributable to a strong desire among all study participants to maintain a local level of basin water management, something a state sponsored AMA does not offer.

Third, policy options 4 and 5 garnered appreciable support from /all clusters. This indicates wide interest in water management options which incorporate supply augmentation strategies (policy 4) and also conservation measures (policy 5). Looked at by cluster, some other conclusions can be drawn. Cluster One, the fiscal conservatives, favor the status quo, but not strongly. Policy 4, the augmentation option is the next best option for this group. All other options are fairly tightly grouped from a range of .51 to .61. The options least favored by this group are the AMA options, but again, not strongly.

Second, Cluster Two, pro-development/growth interests favor the status quo also, but not strongly. This group rates favorably the Policies 4 and 5, the augmentation and conservation options. There is a larger range among options in this group. Finally, all the AMA policy options are strongly rejected.

Third, Cluster Three, the environmentalists would favor Policy 3-1, a "Customized" AMA (.71), but also prefer Policies 4 and 5, the augmentation and conservation options. This group would not, however, favor a conventional AMA, finding it least desirable of all available options.

CHAPTER V. SUMMARY AND CONCLUSIONS

The people of the San Pedro River Basin face decisions concerning water use in the basin. This study used decision analysis techniques, specifically MATS to determine the social values of basin residents. These values were then used as benchmarks to evaluate a range of policy options.

Some conclusions can be drawn from the study both about appropriate water management policies for the San Pedro basin and about the use of MATS or similar techniques based upon decision analysis evaluation procedures.

Study Conclusions

1) There is a strong concern for hydrologic conditions in the basin. Throughout the first round of sampling, Water Table Stability ranked consistently among the most important factors, indicating a great deal of concern for current hydrologic conditions within the basin. Participants in the first round of sampling are represented in all three identified interest groups, and Water Table Stability was weighted as important by them all.

2) Although three clusters did emerge, the clusters are not well-defined; all groups display some heterogeneity. A diverse range of preferences exists for the social values.

The development of defined stakeholder groups in the basin is at an early stage.

3) Basin residents showed a strong preference for local control for water policy management decision-making. This preference can serve as the basis for designing a locally controlled water management entity. This entity could provide a forum for decision-making and also a way to implement future policies.

4) There is also a general rejection of the state-controlled AMA's similar to those in Tucson and Phoenix. However, the concept of an "unconventional" AMA which relies on pricing does have some support.

5) There is support for policies concerning supply augmentation and conservation.

Recommendations for the Use of MATS

Those involved in future applications of MATS should note some methodological considerations gleaned from this study. First, clearly a significant number of the study participants did not understand the MATS exercise as conducted. The initial estimated time needed for each interview, 20 minutes, proved far too low. Instead, and for various reasons, each interview generally took an hour. These included limited experience with computers in general on the part of some participants, difficulty in grasping concepts such as relative weighting, and some difficulty in organizing thought processes (a possible criticism of the rational-analytic model could be made).

Another important consideration is the choice of value attributes, or factors. Substantial time was given to this portion of the study, including meetings of the university team as well basin residents themselves. However, the importance of value and attribute identification cannot be over-emphasized. Even with the extensive meetings and subsequent revision of the list of attributes, the first two suffered from obvious judgmental dependencies.

For this same reason, the issues of risk and attitudes toward the present status quo in basin water management were not adequately addressed within the scope of this study. The development of measurable value dimensions that address the complex issues associated with risk and in particular the risk of maintaining current practices would greatly enhance the understanding and quality of the decision analysis.

The use of MATS is probably best at the predecision phase. It should be used to help decision-makers reconcile their differences over a clearly stated range of competing value dimensions. It is very useful for determining the appropriate social values that underlie decisions and can help decision-makers focus subsequent efforts.

Also, it may not be the best choice for direct public interaction. The participants who fared the best with completing the MATS exercise were generally either public officials or a select few who were generally very well-informed.

The quality of the MATS analysis is highly dependent on the proper definition of the components. If the factors in particular are ill-defined, the analysis will be faulty. The importance of choosing appropriate value attributes (factors) cannot be over-emphasized.

Directions for Future Policy Development

The development of objectives and relevant policies is an evolutionary process and a challenge. Also, in the instance of common pool resources, decisions are further complicated by Hardin's tragedy of the commons, which as Ostrom suggests, may require an approach that relies on local voluntary binding agreements to best approach the commons dilemma. This study suggests there is an opportunity in the basin for this type of approach because of the interest in local control of water resources which is coupled with a common degree of concern for hydrologic conditions.

While not providing an optimal solution for water management in the basin, this study does provide guidance for the development of policies. The lessons learned from MATS can be used to search for options which create positive impacts on most of the identified factors.

These options include policies under the unconventional AMA, particularly those which emphasize pricing and local control, and also policies under the conservation and augmentation options. Policies of this nature would include expansion of the wastewater treatment plant and subsequent reuse of the water, other general augmentation measure such as capture of runoff, and finally a variety of voluntary conservation measures.

Appendix A: Impacts of the Water Management Options

In order to perform the MATS analysis, it is necessary to estimate impacts for each option under consideration. Impacts are the effect that the implementation of the various water management options (plans) would have on the set of value attributes (factors). Impacts must be quantitative, falling within the ranges of the value attributes. Impacts often require heroic assumptions because we have no idea what the actual effects of policies are until they are implemented, however; they must be made in order to complete the analysis. Impacts were estimated only for two factors in this study, Median Annual Household Income and Riparian Acreage. The other two factors in the final analysis, Urban Population and Basin Control of Water Resources, did not require impact estimation because urban population was assumed to continue to expand at current rates regardless of water management policy, and the dichotomous nature of the Basin Control factor did not lend itself to quantitative analysis.

	Med. Ann. Hshld Inc. ($) current value = $14,000 est. Impacts	Riparian Acreage current value = 22,500 est. Impacts
Status Quo	13,990	-30.0
Policy 2-1	13,970	+47.8
2-2	13,978	+181.5
2-3	13,987	+454.6
Policy 3-1	13,951	+435.8
3-2	13,915	+444.4
3-5	13,824	+447.8
3-10	13,698	+448.3
Policy 4	13,990	-80.0
Policy 5	13,976	+52.0

The cost of upgrading agricultural land to meet 85% efficiency requirement was estimated at $500/acre. The cost of upgrading effluent treatment for recharge purposes was estimated at exactly double current treatment costs per acre foot.

Appendix B: Results of the Nominal Group Process

What types of activities, factors, or controls should be included in the management plan for the San Pedro basin?

1. Develop as good an understanding as possible of surface and groundwater hydrology, including the strengths and weaknesses of existing data.

2. Develop solutions after problems defined.

3. Cost of implementing the plan.

4. Commitment by the County to implement the plan, now and in the future.

5. Quantitative evaluation of water quality available for human use on a long-term, sustained yield basis.

6. Management of the entire basin watershed, including the mountains.

7. Develop accurate data on ecological conditions of the basin, including wildlife, so as to be able to predict the effects of population growth on such conditions.

8. Planned vs. random growth.

9. Explore alternatives for both reuse of water and natural/artificial recharge.

10. Information exchange; technology transfer.

11. Develop a predictive capability, based on economic divisions and uses, for water usage.

12. Cost/benefit analysis of management alternatives.

13. Interpret technical information for the public.

14. Quantify water requirements of the natural ecosystem (entire watershed), excluding human use.

15. Develop priorities.

16. Include eco-tourism and water conservation strategies in the economic analysis.

17. Address the conflict between agriculture and urban development.

18. Examine options stemming from the Gila River Adjudication including: dealing with the Native Americans directly, and participating in negotiations concerning Congressional legislation.

19. Alert public to foreseen problems.

20. Water quality.

21. Develop cooperation between basin interest groups.

22. Quantify potable water resources.

23. Define rational for direction of planning efforts.

24. Develop goals and objectives.

25. Produce a working model that expresses the management plan.

26. Develop a vehicle for making recommendations to local and regional governments.

27. Determine constraints of federal and state law on the plan.

28. Identify legal and legislative mechanisms for implementing the plan.

29. Make plan visible and saleable.

30. Public participation.

31. Explore augmentation alternatives.

32. Include Mexican issues such as: hydrological data from Mexico, inclusion of Mexico in the plan, negotiation with Mexico, allow Mexico to use management plan.

33. Monitor water demand.

34. Collect water data on an on-going basis.

35. Examine the full range of hydrological scenarios.

36. Monitor ecosystem productivity from a holistic perspective.

37. Develop plan as a "living" document.

38. Funding for planning efforts.

39. Determine viability/affordability of plan.

40. Include economic aspects of tourism and recreation in the plan.

41. Determine economic aspects of safe yield.

42. Include economic projections in the plan.

43. Clarify the political purpose of the plan.

44. Examine the political feasibility of water transfers.

45. Set management control levels to the minimum.

46. Manage development of new wells.

47. Manage runoff.

48. Control new agricultural use.

49. Minimize economic impacts.

50. Coordinate water management plan with land-use plan.

51. Clarify who is in control of the management plan and to whom they must justify their decision.

52. Examine agricultural irrigation efficiency.

53. Determine the economic impacts of water conservation.

54. Encourage reduced water use.

55. Preserve the NRCA.

56. Analyze the effects of water conservation on biodiversity.

57. Maintain efforts to inform the public of planning efforts.

Appendix C: Table of Weights

Stake holder	Median ($) Annual Household Income	Riparian Acreage	Urban Population	Presence of Local Control
1	0.200	0.400	0.200	0.200
2	0.276	0.069	0.104	0.551
3	0.037	0.082	0.504	0.377
4	0.181	0.273	0.364	0.181
5	0.083	0.164	0.251	0.502
6	0.187	0.375	0.219	0.219
7	0.105	0.417	0.239	0.239
8	0.294	0.257	0.113	0.337
9	0.200	0.402	0.198	0.200
10	0.204	0.328	0.219	0.250
11	0.300	0.400	0.200	0.100
12	0.222	0.296	0.222	0.259
13	0.177	0.353	0.235	0.235
14	0.120	0.481	0.239	0.160
15	0.395	0.099	0.253	0.253
16	0.381	0.190	0.190	0.238
17	0.407	0.203	0.305	0.086
18	0.399	0.101	0.399	0.101
19	0.499	0.126	0.250	0.126
20	0.744	0.186	0.046	0.024
21	0.504	0.054	0.221	0.221
22	0.666	0.084	0.166	0.084

23	0.842	0.105	0.027	0.027
24	0.364	0.090	0.364	0.182
25	0.389	0.223	0.194	0.194
26	0.154	0.615	0.154	0.077
27	0.160	0.481	0.240	0.120
28	0.158	0.281	0.281	0.281
29	0.064	0.517	0.395	0.024
30	0.364	0.364	0.091	0.181

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