SYSTEMATIZATION OF WATER ALLOCATION SYSTEMS:

AN ENGINEERING APPROACH

A Dissertation

by

DEBORAH MATILDE SANTOS ROMAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2005

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Ralph Wurbs
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	Kelly Brumbelow
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ABSTRACT

Systematization of Water Allocation Systems: An Engineering Approach.

(December 2005)

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The allocation of water resources is typically accomplished within the framework of water allocation systems (WAS). In general, a WAS sets priorities, applies rules, and organizes responses to a range of water allocation scenarios. This research presents a comprehensive study of water allocation strategies and provides a conceptual framework of principles and guidelines for designing, assessing, implementing and supporting WAS. The voluminous compilation of international treaties and conventions, interstate compacts, intrastate administrative documentation, and scientific/engineering literature was researched in order to identify different water allocation strategies and mechanisms. From this analysis eight fundamental areas of WAS were identified: water rights, determination of water allotment, administrative systems, reservoir storage considerations, system reliability, multiple uses, instream flow requirements, and drought management. The systematic scrutiny of these eight areas at the international, interstate, and intrastate levels defined the conceptual framework for assessing WAS. The Texas experience with regard to its Water Availability Modeling system is also reviewed with particular emphasis on the application of the Water Rights Analysis Package (WRAP) model in supporting water allocation efforts. The Lower Rio Grande WAS was used as a case study to demonstrate how the principles presented in the conceptual framework can be used to assess water allocation issues and identify alternative strategies. Three WRAP simulation studies utilizing several components of the conceptual framework were performed in order to assess the Lower Rio Grande WAS. The simulations focused on three of the major water allocation issues of the Texas Rio Grande: reallocation among uses, instream flow requirements, and drought management. The simulations showed several deficiencies in the Lower Rio Grande WAS, particularly regarding the size of the domestic-municipal-industrial (DMI) reserve and its effect on the reliability of other uses. The simulation results suggest that water from the DMI can be

liberated to be used by irrigators and to support environmental flows without affecting the reliability to municipal users. Several strategies were proposed that can potentially improve the overall efficiency of the system. Nonetheless, implementing new strategies and water allocation policies in the Lower Rio Grande WAS would require considerable changes in regulation policies.

To my beloved husband and friend, David.

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND

One of the fundamental necessities for the well-being of human societies is the availability of reliable sources of fresh water. The water resources of a region play a central role in maintaining human health and welfare, environmental integrity, and economic growth. Water is withdrawn and stored from natural systems such as rivers, lakes, and groundwater aquifers for a variety of economic activities, especially agriculture, industry, and municipal uses. As the world population expands and living standards rise, so does the demand for increased exploitation of water resources. Since water is a renewable resource, the primary challenge is not so much how to manage a declining resource, but how to respond to the scarcity resulting from the geographic and temporal mismatch between supply and demand. In many regions of the world the demand for water has already exceeded the local supplies. Moreover, seasonal variations in precipitation can often result in extended dry periods leading to drought conditions during which water supplies are severely limited.

The water scarcity problem is exacerbated by competition among users and uses. The usage of water by an individual or institution undeniably alters the quantity, quality, and reliability of the resource for other users. This competition has often moved people to conflict and even violence. Conflicts range from minor disputes among neighboring users, to interstate and international disagreements over the use of the resources they share. In the United States (US), battles over water are played out in courtrooms, legislatures, and Congress; and now more than ever before, in multi-state negotiations that result in huge expenditures for the parties involved.

This dissertation follows the style of the *Journal of Water Resources Planning and Management*.

At the international level, history suggests that water is an increasingly salient element of politics, including violent conflicts. During the 1950's and 60's, fighting broke out between Israel and Syria over the control of the waters of the Jordan River. These military actions contributed to the tensions that lead to the Six Day War of 1967 (Gleick 1993). Also, disputes over quantity and quality of the Colorado and Rio Grande Rivers, and most recently, Mexico's incompliance of the 1944 water allocation Treaty has resulted in a long history of political frictions and tensions between the US and Mexico (Gleick 1988). Clearly, water scarcity issues and the political conflicts that may arise from such issues highlight the importance of developing effective policies and principles for the proper allocation of this limited resource.

The allocation of water resources is typically accomplished within the framework of water allocation systems (WAS). In general, a WAS sets priorities, applies rules, and organizes responses to a range of water allocation scenarios. The development of WAS has become a central issue in water resources management, for an effective WAS can help to ensure peace, stability, and prosperity at the local, national, and international levels. The primary objective of a WAS is to facilitate efficient use of water resources by (1) distributing water equitably among users, (2) protecting existing users from having their supply diminished by new users, (3) establishing rules for sharing limited water resources during drought periods, (4) protecting the long-term reliability of the resource by avoiding over-exploitation (Wurbs 2004) and (5) adapting to changes in the societal values of water by accommodating new users and uses. Accomplishing this, however, is a challenging task for the institutions that mediate access to water.

WAS contain multiple overlapping legal systems and levels of water management policies and practices (Wurbs 2004). The specific rules for allocating water reflect continual adaptations to different water needs and are molded to the hydrologic and socio-economic characteristics of a region. Among nations, water is allocated by means of treaties, decrees, and other agreements. The principles and doctrines that have historically governed such agreements are commonly known as international water law. In the US, water is allocated among states through interstate river compacts and other legal means. Compacts are negotiated agreements entered voluntarily by two or more states and, once ratified by Congress, they become both a legal contract and federal law. Within states, water is distributed among water supply organizations or individual users through water rights systems. Two alternative doctrines have evolved as individual states resolve water rights issues: riparian and prior appropriation, or a combination of both. The riparian doctrine establishes rights based on the ownership of land adjacent to watercourses, while the prior appropriation doctrine gives the right to use water in a "first in time, first in right" basis, determined by the date of appropriation.

Effective water allocation and management requires an understanding of water availability and reliability (Wurbs 2003). However, water availability not only relies on hydrological, but also on institutional considerations. The myriad of water management entities and water users within an institutional setting add to the numerous complexities involved in creating and administering WAS (Wurbs 2004). Computer-based decision support systems provide useful tools for assisting water managers in this intricate process. Computer simulation models can be used to evaluate water management strategies, plan development projects, simulate allocation under alternative water availability scenarios, support the negotiation of agreements, administer water rights systems, and the like. The state of Texas has successfully developed and implemented a Water Availability Modeling (WAM) system to support the administration of its water rights permit system. The WAM system was authorized by the 1997 Senate Bill 1, the Brown-Lewis Water Management Plan. A key component of the WAM system is the Water Rights Analysis Package (WRAP). This computer model has been used to simulate water allocation and management scenarios in all Texas river basins, including the international Rio Grande.

1.2 MOTIVATION FOR THE STUDY

While the importance of effective water allocation is well recognized, methodologies are extremely disparate and somewhat obscure. Although most international treaties define general water allocation objectives, usually they neither clarify the allocations among specific users nor set priorities under emergency shortages. Also, when the water allocation mechanisms in interstate compacts are vague, and thus subject to conflicting interpretations, they may lead to lengthy disputes and waste of resources on litigations and Supreme Court appeals. The manner in which water rights systems have evolved in each state has resulted in a lack of uniformity in water allocation rules and policies. This lack of specificity at all levels precludes selecting effective allocating mechanisms, which in turn may lead to inconsistencies among actions, inefficient performance, and incompliance of the system objectives (Frederiksen 1992; Wolf 1997). In addition, there is an eminent lack of comprehensive studies regarding the development and implementation of WAS. Most studies related to water allocation are descriptive in nature, addressing subjects like conflict resolution, hydro-politics, and water law from a non-technical perspective. Also, there is a tendency to overlook the details of the methodologies for allocating water. One of the major contributions of this research is the identification of the main concepts and critical issues in the fields of international and interstate water allocation, water rights systems, and decision support modeling.

This dissertation is directed toward providing an enhanced understanding of the specific mechanisms for allocating water by systematically addressing: (1) how water allocation is achieved among nations, states, water management entities, and individual users, and (2) how computer simulation models can be used to support and facilitate water allocation efforts. The dissertation presents a comprehensive study of water allocation strategies and provides a conceptual framework of principles and guidelines for designing and implementing WAS.

1.3 RESEARCH SCOPE

The purpose of this research is to develop a generalized theory regarding the mechanisms for allocating surface waters. The research objectives are to:

(1) Develop an improved understanding of water allocation issues and rules incorporated in WAS by identifying the mechanisms used for water allocation.
(2) Formulate a systematic framework of principles and guidelines to be considered and alternative mechanisms that may be adopted in the implementation and administration of surface WAS.
(3) Evaluate the analysis and decision-support capabilities of computer simulation models with a particular emphasis on the WRAP model and its application in Texas.

The systematic framework is structured based on a hierarchy of water management levels that include:

(1) International river basins involving water allocation among nations
(2) Interstate river basin compacts and other interstate allocation arrangements in the US
(3) Intrastate water allocation based on water rights systems in the US

Following this hierarchy, the voluminous compilation of treaties, compacts, and scientific and engineering literature was reviewed and researched from the perspective of eight major areas fundamental to any WAS. The systematic scrutiny of these areas at all three management levels will define a conceptual framework for assessing water allocation. These areas are described below:

(1) *Water rights.* The rules governing the sharing of limited streamflow and storage among users are examined. These rules are defined within the WAS to determine who has the right to use the water and in what priority.
(2) *Determination of water allotment.* Hydrological and policy criteria for assigning diversion and storage quantities to water users are addressed. Past experiences regarding the use of specific water allocation mechanisms are presented and critically reviewed.
(3) *Administrative systems*. The institutional framework for water allocation may involve complex interactions among federal and state agencies, regional and local authorities, municipal and irrigation districts, and other public and private water supply entities. The role and jurisdiction of these institutions are discussed.
(4) *Reservoir storage considerations*. Balancing the trade-offs between using water for present needs and storing it for future uses is a complex task. Approaches to assess reservoir storage and other operational considerations are explored.
(5) *System reliability*. Reliability is a measure of dependability and can be used to asses the capabilities of a stream/reservoir system to satisfy specified water use requirements. The dissertation explores how reliability considerations can be incorporated into WAS to provide a better basis for decision-making.

(6) *Multiple uses.* Water allocation involves interactions and tradeoffs between purposes that are sometimes complementary but often competitive. Water uses recognized by WAS are outlined and the specific provisions for dealing with conflicting uses are studied.

(7) *Instream flow requirements.* Instream flow uses such as habitat preservation, recreation, aesthetics, and conservation are becoming an increasingly important factor in water management decisions. This research investigates strategies used to incorporate these non-traditional uses into the WAS scheme.

(8) *Drought management.* A key component of a WAS, particularly in arid regions, is to establish methodologies to respond to periods of water scarcity. The special conditions defined within WAS for declaring a drought state are outlined. This research evaluates the adjustments to normal water allocation rules and/or implementation of new rules that have been required to cope with drought conditions.

The Rio Grande Basin is adopted as a case study for more detailed investigation. Water in this arid region is over-appropriated, as demands exceed supplies. Surface water allocation on the Lower Rio Grande is different from the rest of Texas. Water permits in the Lower Rio Grande are divided into three categories and priorities are given depending on the use of the water. The region is also subject to periodic droughts, intensifying the importance of effective water allocation in this already complex system. Pursuant to the 1997 Senate Bill 1 and other legislation, the state has progressed significantly in improving its WAS. A major advancement has been the integration of the WRAP model for decision support. The dissertation research includes a review of the WAM system with particular emphasis on features adopted in modeling the treaties and compacts specifications that influence the Texas WAS. The WRAP model is used to test the allocation issues identified in the conceptual framework. The WRAP simulation study investigates various water allocation/management issues and strategies in the Rio Grande that are also relevant to other regions of the world.

This dissertation organizes the extensive literature of strategies and approaches for allocating water at all three management levels. It is expected that the conceptual framework and guidelines that are developed will assist in the design, development, and implementation of new WAS. This format can also be used as a guide on how to systematically approach new water allocation issues and for future evaluations of existing WAS. Also, this comprehensive analysis will help identify areas where policy and institutional reform may be needed. The conceptual framework may also be used to guide in the design of new water allocation agreements and in the revision of old ones. The review of existing computer modeling capabilities will provide water management agencies helpful information for comparing and selecting an appropriate model to support their WAS. Managers can also use the Rio Grande case study as a model for improving water allocating practices and integrating computer models to assist in the various phases of water allocation.

1.4 ORGANIZATION OF THE DISSERTATION

This dissertation is comprised of nine chapters. Chapter II provides an explanation of the doctrines, conventions, treaties, and other rules and institutions governing water allocation at the international level. Chapter III provides an overview of the main venues for the allocation of water among states with a special emphasis on interstate water allocation compacts. A detailed description of the water rights systems adopted in the US and their respective water appropriation doctrines is presented in Chapter IV. Chapter V provides descriptions and applications of a series of site-specific and generalized computer models that can support the various aspects of WAS. A comprehensive review of the current WAS in Texas is presented in Chapter VI. This chapter also explores the modeling strategies that have been implemented in the state to address several water allocation issues at all management levels. The conceptual framework for the systematization of WAS is developed in Chapter VII. The chapter breaks down each of the eight fundamental areas of water allocation, discusses issues, and analyses the strategies and mechanisms used to address such issues within the structure of WAS. The significance of several of the fundamental water allocation areas identified in the framework is demonstrated in Chapter VIII by means of a computer simulation case study. The Rio Grande Basin provides an excellent case study, as water allocation is governed by international treaties, interstate compacts, and within Texas, by two distinct water right systems. The research summary and conclusions are presented in Chapter IX.

CHAPTER II

INTERNATIONAL WATER ALLOCATION

Almost half of the world's land surface lies within a basin shared between at least two countries and about forty percent of human population inhabit international basins (Wolf et al. 1999). International rivers are those that run through or between more than one state. Transboundary rivers can be successive (i.e. run through the states) or contiguous (i.e. forming the common boundary). The legal and political implications of utilizing such water resources are delicate and complex. Around the world almost all easily accessible national resources have already been developed or are in the process of being developed. As a result, the cost of new projects per cubic meter of new water available will continue to increase (World Bank 1992). International water bodies are usually the only resources of water that could be developed economically since often they have not been considered in the past due to a lack of agreement and the political complexities and risks were considered too high for the unilateral development of the resource (Biswas 1999).

Water is a non-substitutable resource that is becoming more polluted and scarce as population grows and standard of living rises. Its scarcity either temporal or geographical leads to intense political pressures. Furthermore, water demands are often conflicting and since river basins do not follow legal or political boundaries, institutions are often incapable of meeting the administrative challenges that arise. As a result, the potential for conflict and even violence is ever present. Nonetheless, historically there are more instances where water has been a catalyst for agreement than for war (Wolf 1998). Even though violence has not been the norm for resolving water conflict among nations, water has been a critical factor of political instability, economic insecurity, and human suffering. As more stress is put upon international water resources, the ability for nations to peacefully resolve conflicts over internationally distributed water resources will increasingly be a factor in stable and secure international relations. However, international water law is still poorly developed, vague, and without any effective enforcement mechanism. This Chapter presents a review of the legal doctrines, principles, conventions, and international institutions that define international water law and the mechanisms for the resolution of conflicts among states. It also presents a summary and discussion of international water allocation treaties.

2.1 DOCTRINES, PRINCIPLES AND CONVENTIONS

The political mechanisms used to allocate water among riparian countries are known as international water law. Modern international water law is the result of an evolutionary process in legal doctrine related to historical, agricultural, and navigational uses of transboundary freshwater resources. Prior to the industrial revolution, water uses were more related to navigational activities and old legal doctrines were more concerned with riparian countries ensuring proper water flow and preventing harm to their neighbors (Teclaff 1967). The doctrine of "*sic utere tuo ut alienam non laedas*" (use your property in such a way that it does not injure another) was usually observed. This doctrine aims to prevent any state from using or allowing the use of transboundary waters in a way that may harm the territory or water rights of their bordering states (Eckstein 2002). After World War I and with the advent of industrialization water demands have shifted to non-navigational uses such as agriculture, industrial, municipal, and more recently, sporting, and conservation among others (Lien 1998). Since that time, organs of international law have tried to provide a framework to guide in the allocation of water among increasingly intensive water users. However, these principles of customary law developed by advisory bodies and private organizations can be better categorized as guidelines, also called "soft law", and are usually not intended to be legally binding (Cano 1989, Wolf 1999, Beach et al. 2000).

In early years international law basically consisted of bilateral treaties among bordering countries for defining political borders, flow control, agricultural development, and the reallocation of water for growing population demands and industries. As a result, international law was plagued with incongruent and ambiguous legal principles devised and interpreted to fit specific interests (Wolf 1997; Eckstein 2002). According to Wolf (1997), such principles are mostly based either on hydrography or chronology. Hydrographic concerns refer to the relative location of the countries with respect to where the aquifer or river originates and how much of that territory falls within a certain state. Chronology on the other hand, refers to who has been using the water the longest.

Historically, extreme doctrines developed first (Housen-Couriel 1994). For instance, it is not unusual for upstream states to initially claim the doctrine of "absolute sovereignty" (hydrography), which argues that a state has absolute rights over all the waters flowing through its territory (Lipper 1967). On the other hand, downstream states initially claim the doctrine of "absolute riverain integrity", which asserts that every riparian state should be guaranteed the natural flow of the river crossing its territory (Eckstein 1995). Neither of these doctrines has reached acceptance in the international water politics setting. Another extreme position concerning the chronography of water usage is the doctrine of "historic rights" (similar to the prior appropriation doctrine). According to this doctrine, older users have the right to use the water in a "first in time, first in right" basis (Wolf 1997).

With time, more moderate and therefore more feasible doctrines developed. Moderated principles allow for the sharing of the benefits of the water resources by accepting some limitations to both the countries sovereignty and the river's integrity. The doctrine of "limited (or restricted) territorial sovereignty" recognizes the right of a country to make use of transboundary water resources while agreeing not to cause harm to any other riparian state (Lien 1998). The doctrine of "equitable and reasonable utilization" states that states should utilize an international watercourse in such a way that is beneficial and takes into account the interests of the other watercourse states. Most recently, the doctrine of "community of co-riparian states" has emerged in which integrated river basin development transcends national boundaries and the international basin is developed and managed as a unit (Dellapenna 1994b, Correia and Silva 1999).

The doctrines and principles of international water law are defined within the context of international conventions, treaties and customs of law. International conventions in general establish rules that are recognized by the participant states, provide insight to the conception of international law held by nations, and it is also where general practices are accepted as law. International custom refers to the most basic and generic concepts that can be used to identify rules of international law as they are usually observed in treaties and other agreements (Utton 1991). For instance, even though water treaties are non-binding among non-signatory states, they indicate that the principle of limited sovereignty is usually preferred in international practice.

2.2 INTERNATIONAL RULES AND CONVENTIONS

International multilateral conventions, although fewer than bilateral treaties, bear evidence that the needs of co-riparians must be considered and reflect which position of law different nations are willing or not willing to take. Several international efforts have been made to develop an official international doctrine of water allocation. In 1966 the International Law Association (ILA), a private international organization, developed the *Helsinki Rules* in order to bring uniformity to the international water law field. The basic goal was to provide for the equitable allocation of the waters of an international drainage basin (Caponera 1985). Article V states 11 factors (e.g. climatic, historical, economic, etc.) that should be taken into account in determining "reasonable and equitable apportionment". The concept of "beneficial use" of water was also addressed (Housen-Couriel 1994). In addition, other principles were also included such as no reservation of future uses by an individual state, no inherent preference of one category over another, and existing economic activities should be considered equitable and reasonable unless established otherwise (Eckstein 2000). However, even though the principle of limited sovereignty is clear throughout the *Rules*, most of the concepts used such as "reasonable and equitable share" are vague and were considered more aspirational than practical (Utton 1991).

Overall, the *Helsinki Rules* prompted more controversy than advancement. In 1970 when the United Nations (UN) considered the *Rules*, objections were raised that took more than two decades to resolve (Wolf 1997). For instance, some states argued that the drainage basin approach was an infringement to their territorial sovereignty, while other states felt that the drainage basin was the most "rational and scientific" approach given the many complexities of transboundary water systems (Biswas 1993). Nevertheless, and despite their soundness, the *Helsinki Rules* have received little recognition as official codifications of international water law being quoted only once on an international binding agreement (i.e. the Mekong River Agreement).

In 1970 the UN General Assembly started an effort to review the status of international water law. It was not until 1997 that the UN Convention on the Law of the Non-Navigational Uses of International Watercourses was submitted and signed by many countries. Even though it is primarily directed at reducing pollution, the Convention, is the most recent and authoritative formulation of allocation rules for international rivers, yet it is still pending ratification.

The Convention is intended to be a framework agreement for the use, management, and preservation of transboundary water resources. It is consists of thirty seven articles which are divided in seven parts. The most important provisions regarding water allocation are contained in Part II in which the three most relevant principles of customary law are confirmed: equitable utilization, prevention of significant harm, and prior notification of planned measures. Although these doctrines are well-known, the fact that they have been accepted by a diplomatic and democratic conference establishes its status as recognized principles of international law (Utton 1991, McCaffrey 2001, Eckstein 2002). Article VI of the Convention gives a list of factors that must be taken into account when determining equitable utilization of the resource and Article IX requires riparian states to share information in a regular basis regarding the conditions of the watercourse. Even though these guidelines can be useful in defining reasonable use, as McCaffrey (2001) points out, it would be nearly impossible for a state to ensure this principle since it is more appropriate for implementation through a joint commission, a court, or a third party. Left without an enforcement mechanism, the article's utility is questionable.

In Article VII the Convention establishes the obligation not to cause significant harm. This is particilarily difficult when the dilemma is to ensure the equitable right of a country to use the water without causing appreciable harm to a possibly well established older economy of another riparian country downstream. For this article to be approved, several flexibilities had to be included. First, the "obligation" not to cause harm was defined not as an absolute but as due diligence (i.e. best efforts) to use the resource in such a way as not to cause significant harm. Second, it defines the concept as a process in which significant harm is avoided as far as possible while reaching equitable utilization.

The major controversy revolves around which concept, equitable utilization or obligation not to cause significant harm, should have prevalence over the other (McCaffrey 2001). It is understood that the Convention text gives prevalence to equitable utilization, but in order to be approved, the Convention included enough text to satisfy all groups, creating some confusion on which section of the Convention applies in what situation. Moreover, the Convention does not go as far as it should have in some areas like defining methodologies for water allocation, environmental protection, and water conservation (UN 1997). Therefore, it is left to the ability and desire of states to use the Convention guideline principles as a framework to design and implement more specific allocation agreements and practices (Eckstein 2000).

Beginning in 1996, the ILA undertook the task of reformulating the *Helsinki Rules* in order to incorporate international environmental and human rights law. In August 2004, the ILA approved the *Berlin Rules on Water Resources*. The *Berlin Rules* intend to cover subjects not reflected by its predecessor the *Helsinski Rules* and the UN Convention on the Law of the Non-Navigational Uses of International Watercourses. The *Berlin Rules* summarize a new paradigm of international water law that focuses on ecological integrity, sustainability, public participation, and minimization of environmental harm. Subjects related to water apportionment and allocative and enforcement mechanism are borrowed from the *Helsinski Rules* with some revised provisions from the UN Convention. In general, most recognized bodies of international law provide little practical guidelines for allocations, which are in essence the cause of water conflicts (Wolf 1997).

2.3 INTERNATIONAL INSTITUTIONS

Ameliorating water conflicts and political tensions resulting from water disputes will increasingly involve sophisticated mechanisms of dialogue and cooperation. Legal and institutional capacities that can deal with the international dimension of these situations are limited, but progress has been made (Wolf 2001). This institutional framework is needed to promote good relations among riparian nations and provide for improved water resources management. There is no comprehensive global institution for the management of transboundary waters. Instead, several organizations within the UN such as the World Bank, UN Environment Programme (UNEP), UN Development Programme (UNDP), and UN Educational, Scientific and Cultural Organization (UNESCO) have dealt with issues related to internationally shared waters. However, these efforts have been initiated and fueled more by individuals within the organization than by the institution's objectives or commitment (Nakayama 1997). Several partnerships between these agencies also exist such as the Global Water Partnership and the World Water Council that aim to coordinate efforts for water development and policy improvement. Nonetheless, none of these agencies have the power within their mandates to implement mechanisms for conflict resolution or enforcement (Wolf 2001).

Perhaps the only international organ with any kind of leverage for resolving disputes over international waters is the International Court of Justice (ICJ). The general functions of the ICJ are to settle, in accordance with international law, the legal disputes submitted to it by states, and to give advisory opinions on legal questions referred to it by duly authorized international organs and agencies. Cases in the ICJ are entered into voluntarily and only recognized nations can bring their cases to the Court consideration. Other political entities such as ethnic or minority groups would have no representation. However, the contribution of the ICJ in transboundary water allocation disputes is limited since there is no practical mechanism to enforce the Court's decisions, with perhaps the exception of extreme circumstances. Therefore, a politically strong nation could completely ignore the Court's ruling with little or no repercussions (Wolf 2001). The ICJ has been used only once to intervene in a water related conflict for the apportionment of the Gabcikovo-Nagymaros project in the Danube River. In 1992 the case was submitted to the Court and in 1997 the Court ruled that Hungary and Slovakia must comply with their 1977 water treaty in financing and operating a major reservoir project. Hungary however, disregarded the Court's ruling and proposed a different plan that was clearly disadvantageous to Slovakia. In response, Slovakia has returned to the Court in search for resolution but the conflict is yet to be resolved.

2.4 INTERNATIONAL TREATIES

In the absence of detailed and clear water law and adequate enforcing institutions, the allocation mechanism that has been used by riparian nations more often and with greater success, has been bilateral and multi-lateral water treaties. Historically, thousands of treaties have been signed regarding international uses of water, the majority of which have been related to navigation. During the last hundred years, an increasing number of treaties have been signed that deal with non-navigational uses of water. Some of the water management issues covered in treaties are hydropower, flood control, boundary delineation, water allocation, and more recently, pollution control.

There has been a general misunderstanding and ignorance of the magnitude of the problem of allocating the water of international rivers. Most of the literature has been plagued with hypothetical and unscientific facts based on old and questionable studies from the 1970s (Biswas 1999). It was not until 1999, when Wolf et al.'s work was published, that the overall magnitude and seriousness of the situation began to be understood. There are approximately 261 international river basins from which 145 international water treaties have been signed during the last 50 years. For the most part, these water treaties establish general goals of cooperation and equitable apportionment to maintain amicable relationships between riparian countries. Yet, specific guidelines for allocation, enforcement, and conflict resolution are lacking.

Only 54 international water treaties have some definition for water allocations. About 35 have clear specifications for allocation. Table 2.1 presents a summary of international water treaties with clearly specified allocations. Some of the allocation mechanisms utilized in the treaties are: equal portions, fixed annual or daily amounts or flows, storage allocations, minimum flows, allocative schedules or formulas dependent on current flows, "needs-based" allocation, and baskets of benefits in exchange for water (e.g. hydropower, money, etc). Some of the treaties establish joint commissions with the responsibility of determining the allocations and/or approving water rights and projects in the transboundary basin.

Water treaties have been the venue that water sharing countries have used the most to compensate for the gaps in detailed water law and adequate institutional framework. Most water allocation treaties pre-date water law conventions, thus establishing their own legal basis. In addition, several treaties have established their own institutional support by creating joint administrative commissions for the management and planning of international basins and the resolution of future conflict. However, the big picture is still that the legal management of transboundary waters remains conceptually deficient (Frederiksen 1992, Wolf 2001). Most of international water allocation treaties lack provisions for monitoring, information sharing, enforcement, conflict resolution, and/or incentives for compliance and cooperation. More importantly, less than a fourth of the treaties delineate a specific allocation mechanism (i.e. 35 of 145 treaties) which is usually the core of conflict. This lack of specificity could be the result of the vagueness of international water law, the lack of an effective enforcement institution or both. Nonetheless, the international treaty appears to offer the most effective venue for providing effective allocation and management of international waters.

Table 2.1. Summary of International Treaties with Clear Allocation Mechanisms

International Transboundary Water Treaty	Signatory Countries	Year	Transboundary Basins	Allocation	Other Specifications	Conflict Resolution
The 1944 Treaty	USA and Mexico	1944	Colorado, Tijuana and Rio Grande	Fixed allocations of streamflow and storage	A joint commission is created for administration	None
Mexicali Valley Agreement	USA and Mexico	1966	Colorado	USA releases a fixed amount of water from storage to Mexico	Monetary compensations for loses in hydropower	None
Austria and Bavaria Agreement	Austria and Bavaria	1950	Rissbach, Durrach and Walchen	Diversions must be curtailed to ensure proper flow at the border	None	None
Austria and Hungary Treaty	Austria and Hungary	1956	Danube	A commission is to approved granting of water rights	Parties agree to take measures to regulate use.	None
Iran and Iraq Agreement	Iran and Iraq	1975	Tigris, Euphrates and Shatt al Arab	Water to be divided in equal parts	Border issues are discussed	Disputes to be resolved according to a different legal agreement
Iraq and Kuwait Agreement	Iraq and Kuwait	1964	Euphrates	Kuwait is guaranteed a minimum daily flow	None	None
Ganges River Treaty	Bangladesh and India	1996	Ganges	Allocations to be made according to a formula based on 10-day period average flows	Allocations to be adjusted according to several minimum flows. A commission oversees the allocations	None

Table 2.1. Continued

International Transboundary Water Treaty	Signatory Countries	Year	Transboundary Basins	Allocation	Other Specifications	Conflict Resolution
Eritea and Sudan Agreement	Eritea and Sudan	1925 & 1951	Gash	Eritea receives a maximum of 65 MCM	None	None
Horgos River Protocol	China and Russia	1915	Horgos	Flow to be divided equally	Existing uses of canals must remain the same	None
Finland and Norway Convention	Finland and Norway	1925	Pasvik and Jakobselv	Water to be divided in equal parts	None	UN to be the third party in conflict discussion
Lake Constance Agreement	Germany, Switzerland, and Austria	1966	Lake Constance	Maximum flow can be withdraw by the parties without authorization	Diversions in excess of those flows must be authorized	Council
Franco-Italian Convention	Italy and France	1967	Roya	Fixed allocations of streamflow	If streamflow below certain flow, allocations must be reduced proportionally	UN to be the third party in conflict discussion
Israeli-Palestinian Interim Agreement	Israel and Palestine	1995	West Bank and Gaza Strip Waters	Palestine get fixed amounts of water from several water sources	Israel to finance new water deliveries	UN to be the third party in conflict discussion
Declaration of the Peruvian-Ecuatorian Frontier	Ecuador and Peru	1944	Amazon, Zarumilla, Tumbes, and Chira	Peru agrees to supply water to Ecuatorian villages	None	None

Table 2.1. Continued

International Transboundary Water Treaty	Signatory Countries	Year	Transboundary Basins	Allocation	Other Specifications	Conflict Resolution
Iran and Soviet Union Agreement	Iran and Soviet Union	1957	Araks and Atraks	Water to be divided in equal parts	A joint commission is created for determination of boundary line	None
Columbia River Treaty	Canada and USA	1961	Columbia	Canada to maintain minimum flow in Kootenay River at border	Hydropower and Flood Provisions	Council
Cunene River Agreement	Portugal (Angola) and South Africa	1939 & 1969	Cunene	Water to be divided in equal parts	South Africa to provide compensation for flooded area in dam construction. Hydropower provisions	None
Treaty between Nepal and India	India and Nepal	1996	Ganges-Brahmaputra-Meghna	Nepal gets minimal flows and India compromises to maintain minimal flows	Treaty waiting to be ratified	Council
Indus Waters Treaty	India and Pakistan (and World Bank)	1948 & 1960	Indus	India receives 100% flow from eastern rivers. Pakistan 100% flow from western rivers	Deliveries to Pakistan from eastern rivers were to be honored until 1970	Council and third party negotiation
Syria and Jordan Yarmuk Agreement	Syria and Jordan	1953	Yarmuk	Minimum flows to be delivered to Jordan for irrigation	Hydropower Provisions	None

Table 2.1. Continued

International Transboundary Water Treaty	Signatory Countries	Year	Transboundary Basins	Allocation	Other Specifications	Conflict Resolution
Johnston Accord	Israel, Jordan, Lebanon and Syria	1955	Jordan and Yarmuk	Flow is divided according to the irrigable land in each country	USA shared cost of projects as incentive for compliance and enforcement mechanism	UN to be the third party in conflict discussion
Jordan and Israel Treaty of Peace	Israel and Jordan	1994	Jordan and Yarmuk	Fixed quantities are assigned for Israel for summer and winter months	Jordan also receives desalinated water and both parties will work together to find other sources of drinkable water	None
Mekong River Declaration	Cambodia, Thailand, Laos, and Vietnam	1975	Mekong	All diversions are to be approved by the Commission	A Commission is created for the of the management of the water resources	Council, Governments intervention and Mediation
Sudan and United Arab Agreement	Sudan and Egypt	1959	Nile	Fixed allocations of flow and proportionate allocation of storage	Egypt to pay Sudan for inundated lands and dam construction	Council
Nile Waters Agreement	Egypt and United Kingdom	1929	Nile	During dry season Sudan diversions must follow a schedule determined in a previous study and included as an article of the agreement	None	UN to be the third party in conflict discussion

Table 2.1. Continued

International Transboundary Water Treaty	Signatory Countries	Year	Transboundary Basins	Allocation	Other Specifications	Conflict Resolution
Lesotho Highlands Treaty	Lesotho and South Africa	1986	Senqu/Orange	South Africa receives water and Lesotho gets hydropower from a reservoir	Both countries to share payments of loans for the construction of reservoir	Council
Lake Lanoux Agreement	France and Spain	1958 & 1970	Lake Lanoux	France to deliver a minimum annual amount of water	Hydropower considerations	UN to be the third party in conflict discussion
Finland and Norway Agreement	Finland and Norway	1951	Naatamo & Gandvik	Finland not to object diversions from 4 reservoirs in the Naatamo to compensate for loss of flow in the Gandvik due to construction of hydropower dam	Monetary compensation to Norway for loss of power. Provisions for the protection of salmon	None
Niagara River Treaty	USA and Canada	1950	Niagara River	Diversions must be curtailed to ensure minimum flows between certain dates and times	Hydropower and scenic considerations	Council
Convention between the Governments of Yugoslavia and Austria	Austria Yugoslavia	1954	Danube	Several minimum flows are to be maintained and depending on the flow diversions might be limited	Hydropower considerations	Arbitration

Table 2.1. Continued

International Transboundary Water Treaty	Signatory Countries	Year	Transboundary Basins	Allocation	Other Specifications	Conflict Resolution
Agreement between Great Britain and France	France Great Britain	1906	Gambia	Water rights of local inhabitants are protected	Boundary delineation	None
Helmand River Delta Agreement	Iran Afghanistan	1950	Helmand	A commission is created to measure and divide the waters.	None	None
Meuse River Agreement	Belgium Netherlands	1863 1961	Meuse	Water quantities allocated depend on levels of water in the Meuse	Cost Sharing specifications, Belgium 2/3, Netherlands 1/3	None
Oder River Agreement	Poland Czechoslovakia	1958	Oder	Council to decide the allocations by type of use	None	Council
Argentina and Paraguay Agreement	Paraguay Argentina	1945	Pilcomayo	Commission to decide the allocations by type of use	Boundary delineation	None

CHAPTER III

INTERSTATE WATER ALLOCATION

In the United States, a state has broad authority, under the Constitution, of all the waters within its borders limited only by a federal navigation servitude and the Congressional power under the Commerce Clause to control navigation. Nonetheless, a state has no direct authority over a neighboring state's water and when exercising its authority over an interstate stream, a state cannot dismiss the interests of downstream states. Determining how much water from an interstate stream a state is entitled to is not an easy task and jurisdiction over this type of disputes resides outside the states themselves.

There are three venues for the allocation of water among states: congressional apportionment, judicial adjudication, and interstate compacts. The congressional or statutory apportionment occurs when the allocation of water is determined by Congressional action and it has been rarely used for interstate water apportionment. When a state determines that there is clear and convincing evidence that its rights to use its share of interstate waters have been curtailed or diminished, the state has the right to resort to litigation in the Supreme Court under the doctrine of equitable apportionment. Finally, the most common and perhaps the preferred method for interstate water allocation is the interstate compact. Compacts are legal agreements between states that are also ratified as federal law. This Chapter provides an overview of these three venues with special emphasis on interstate water allocation compacts.

3.1 CONGRESSIONAL APPORTIONMENT

The United States Congress has the power to apportion water of navigable rivers among states, in furtherance of commerce or where waters are to be released from storage in federal reservoir projects. Where Congress has exercised its constitutional power over waters, courts have no power to substitute their own notions for the apportionment (*Arizona v. California* 1963). Congressional allocation has occurred twice, in the allocation of the Colorado River and the Lake Tahoe and Truckee and Carson rivers. Although the waters of the Colorado River were originally allocated by the Colorado River Compact of 1921, it did not resolve differences over allocation among the lower basin states (Arizona, California, and Nevada). For years Arizona thwarted California's attempts to develop the river for fear of California taking a disproportionate share of the lower basin supply. Finally in 1963, the Supreme Court held that Congress, in passing the Boulder Canyon Project Act of 1928, divided the waters of the river among the lower basin states. This action by the Court recognized that Congress may act when the other apportionment mechanisms of compacts and judicial adjudications have failed, are unavailable, or are not used (Getches 1997, Tarlock et al. 2002). In 1990, Congress passed the Truckee-Carson-Pyramid Lake Water Rights Settlement Act, which specifies how the waters of Lake Tahoe and the Truckee and Carson rivers are to be apportioned between California and Nevada.

There are two major aspects that make Congressional apportionment to be considered an inefficient method of water allocation. Its major shortcoming is that it is highly unlikely that members of Congress will have the specialized knowledge necessary to deal with water disputes. The second aspect is that Congressional decisions are mostly based on political reality rather than legal, social, and economical reasons. Therefore, it is better for the states to determine water apportionment by voluntary agreement rather than having a congressional majority decide for them since many of the Congress members may have little interest on the region or may base their decision on mere political interests (Copas 1997).

3.2 JUDICIAL ADJUDICATION

The Supreme Court has original jurisdiction in all cases in which a state is a party. The Supreme Court's original jurisdiction has been invoked in disputes over the waters of the Arkansas, Colorado, Connecticut, Delaware, Laramie, Mississippi, North Platte, Pecos, Republican, Rio Grande, Vermejo, and Walla Walla Rivers (Tarlock et al. 2002). When a state feels it has been wronged or deprived of its fair share of the waters, it can file a complaint and follow the required hearing and motions (e.g. to suppress, dismiss, etc.). If the complaint survives these procedures, the respondent state must file an answer. Typically, the Court appoints a special master (usually a retired federal judge or a distinguished water lawyer) to hear and evaluate the evidence. The special master prepares findings of fact and conclusions of law and recommends a decree which the Court is free to follow or disregard.

The Supreme Court has developed its own common law in exercising its jurisdiction over interstate water disputes by applying either the doctrine of "equitable apportionment" to surface water or the commerce clause to groundwater (*Sporhase v. Nebraska* 1982). Equitable apportionment is a regulatory doctrine fashioned by the courts to assure a balance between states by "dividing the pie", that is, an interstate stream between the states that share its waters. The basic tenet of this doctrine is that "equality of right", not of quantity, should govern. This simply means that the states stand "on the same level… in point of power and right under the constitutional system" (*Kansas v. Colorado* 1907). Thus, this doctrine prevents any state, simply because it is upstream, bigger, more economically advanced, or more aggressive in litigation, from taking more than its fair share of the river. The courts are called to settle disputes among states in such a way that it recognizes equal rights to all states by establishing justice and demanding "delicate adjustments" of the interests of the states (*Kansas v. Colorado* 1907; *Nebraska v. Wyoming* 1945). In other words, even though equitable apportionment respects territorial authority, it limits the water use within the state in order to accommodate for the competing needs of the water sharing states (Utton 1988).

When dealing with water disputes the Supreme Court is not bound by the laws of the individual states or by their allocation doctrines. The Court however, may use the states system as a source of principles for water allocation. For instance, when all states prescribe to the doctrine of prior appropriation, priority becomes the "guiding principle" in the allocation among competing states, but state law is not controlling (*Colorado v. New Mexico* 1982).

The ruling of the Court overrules the states law and the overall criterion of allocation is equitable apportionment not prior appropriation. The factors that might justify deviation from priority include: physical and climate conditions, rate of return flows, economy of established uses, availability of storage, practical effect of wasteful uses, comparison between damage upstream due to curtailed uses and benefits downstream (Getches 1997).

In cases involving riparian states, the Supreme Court has used several guiding principles of riparian law such as giving greater importance to instream uses than to consumptive uses by protecting base flow and keeping the status quo among similar users (Tarlock et al. 2002). For the most part, the Court tries to avoid intervention in intrastate allocation, and has often taken a "mass allocation" approach. In these cases, the Court awards each state a quantity of water to be distributed by the state's allocation system (Getches 1997). In addition to the basic two state law systems, the Court has developed its own body of federal law applicable to reserved federal and Indian lands water rights, especially in the west (Muys 2003).

Historically, the Court has been reluctant to take jurisdiction in water allocation disputes for a number of reasons concerning the vagueness of allocating standards, need for supervision, massive amount of technical data and the Court's lack of expertise on the subject, as well as the staggering expenses of litigation and of paying a special master. It has been argued that to educate the Court to a point where it could make an informed decision requires too many resources to be truly efficient (Copas 1997). Moreover, even when the Court reaches a satisfying solution to a water dispute there are no other mechanisms of enforcement and avoidance of future conflict.

Since the only alternative available to states under the equitable apportionment doctrine is more litigation, states would have an incentive to cheat because further litigation is ungainly to the other states, especially if they have been already in full-scale judicial action (Copas 1997). Moreover, the Court will not pursue any suit unless it is "justifiable". According to the Court, a justifiable complaint is one that involves an "invasion of rights of serious magnitude… established by clear and convincing evidence" (*Connecticut v. Massachusetts* 1931). In other words, the Court will not intervene for cases of water development for future projects or cases where no harm has yet been done. This approach is more remedial as it intends to promote states to reach agreements on their own instead of battling each other in Court. A more beneficial approach is for the states to reach a voluntary agreement, since there is no guarantee that the Court will protect existing economic conditions when making a decree. In addition, the burden of proof requirements established by the Court are such, that the conflict must be allowed to "ripen" to the point where the political and economical costs of reaching a satisfying adjudication may be deemed too high to pursue (Sherk 1994).

3.3 INTERSTATE COMPACTS

Interstate compacts are negotiated agreements entered into voluntarily by two or more states. The United States federal government can also be a party to an interstate compact to represent the government needs for federal lands, Indian rights or other national interests (Tarlock et al. 2002). These are called federal-interstate compacts (Grant 1991). Once ratified by Congress, they become both federal laws and contracts among signatory parties.

States form compacts to allocate debt, establish an authority for the operation of an interstate port, clear jurisdictional questions, establish cooperative services, provide for the allocation and management of water resources and related projects, and the extradition of felons (Girardot 1989). Interstate water compacts are formed for a variety of purposes besides water allocation, including storage, flood control, pollution control, and comprehensive planning and management. Compacts have become the most common venue for transboundary water allocation between states, especially among western states. They have been used to allocate interstate waters twenty-two times by an agreed “equitable apportionment” between states that otherwise might have required Supreme Court adjudication. In addition, four federal-interstate compacts have been signed for water allocation purposes.

The advantage of compact water allocation lies in its legal and political characteristics that allow it to adapt to the unique needs of a particular basin and the regional philosophy of water appropriation. They can also be used to create permanent administrative entities for the management of the compact or the region’s water resources as a whole. Another great virtue of compacts is that they allow parties to allocate unappropriated water, thus making a “present appropriation for future use” which is crucial to long term water planning and management (Getches 1997). Since judicial adjudication is bound by justifiable cause and harm, it cannot equitably apportion unused water (Grant 1991). Also, the flexibility inherent in the opportunity to fashion the agreement encourages compromise between states and the creation of unconventional and creative solutions to the ever changing challenge of supplying water for the future.

A Congressional authorization usually starts the process of negotiation among states pursuing an interstate water agreement. The states then appoint one or more representatives for the negotiations which are often assisted by a federal representative. If an agreement is reached, the governor and legislature of each state must ratify the compact. The final step, as required by the Constitution, is Congressional approval by enactment of legislation. As compacts become federal law, they supersede state law and any law inconsistent with it must give way (Grant 1991).

Table 3.1 presents a summary of the interstate and federal-interstate water apportionment compacts, the signatory states, and their major allocative and conflict resolution mechanisms. Compacts that allocate water among signatory parties vary in their terms, from allocating storage to dividing the actual flow in the stream. Flow can be apportioned by determining a percentage of the streamflow for each state (Table 3.2), requiring the delivery of a fixed quantity of water at a specific point on the stream (Table 3.3), or some proportion determined from a hydrologic model (e.g. Pecos River) (Table 3.2).

The allocation mechanisms adopted in these compacts determine the distribution of risks and losses in periods of low flows (Bennett and Howe 1998). For instance, under the fixed allocation rule, an upper state is required to deliver a minimum quantity of water or to sustain a minimum flow rate to the downstream state, therefore absorbing the entire loss during droughts. However, under a percentage allocation rule, states both on the upper and lower portions of the basin share the losses and gains during periods of low and high flows. Some states that follow the fixed allocation approach have avoided this risk inequality by adopting limited flow guarantees (e.g. South Platte River Compact). Instead of promising a given quantity of water no matter the circumstances, in the case of insufficient flows, the upstream state commits to implement specific actions to reduce consumption (McCormick 1994). In this way the upper state takes the initial risk of low supplies but beyond some critical point, the risk is shared.

States following a proportion rate approach use hydrologic models as the basis of their allocation. The end result is similar to the percentage allocation but the division of water obeys a schedule that varies with the streamflow instead of being a fixed percentage. This proportion rates are specified in the compact and were determined from the modeling techniques available at the time of the compact formation. The reasoning is that the states share the risks of dry years equally as it is represented in the model. Even though it may appear that this methodology is more scientific and should be a better representation of the general hydrologic conditions than determining a quantity of water from mere observations, the reality is that models can be proved inadequate later and the method is not better than the model used and the available data (McCormick 1994). This has been the case in both

Table 3.1. Summary of Water Allocation Compacts

Interstate Agreements	States	Year	Allocation Method	Administrative Agency Created?	Conflict Resolution Mechanism
Animas-La Plata Project Compact	New Mexico Colorado	1963 1995	Equal Priority of demands - Not real allocation	No	None
Arkansas River Compact	Arkansas Oklahoma	1970	Flow - Percentages	Yes	Arbitration
Arkansas River Compact	Colorado Kansas	1948	Flow - Fixed Quantities	Yes	Arbitration by federal representative
Arkansas River Compact	Kansas Oklahoma	1965	Storage - Fixed Quantities	Yes	None
Bear River Compact	Wyoming Idaho Utah	1978	Flow - Percentages Storage - Fixed Quantity	Yes	Voting
Belle Forche River Compact	South Dakota Wyoming	1949	Flow - Percentages	No	None
Big Blue River Compact	Kansas Nebraska	1971	Flow - Fixed Quantities	Yes	None - Court Enforcement Encouraged
Canadian River Compact	New Mexico Texas Oklahoma	1950	Storage Fixed Quantities	Yes	None

Table 3.1. Continued

Interstate Agreements	States	Year	Allocation Method	Administrative Agency Created?	Conflict Resolution Mechanism
Colorado River Compact	Arizona California Nevada Colorado New Mexico Utah Wyoming	1922	Flow - Fixed Quantities	No	Voting
Costilla Creek Compact	Colorado New Mexico	1922	Unique allocation for irrigation rights	Yes	None
Klamath River Compact	Oregon California	1957	Unique allocation - priorities by use when insufficient flow	Yes	Arbitration
La Plata River Compact	Colorado New Mexico	1922	Flow - Percentage (below minimun flow)	No	None
Pecos River Compact	New Mexico Texas	1948	Flow Percentages - based on model	Yes	None
Red River Compact	Arkansas Lousiana Oklahoma Texas	1978	Flow - Percentages Storage - Percentages	Yes	Voting
Republican River Compact	Colorado Kansas Nebraska	1942	Flow - Fixed Quantities	No	None

Table 3.1. Continued

Interstate Agreements	States	Year	Allocation Method	Administrative Agency Created?	Conflict Resolution Mechanism
Rio Grande Compact	Colorado New Mexico Texas	1938	Flow Percentages - based on model	Yes	None
Sabine River Compact	Lousiana Texas	1953	Flow - Percentages	Yes	Voting
Snake River Compact	Idaho Wyoming	1949	Flow - Percentages	No	Voting
South Platte River Compact	Colorado Nebraska	1923	Flow - Fixed Quantity (minimun flow at border)	No	None
Upper Colorado Basin Compact	Arizona Colorado New Mexico Utah	1948	Flow - Percentages Storage - Fixed Quantities	Yes	None
Upper Niobrara River Compact	Nebraska Wyoming	1962	Storage - Fixed Quantities	No	None
Yellowstone River Compact	Montana Wyoming North Dakota	1949	Flow - Percentages	No	Voting
Delaware River Basin Compact*	Delaware Pensylvania New Jersey New York	1961	Allocation by the Commission	Yes	Voting (Empowered Commision)
Susquehanna River Compact*	Maryland New York Pennsylvania	1970	Allocation by the Commission	Yes	Voting (Empowered Commision)

* Federal-interstate Compacts

Table 3.1. Continued

Interstate Agreements	States	Year	Allocation Method	Administrative Agency Created?	Conflict Resolution Mechanism
Appalachicola-Chattahoochee-Flint River Basin Compact*	Alabama Florida Georgia	1997	Commision is to determine allocation formula	Yes	None - Court Enforcement Encouraged
Alabama-Coosa-Tallapoosa River Basin Compact*	Alabama Georgia	1997	Commision is to determine allocation formula	Yes	None - Court Enforcement Encouraged

* Federal-interstate Compacts

Table 3.2. Summary Description of Water Compacts - Allocation by Percentage

Interstate Compact	Signatory States	Flow Percentage	Other Allocations	Special Conditions	Conflict Resolution
Arkansas River Compact	Arkansas Oklahoma	50% Spavinaw Creek 60% Illinois River 60% Roteau River 100% AR Lee Creek 60% Arkansas River 100% OK Lee Creek	None	None	Commision has 3 representatives per state but only one vote per state
Bear River Compact	Wyoming Idaho Utah	58.9% River's Upper Division 43% River's Central Division 57% River's Central Division 41.1% River's Upper Division	85,150 ac-ft Total Storage 125,000 ac-ft Lower Division 6,824 ac-ft Total Storage 94,850 ac-ft Total Storage	Flow allocations only after stream levels fall below certain critical level.	Decisions require 2 votes from each state (6 total)
Belle Fourche River Compact	South Dakota Wyoming	90% Belle Fourche River 10% Belle Fourche River	States can temporarily store any additional water	Wyoming has unrestricted use of water for domestic uses < 20 ac-ft	None
La Plata River Compact	Colorado New Mexico	50% La Plata River 50% La Plata River	None	Allocation when flow <100 cfs	None
Pecos River Compact	New Mexico Texas	Residual % after Texas share % Determined from hydrologic model	None	Texas is entitled to amounts equal to the 1947 conditions of the Pecos.	None

Table 3.2. Continued

Interstate Compact	Signatory States	Flow Percentage	Other Allocations	Special Conditions	Conflict Resolution
Red River Compact	Arkansas	25% Reach II 40% TX-AR portion Reach III 60% AR-LO portion Reach III 60% Reach IV		Basin divided in 5 reaches. The Compact also establishes instream flow requirements for some reaches.	Each state has 2 commissioners,but only one vote. Projects approval requires 3 votes, implementation of compact clauses require 6 votes, and water rights decisions require unanimous vote.
	Lousiana	25% Reach II 60% AR-LO portion Reach III 40% Reach IV 100% Reach V	50% Caddo Lake		
	Oklahoma	40% Reach I 25% Reach II	50% Lake Texoma		
	Texas	60 % Reach I 25% Reach II 60% TX-AR portion Reach III	50% Lake Texoma 50% Caddo Lake		
Rio Grande Compact	Colorado	% Determined from hydro- model	None	The percentage of flow delivered to downstream states is determined from the flow at index stations. Some deliveries are fixed quantities.	The state Enginneer from each state serve as commissioner.
	New Mexico	% Determined from hydro-model			
	Texas	% Determined from hydro-model			
Sabine River Compact	Lousiana	50 % Sabine River	None	An instreamflow requirement of 36 cfs is established.	Each state has 2 representatives and a non-voting federal representative.
	Texas	50 % Sabine River			

Table 3.2. Continued

Interstate Compact	Signatory States	Flow Percentage	Other Allocations	Special Conditions	Conflict Resolution
Snake River Compact	Idaho Wyoming	96% Snake River 4% Snake River	None	None	Each state has a representative. If a split decision occurs a third party is selected by both states.
Upper Colorado Basin Compact	Arizona Colorado New Mexico Utah Wyoming	 51.25% Flow 11.25% Flow 23% Flow 14% Flow	Allocations are to be made after Arizona receives 50,000 ac-ft/yr of storage.	None	Each state except Arizona has a commissioner. Quorum is reached with 4 votes.
Yellowstone River Compact	Montana Wyoming North Dakota	40% Clarks Fork 80% Bighorn 60% Tongue 58% Powder 60% Clarks Fork 20% Bighorn 40% Tongue 42% Powder	None	Allocations apply to unappropriated water after existing water uses are met at all 3 states.	Montana and Wyoming have representatives with vote. North Dakota does not have a vote. If a tie occurs, a federal representative will have the decisive vote.

Table 3.3. Summary Description of Water Compacts - Allocation by Fixed Quantities

Interstate Compact	Signatory States	Allocated Quantity	Other Allocations	Special Conditions	Conflict Resolution
Arkansas River Compact	Colorado Kansas	Releases < 100 cfs - Winter Releases < 500 cfs - Summer 500 - 750 cfs - Summer	If storage at John Martin Reservoir < 20,000 ac-ft, total reservoir releases < 1250 cfs.	None	Each state has 3 representative but 1 vote. A federal representative serves as arbitrator if tie occurs.
Arkansas River Compact	Kansas Oklahoma	65,000 ac-ft storage at Grand-Neosho River 300,000 ac-ft storage at Verdigris River 600,000 ac-ft storage at Arkansas River 5,000 ac-ft storage at Cimarron River 5,000 ac-ft storage at Cimarron River	Unrestricted use of flow within each state.	Yearly amounts.	Each state has 3 comissioners. No voting power.
Big Blue River Compact	Kansas Nebraska	200,000 ac-ft storage at Little Blue 500,000 acf-ft storage at Big Bue	Unrestricted use of flow within the state. Maintain minimun flows at index gaging stations from May - September	None	Each state has 2 representatives. No voting power.

Table 3.3. Continued

Interstate Compact	Signatory States	Flow Percentage	Other Allocations	Special Conditions	Conflict Resolution
Canadian River Compact	New Mexico	200,000 ac-ft storage below Conchas Dam	Unrestricted use of flow above Conchas Dam	None	Each state has 1 commissioner. Unanimous vote required for decisions.
	Texas	500,000 ac-ft storage + whatever water is stored for conservation in OK	Unrestricted use of flow within the state.		
	Oklahoma	300,000 ac-ft storage in the North Canadian River	Unrestricted use of flow within the state.		
Colorado River Compact	Arizona	Lower State allocation	Lower basin states are entitled to 7,500,000 ac-ft/yr of water and can increase their use 1,000,000 ac-ft/yr. The Lower basin states must receive at least 75,000,000 ac-ft/10yr.	The basin is divided into Upper and Lower basins	If problem arise, governors apoint commissioners for voting resolution.
	California	Lower State allocation			
	Nevada	Lower State allocation			
	Colorado	Upper State allocation			
	New Mexico	Upper State allocation			
	Utah	Upper State allocation			
	Wyoming	Upper State allocation			
Republican River Compact	Colorado	54,100 ac-ft/yr of water	50 cfs in Pioneer Canal for consumptive use in CO and NE	Allocations are to be made from "virgin water supply" (undepleted by man). If conditions change by more than 10%, allocations must change accordingly.	None
	Kansas	190,300 ac-ft/yr of water			
	Nebraska	234,500 ac-ft/yr water			

Table 3.3. Continued

Interstate Compact	Signatory States	Flow Percentage	Other Allocations	Special Conditions	Conflict Resolution
South Platte River Compact	Colorado	Full use of water below Lodge Point but must allow at least 120 cfs/day to flow to NE	None	Allocations are valid only between April 1 and October 15.	None
	Nebraska	Full use of water above Lodge Point			
Upper Niobrara River Compact	Nebraska Wyoming	No reservoir can exceed 20 ac-ft	WY has no restriction in its use of surface water.	Existing rights in NE are respected. Groundwater to be allocated after study.	None

instances when the proportion model approach has been used (i.e. Pecos and Rio Grande River Compacts) and conflicts over compact compliance have prevailed among water sharing states. In the case of the Pecos River, twelve years were spent interpreting the allocation formula specified in the compact that required New Mexico to deliver to Texas the same amount of water as in the 1947 river conditions.

This problem however, is not exclusive to proportional model compacts. Water supplies estimates in compacts are often inaccurate. For instance the Rio Colorado Compact is a fixed allocation compact that apportions 7,500,000 ac-ft/yr of water to the lower states of the basin (i.e. Arizona, California and Nevada). It is now apparent that the annual flow estimate of 1922 of 16,000,000 ac-ft was too high and the mean annual flow is actually about 13,500,000 ac-ft (Getches 1985). Nevertheless, upper basin states are obligated to deliver the amount specified in the compact even at the risk of having available far less water than originally expected. Other compacts present other unique water allocation mechanisms. For instance, the Costilla Creek Compact establishes priorities among irrigation ditches regardless of state lines. Also, the Klamath River Compact establishes a system of priorities according to type of use when flows are insufficient.

Storage allocations in compacts are usually used to limit the amount of water that can be stored by the upstream state. In these cases the downstream states assumes the risk of low water supply since it will only be entitled to whatever flow is left after the upstream state has refilled its storage. Storage allocation compacts are usually used where the flow regime does not match consumption patterns so storage is needed to ensure that the upstream state will enjoy its share of the resource.

Compacts implement and enforce water allocation following one of two basic approaches. The first is a prescriptive approach that provides guidelines and delimits scopes of the arrangements to control the use of the water and the activities of the water management agencies. In other words, the agreement itself becomes the enforcement mechanism to apportion the resource. The second approach is the establishment of an interstate commission or agency (Carriker 1985, Copas 1997). About two thirds of all interstate water allocation compacts create compact commissions. These commissions are composed of representatives from the parties entered in the compact (i.e. states and/or the federal government). Generally, the purpose of such commissions is to accumulate information, facilitate communication, and negotiate during changing circumstances (Copas 1997).

There is a difference in power and structure among commissions created by interstate compacts and those created by federal-interstate compacts. In the case of the former, water the functions of interstate compact commissions are usually more limited, basically because states have been reluctant to delegate their sovereign prerogatives to an entity they cannot fully control (Grant 1991). On the other hand, federal-interstate compacts (e.g. Delaware and Susquehanna River Basin Compacts) have established commissions with extensive planning, regulatory, and enforcement powers.

The Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa River Basin Compacts are a very unique type of compact. They both create commissions prior to the allocative agreement in order to provide for the necessary conditions for developing a water allocation formula among the compact signatory states. In addition, the compacts mandate the commissions to gather the necessary data, resources and research for developing the formula and empower them to further enforce the management and administration of the basins water resources. Allocative decisions however, required unanimous voting of the commission. Nonetheless, after the states spent millions of dollars and repeatedly extended decision deadlines, the states were not able to reach or ratify any allocative agreement and the Apalachicola-Chattahoochee-Flint Compact expired on August, 2003.

It is interesting to notice that the difference in power given to compact commissions occur in the context of the differences between eastern and western allocation philosophies. The authority given to the Delaware and Susquehanna River Commissions makes sense in the east with its urban areas and relative abundance of water. In the west however, compacts were negotiated to ensure the state's power over a scarce resource (McCormick 1994). Therefore, the nature of water rights in the west is defined in terms of property and any attempt to restrict vested rights beyond the state's law could be interpreted as unconstitutional.

Even in interstate basins with water allocation compacts in place, disputes are not uncommon. The fact that compacts are consensual in nature presents a dilemma. If the states cannot agree, there is no compact. Therefore, conflict resolution is one of the major aspects of compact drafting, approval and enforcement. At any point, a state may claim that another compact sharing state is failing to comply with the compact specifications, or may disagree on how the language used in the compact is construed. Disputes among signatory parties can be brought to the Supreme Court for resolution, but as previously discussed; this process is usually lengthy and very expensive. For this reason, some compacts define methodologies for conflict resolution. If a commission has been established by the compact, it is usually the first forum for resolving disputes. If there is no commission, other state water officials can be involved in conflict discussion, but the process lacks formal structure. The most common mechanisms for conflict resolution are voting and arbitration (McCormick 1994, Grant 1991).

Voting can occur among commission members or, in the case of no commission, among state officials in order to use a majority criterion to reach a decision. This however, is a major drawback when there are only two signatory parties or when unanimity is required. Several compacts have non-voting federal representatives and some of those allow these members to vote when a tie needs to be broken (e.g. Yellowstone and Snake River Compacts). In reality only the Delaware River Basin Compact gives its commission enough power to make and enforce independent decisions through voting when conflicts arise. This commission has the power to allocate the waters of the basin among the signatory states in accordance with the Supreme Court's doctrine of equitable apportionment and impose penal sanctions to compact violators (Muys 2003, Copas 1997). This is not the case in most compacts where the states have retained the power of veto in conflicts concerning allocation. Due to the political nature of the process and the long tradition of distrust regarding matters of water (especially among western states), the voting mechanism is usually ineffective for resolving major disputes (McCormick 1994).

Traditionally, the only alternative to voting has been Supreme Court litigation. However, in recent years arbitration has become a popular alternative for conflict resolution. Arbitration is similar to litigation in that a neutral party serves as a decision-maker once sufficient evidence of facts and law has been presented. The attractiveness of arbitration is that arbitrators can be selected based on their knowledge on the subject and therefore their decision should be better than that of a judge with no experience in the field. It is also believed that the process is less expensive and faster than litigation (Girardot 1989). However, some critics argue that even though arbitration is a reasonable alternative to the problem, arbitration of water compact disputes are as expensive as legal litigation and that arbitrators are sometimes perceived to be more concerned with reaching a settlement than enforcing the legal rights of the parties (McCormick 1994). As a result, Supreme Court litigation still appears to be the preferred mechanism for the definite resolution of conflict over compact allocation. This situation stresses the importance of language and methodology clarity in compact scripting in order to avoid future conflict. It has been argued that some compacts have only been ratified by the involved parties because difficult points have been deliberately defined ambiguously in order to reach a faster agreement (Tarlock et al. 2002).

Conflict may also occur between federal water development projects and non-federal projects operating under state law. Moreover, most compacts were created and ratified prior to major federal environmental legislations such as the Clean Water Act and the Endangered Species Act and are environmentally outdated. Therefore, it is inevitable that disputes between federal and non-federal water uses will continue to arise under many compacts (Muys 2003). The Constitution states that in the case of irreconcilable conflict between federal and state law, federal law must prevail. Therefore, in order for a compact to be comprehensive it should encompass federal water rights.

Approximately half of interstate water compacts provide allocations for federal uses and it is likely that the others would be so interpreted (Muys 2003). Even though most compacts include this recognition of federal water rights, most of them do not include the federal government as a signatory party. For this reason federal-interstate compacts such as the Delaware River Basin Compact of 1961, by having the federal government as a signatory party, had made provisions for a regional approach linking federal and state planning and imposing significant constraints on both the state and federal government. Based on the experience in the Delaware River Basin, the National Water Commission (1973) recommended the federal-interstate compact approach as the preferred institutional strategy for water resources planning and management in multi-state water sharing regions.

CHAPTER IV

INTRASTATE WATER ALLOCATION SYSTEMS

The water resources stored in rivers, lakes and other reservoirs must be shared by a multitude of uses and users. As water use increases and water allocation systems (WAS) evolve, rules are also developed to govern the sharing of the limited resource. These rules are defined within the WAS to determine who has the right to use the available water and in what priority, in order to protect existing users and accommodate new ones. The core principle is to codify arrangements that maximize the efficient use of water. These rules, however, do not occur in a vacuum nor are created by a solitary act of governmental will. They are the result of an evolutionary process of judicial rule-making (i.e. court decisions), also known as “common law”, and legislative action. The cumulative product of this legal process and the statutory and administrative arrangements that define water rights are known as water rights systems.

4.1 WATER RIGHT SYSTEMS

In the United States (US), water rights systems (WRS) have been created to administer and regulate the use of water. WRS define the terms and conditions that must be met in order to claim the legal right to use water. There is no national WRS in the US. Instead, each state has its own approach and set of rules for recognizing legal water rights. In the case of surface water rights, two principal doctrines demarcate the legal boundaries in which WRS operate. These legal doctrines are riparianism and prior appropriation. Traditionally, western states have followed variations of the prior appropriation doctrine while eastern states have applied rules from the riparian doctrine in their regulatory systems. Some states use other variations referred to as hybrid or dual WRS, as they combine elements from both doctrines.

4.2 RIPARIAN RIGHTS

The core principle of the riparian doctrine is that only the owners of lands abutting a watercourse are entitled to use the water. The rights of a riparian owner include: access to the water, wharfing or building piers into the water, use of the water, consumption of the water, and acquisition of accretions and ownership of the subsoil of non-navigational streams. The riparian owner has the right to ingress or egress his/her land by the way of the water and to build wharfs to ensure that right. A riparian right also includes the entitlement to consumptive and non-consumptive uses of water. Consumptive water uses include animal husbandry, extraction of minerals, industrial processing, intensive recreation (i.e. overcrowding and polluting), irrigation, municipal or private owned water systems, as well as any other use with social or economic value. Non-consumptive uses are those that do not significantly alter the quantity or quality of water. Among the most common non-consumptive uses recognized by law, are navigation, fishing, hunting, and swimming (Dellapenna 1991c). In order to ensure access to water, the riparian owner can claim ownership over any alluvium that accrues to his/her land. Finally, although with some state variations, a riparian permit holder may claim ownership over the stream's bed and sedentary shellfish. In the case of navigational waters, access to the subsoil is a public right and thus property is effectively subject to provide easement for public use (Tarlock et al. 2002). A riparian proprietor also has the rights to fish, to have water remain unpolluted, and to protect its banks from erosion (Getches 1997).

A riparian owner can impound water only if the reasonable uses of other riparians are not impaired. Accordingly, releases from the storage facility should be done in such a way that the flow of the stream is not unreasonably altered. Since the riparian doctrine developed in the more humid regions of the country, rainfall and streamflows were usually sufficient to supply nearly all human needs. The riparian "common-law" recognized the right of a riparian owner to have access to an undiminished streamflow, but strictly for domestic purposes. As population and demands for water increased, this limitation on water use was dimmed unreasonable and the doctrine came to be divided into two theories: natural flow and reasonable use.

4.2.1 Natural Flow and Reasonable Use Theories

The natural flow theory establishes that riparian owners can use as much water as needed for domestic uses (i.e. household, livestock, gardening, etc.) while keeping the bordering stream or lake at normal levels. When dealing with other uses that are necessary for the advancement of civilization such as manufacturing, irrigation, and the like, a strict adherence to the natural flow theory does not seem appropriate. Consequently, the courts developed the concept of reasonable use. The basis for this theory is that maintaining the normal levels of lakes and streams is not justifiable when the water may be used for beneficial purposes that would result in greater benefits without causing unreasonable damages to other riparians. In other words, the limits of an individual water right are determined by the impact of the water use on others and do not necessarily prohibit a reduction in streamflow (Carriker 1985).

There is, however, a preference for "natural" uses over other uses which the courts referred to as "artificial". The term "natural" was first used for referring to domestic uses and "artificial" for those uses that produce comfort and prosperity (e.g. irrigation, manufacturing, mining, etc.). As explained above, natural uses would be subject to the natural flow theory and artificial uses to reasonable use. However, reasonable use also reflects a preference for "artificial" uses that have a more "natural" definition as is the case of agriculture (Getches 1997; Dellapenna 1991c; Tarlock et al. 2002). For example, in some states, permits required for other riparian uses are not required for agricultural uses (e.g. Kentucky and Wisconsin).

In the riparian common law, the concept of reasonable use does not have a precise definition. It is a criterion for decision which is strictly relational, and the court usually uses it to decide whether one use is "more reasonable" than a competing or interfering use. Several riparian statutes use terms such as "equitable portion" or "reasonable-beneficial use" but those terms are usually defined in similar terms as the more traditional definition of reasonable use (ASCE 1997). The factors that are used to determine the reasonableness of a water use depend on the interests of the riparian owner, other riparians that could be affected, and the general public. Some of the factors that may be taken into consideration as stated in the *Restatement (Second) of Torts* (1979) are: purpose of use, suitability of the use to the watercourse, social and economic value of the use, extent and amount of the harm caused, and protection of existing users and uses. Nevertheless, and despite the endorsement given by the *Restatement (Second)*, temporal priority does not appear to be a relevant factor in determining reasonableness (Davis 1982).

Reasonable use gives flexibility in the face of changing conditions of water use and supply by considering the social and economic value of the use. Once a right is granted it also provides certain degree of protection from unreasonable uses of water. However, some complexities arise due to a lack of specificity and its dependency to objectivity. Some critics point to the fact that the system restricts the use of the water to riparian owners and uses, ignoring the possibility that better use may be made at other places by riparian and non-riparian owners (Carriker 1985; Tarlock et al. 2002). Another criticism of this theory is concerned with the uncertainty that arises from the process of defining reasonable use for non-domestic purposes. Since the needs of other riparian users have to be considered in order to determine the reasonability of a use, when a riparian desires to commence or enlarge its water use, even riparians with long nonuse of their rights could cause the new use to be considered unreasonable with respect to their rights. This situation creates a need for litigation in order to establish a riparian's entitlement to use water. Litigation adds further complications since courts have been incapable of applying the law uniformly as their decisions vary in a case-by-case fashion. This situation may discourage development because industries may refuse to locate in an area for fear of having their water rights diminish or curtailed for some unforeseen reason. Riparianism also lacks an effective method to deal with water shortages. Even though it is based on equity, it does not provide a method to determine how much a riparian user should reduce his/her water use.

4.2.2 Transfer and Loss of Riparian Rights

Given the fact that property is the basic paradigm of riparian common law, one must expect that riparian water rights are not transferable apart from the land to which those rights are attached. However, there is no reason to believe that the economically most productive use of water will always be exclusive to those lands contiguous to waterbodies. Almost every riparian state has accepted at least some kind of transferring of riparian rights to non-riparian areas. Most courts, however, have not recognized full transferability; instead they have developed complex rules that vary from state to state. The most common means by which riparian rights can be transferred are: conveyance, condemnation, and prescription (Dellapenna 1991c).

Conveyances are deeds to riparian lands that deal with the transfer of the riparian rights. Rights can be transferred by selling or leasing the entire or a portion of the riparian land. Also, the right to use the water may be expressly reserved by a riparian landowner in conveying part of a riparian parcel to another (Getches 1997). If the rights are severed from the land by conveyance and granted to someone else, no subsequent owner of the land should have the right to use the water other than for domestic uses. However, the extent to which conveyances can be used to transfer water rights to non-riparian users varies from state to state and is usually ambiguous (Dellapenna 1991c). Since a conveyance binds the grantor to the grantee and not the grantee to the rest of the riparian owners, it is very problematic to define the extent of such rights, especially for consumptive uses of water.

Under the riparian theory, municipal water supply systems have no special right to use the water. However, public water supply authorities do have the right to condemn (claim) water for the public common good. Most states have statutes that give authority to condemn water rights or even property rights of a riparian land for this purpose even when neither municipal water use constitute a riparian use nor conveyance of water to non-riparian land is accepted (Peck and Weatherby 1994).

Prescription is a means by which a water right can be either gained by an upstream claimant or lost by the current downstream holder. Similar to the adverse possession laws, a prescriptive right can be gained if: (1) the claimant has been in continuous, open, and notorious use of a water body for a prescribed time period, and (2) the claimant's use of water actually deprives the downstream user of water to which he/she is entitled over the specified time (Tarlock et al. 2002). This type of right, however, cannot be obtained if the downstream user files a complaint before the prescribed time has elapsed.

Given the fact that the right to use water in a riparian system is attached to the ownership of land, it cannot be lost through simple non-use. Since use does not create the right, disuse cannot suspend it. Even in the case of conveyance or grant of riparian rights, the riparian land owner can still have the right to use water if there remains enough water for both users. Therefore, as long as a person owns riparian land he/she has the right to use water indiscriminately for domestic uses and/or invoke reasonable use for other non-natural uses (Dellapenna 1991c).

4.3 REGULATED RIPARIAN RIGHTS SYSTEMS

For many years the riparian common law was able to satisfy the water demands of the eastern states. But recent decades have seen increasingly frequent and severe water shortages due to recurring droughts and increasing demands. Analysts of the situation of riparian states have concluded that the application of pure riparian rights creates uncertainties and confusion as to impede the settlements of problems arising during water shortages (Carriker 1985; Dellapenna 1985; Tarlock et al. 2002). Given the limitations of pure riparian rights, about half of the states east of Kansas City have developed new regulatory permit systems based on some riparian principles. These new systems are seen by some analysts as minor modifications to riparian common law and by others as an intent to follow appropriation. However, as recognized by most specialists in the field, it is a fundamentally different approach to water law (Dellapenna 1994a; Davis 1982; ASCE 1997).

The transition from pure riparianism to regulation started in the 1950s by legislative statutes that created permit requirements and administrative structures. To date, 16 of the 30 original riparian states have comprehensive regulatory statutes for their water allocation (Iowa, Maryland, Wisconsin, Delaware, New Jersey, Kentucky, Florida, Minnesota, North Carolina, Georgia, New York, Connecticut, Arkansas, Massachusetts, Mississippi, Virginia, and Alabama). The purposes of the statutes include: conserving water, promoting beneficial and/or efficient use, assuring consistency of the use with the public interest, establishing comprehensive planning, preserving minimum streamflows, promoting flood control, and allocating water during shortages (Dellapenna 1991b).

Possibly the most significant innovation under the regulated riparianism is the requirement of a permit from an administrative agency in order to be entitled to use the water. Some states exclude some uses from having to apply for a permit leaving conflicts with those uses to be resolved in court much like traditional riparian rights. For example, Arkansas requires permits only for the building of dams and diversion of surplus water. Other uses are just required to be registered. Only in the case of a water shortage the administrative agency will determine priorities in a systematic way. In the states were uses are regulated by permits, the rights of competing users are determined by the terms of the permits and not by the riparian characteristics of the use or by judicial action.

Regulated riparianism has some similarities with the original riparian system. For instance, permit applications are judged according to some criteria of reasonable use. The concept of reasonable use, however, is applied differently. The major concern of the administrative agency is that the intended use is in accordance with the state's general water policy and other permitted uses. Uses in non-riparian lands are not considered unreasonable. Also, permits can be made subject to public values such as instream needs and preferences for certain types of use. Permits are also issued for a determined period of time so when the period expires the reasonability of the use can be reexamined (Maloney et al. 1972). Transferability of permits is also encouraged during the validity period.

Even though in practice most regulatory states do not discriminate against non-riparian users, it is surprising to see how few of their regulating statutes address this subject explicitly. Some states like Florida provide for permits to divert water even beyond the watershed boundaries, while others only allow diversions to non-riparian lands within the same basin.

Almost all regulatory states have preferences for different types of uses and they even exempt some uses from the permit requirement. Although such exemptions are usually reserved for domestic purposes, many states also exempt small scale agricultural uses or diversions withdrawing less than some specific amount of water per day (ASCE 1997). Most states have priority schemes for uses that apply either when the permit is issued or at times of water shortages. In general, regulatory systems give higher priority to direct human consumption, then agriculture, and then other uses (e.g. Maryland). Other states like Arkansas adopted schemes that prioritized minimum streamflows over non-domestic uses. The reason for these preferences is rarely questioned. Other than subsidizing some economic activities they also follow some social or political compromise or to reduce administrative costs. In the case of permit exemptions for non-domestic uses such as agriculture, even if they are small scale activities, cumulatively these exemptions can amount to large quantities of water. This practice however, is contrary to the purpose of using water efficiently and makes coping with water scarcity a much difficult task (Dellapenna 1991b).

Another advancement of regulatory systems is the creation of administrative state agencies for the management and enforcement of the permits systems. In addition, the agencies are responsible for supervising and promoting the development and conservation of the state's water resources. Most states have chosen to delegate these functions to an already existing or purposely created centralized statewide agency. Only Florida has chosen to delegate the power and responsibilities of administering the regulated system to five regional water management districts (Dzurik 1996). As opposed to traditional riparianism where decisions of reasonableness are decided by judicial decree, during the permit granting process the reasonableness of the use is determined by the agencies' interpretation of the legislative statute. Although the most important terms of the permits are set by legislation, other terms are devised by the agencies. Some of those terms can include: monitoring and recording requirements, protection of minimum flows, rate of flow of diversion, total quantity to be diverted (i.e. size of the permit), place of the diversion, and other conservation measures (ASCE 1997).

The agencies also have the responsibility to supervise and enforce the terms of the permits. When a user is found to be in noncompliance with the terms of his/her permit or a false statement is found in the application for a permit, formal penalties are needed to ensure the success of the system. Some of the most common enforcement measures authorized in the statutes are: civil penalties, criminal fines, suspension or revocation of the permit, cease and desist orders, administrative fines, civil liabilities, and imprisonment (Dellapenna 1997).

Dellapenna (1997) recognized that the question is not whether regulated riparianism in an ideal system, but rather if it is a better alternative. In traditional riparianism, the decision as to how water will be used lies in the hands of the actual users, and if conflicts emerge, they would resort to judicial action. In the case of regulatory systems, the state bestows the decision making power to a public agency. A major driving force behind the creation of these types of agencies is the long-term protection of the resource since through regulation, depletion of the natural resource may be avoided. Without regulation, users do not feel the need to use the resource in a wisely manner that would secure long-term use. Instead, the mindset is to obtain the greatest benefit at the present time. Another advantage of the regulatory riparian scheme is that permits can provide some security in the case of investments. Once a permit is granted, the right to use the water has been recognized and cannot be curtailed save for cases of water shortage, noncompliance or termination of the permit's period of validity. In riparian law there is no such security since a water user is always at risk of having his/her water right scrutinized and modified, and even deemed unreasonable in relation to other uses. If anything else, regulation of riparianism has strengthened the concept of water as a public resource while reducing the recognition of private property rights in water (i.e. abolition of unused water rights, time-limited permits, authority of administrative agency, etc.) (Cox 1994). Finally, since one of the purposes of regulatory agencies is to provide comprehensive planning, problems can be approached in a proactive manner, instead of the reactive nature of solving disputes in court.

The administrative approach of regulated riparianism has substantial economic and socio-political costs. Economic costs include salary for staff, monitoring, enforcement, and potential litigation among others. These costs are sometimes reduced by exempting minor uses from the permit requirements. However, as explained above, minor uses may represent large quantities of water and exempting them may have a major impact in the effectiveness of the administrative system in managing the resource. Therefore, care should be taken in the evaluation of the tradeoffs between supervision costs and unregulated uses.

Poor management decisions represent a different type of cost that is more difficult to assess. If economic criteria are used to assess decisions, then those uses that result in greater economic benefits are favored. However, this does not necessarily mean that the favored alternative is the most socially responsible decision. In addition, the bureaucratic and political nature of the process raises questions regarding the integrity of the process. Nevertheless, the system has seemed to work fairly well in responding to serious water shortages in several of the eastern states (Iowa Natural Resource Council 1978; Ausness 1983).

4.3.1 Allocating Water to Permit Rights

Once a right is considered reasonable, the observed natural supplies (e.g. flow, storage) are used to define the water allocation. Each regulated riparian system has its own methodology for determining how much water is available for allocation but they usually follow the simple equation:

$$Q_{available} = \text{Streamflow} - \text{Min}_{\text{streamflow standard}} \qquad \text{(Eq. 4.1)}$$

The local available streamflow ($Q_{available}$) is determined by the measured streamflow minus the portion of flow required for ensuring a minimum flow ($Min_{streamflow\ standard}$) (Eheart 2002). Also, the incoming streamflow available for withdrawal at the spot is further reduced by the streamflow required by downstream users. The pass-by flow is determined based on the number of users downstream, their priorities, and their likelihood of being adequately supplied by other tributaries (Eheart 2002).

Individual water permits can be defined using different allocation methodologies. For instance, the fixed flow method assigns each user a constant withdrawal rate limited by the minimum streamflow standard. The assigned rates vary from user to user and are usually dependent on the calendar time and stream conditions. A drawback of this method is that it does not tell the user how his/her withdrawal rate should be reduced during droughts thus giving upstream users some unfair advantage.

Another allocation technique is prioritization. As water permits are granted, priorities can be assigned according to type of use, economic benefit or any other criteria. Any given user can withdraw water as long as all other users' withdrawals with higher priorities and the minimum flow standard have already been satisfied. When flows are insufficient, users forego withdrawals according to their priorities. Problems with this approach arise in areas of high usage of water where setting a priority criteria and establishing sizes of permits and operational rules is practically impossible (Dellapenna 1997). Furthermore, in humid areas it would be extremely difficult to establish priorities among users who may have been sharing the same stream for many generations.

Perhaps the allocative method most consistent with traditional riparianism is the flexible permit system. In this approach, the user's allowable withdrawal increases or decreases continuously with the available streamflow. The allotted withdrawal is a fraction of the available streamflow and it fluctuates in proportion with it. Since it is based in homogeneity no permit has priority over any other and during scarce water periods no user is entirely deprived of water. This scheme, even though it appears fair, may not be economically efficient since equally reduced amounts of water do not necessarily mean equally distributed losses. Also, this method can allocate more water than needed during high flows, which could be seen as an encouragement to waste water that could be used for new users (Eheart 2002). Thus, this method should also include a maximum withdrawal limit to avoid abuse.

The most important aspect of permit allocation is how to determine the size or total amount of the permit. The permit allocation can involve determining a maximum withdrawal, a withdrawal ratio, or both. According to the more traditional riparian practices, the size of the permit is determined by the riparian "need" as requested by the riparian and compared to the "needs" of the other right holders. In more regulated riparian systems, instream flow uses are also considered as valid uses of water or as minimum flows to be protected from withdrawal (Cox 1994). Historical uses may also be evaluated as well other political considerations.

The riparian size method determines the size of the allocation based on the "size" of the riparian land. The essential principle is that the right to use the water is intertwined with the value of the riparian land. Usually under this method the size of the allocation is proportional to the length of the riparian water front owned by the water right holder. Although this methodology may seem appropriate for agricultural purposes, it is not so for other types of operations where the size of the land has no relation with the economic implications of the use.

Conversely, the operational size method defines the allocation accordingly to the operational size of the user. For instance, for municipal uses the size would be determined by the population and for industrial uses the allocation size can be proportional to some measure of the products. The historical use method sizes allocations in accordance with the historical water consumption of the user or the type of use. However, care must be exercised to prevent ineffective usage of water when seniority is used for the sole purpose of securing a larger allocation.

Other methodologies are *ad hoc*, following no particular allocative criteria. The allocations are made in a case-by-case basis according to the judgment of an agency, council, or other specially appointed administrative body. Although this approach is more flexible than the other alternatives, it presents the potential for unfair decisions based on political and personal interests (Eheart 2002).

When storage is available for enhancement of the water supply there are two options to incorporate these benefits into the WRS. First, the agency can assign or sell a fixed or seasonally varying rate that, by been dependent on storage releases from a reservoir, will have a higher reliability than the natural flow. Otherwise, the agency can assign or sell a portion of the storage to users, each of whom will operate his/her portion as a small reservoir. A water permit will be required to refill the right holder's portion of the reservoir. When an entire reservoir is owned by an individual user, precautions must be taken, much like reasonableness, to avoid entire stream segment from been depleted by the reservoir (Eheart 2002).

4.3.2 Duration of Permit Rights

Another important aspect of regulated riparian systems is the duration or period of validity of the water right. Most regulated systems establish time limits for their permits. Determining an optimal period of validity for a water right is a difficult task. Short permit durations discourage economic growth because the riparian water holder may not have sufficient time to recover his/her investment. On the other hand, long permit durations make accommodating new users and uses more difficult and may further complicate management during drought periods (Eheart 2002).

In essence, the challenge is finding an appropriate period of time that would enable water right holders to accomplish their goals while preventing earliest users from monopolizing water usage. Yet, prior literature shows that states do not follow a particular methodology for establishing permit durations as it is mostly an arbitrary exercise. For instance, four states have issued perpetual water rights (New York, Delaware, Virginia, and Kentucky), but for the most part states grant permits of 50 years or less. Florida grants permits for 20 and 50 years to private and public entities, respectively. These durations were adopted from the Maloney, Ausness, and Morris Model Code, which assumed, with little evidence, that these periods would be appropriate (Maloney et al. 1972; Dellapenna 1997). Mississippi established a 10 year expiration period, but it also provides the possibility of an unspecified longer period for public entities. Other states like Maryland and Wisconsin have permit durations of only 3 years and even yearly reviews that could result in permit modification or cancellation. The statutes of Connecticut, Massachusetts, New Jersey and Minnesota do not specify permit durations, instead administrative agencies determine the duration of each permit, and in Minnesota the agency can also cancel a permit for the protection of public interest.

4.3.3 Transferability of Permit Rights

In recent years, most regulated states have allowed voluntary transfers of water permits either on a permanent or a temporary basis. These provisions are based on market principles and have been referred to as permits trading or water rights markets. The basic principle is that greater economic efficiency accrues if permit trading is allowed (Wong and Eheart 1983; Wollmuth and Eheart 2000). Even though this type of trading is structured to operate with minimal supervision, the water rights administrative agency should always be the final referee in any permit transfer and should have the authority to disapprove any particular trade (ASCE 2002).

It is understood that voluntary transfers can allow water to go from low-value uses to high-value ones. In addition, water rights transfers can also provide incentives for efficient water use and conservation. As a result, market-based programs have been wildly accepted as incentives for environmental protection (U.S. Congress 1988; Stavins 1989). Nonetheless, even where markets are allowed they have not been widely used usually because potential traders have chosen not to trade (ASCE 2002). In cases were the administrative agency gets more involved in promoting water markets, water right holders have been more comfortable and willing to participate and the outcome have been quite productive (Eheart 2002). However, allowing water transfers means relinquishing some control over the location of withdrawal points which could result in having points on the stream where water is being heavily diverted. This can negatively impact water users not involved in the trading. It is therefore encouraged that the agency undertakes simulation exercises of possible trading scenarios beforehand in order to assess the effects of water market trading on the aquatic environment and on other water right holders (ASCE 2002).

4.4 PRIOR APPROPRIATION RIGHTS

The prior appropriation doctrine was developed to serve the practical demands of the 19^{th} century's westward expansion in the US. The previously established riparian system did not allowed to transport water from the stream to other locations outside the abutting lands. As a result, a statutory system developed where water rights were granted according to the time a person applies a particular quantity of water to a beneficial use (Getches 1997). The date of appropriation determines the right's priority. If water is insufficient to meet all needs, earlier users (senior appropriators) will obtain all their allotted water while those who appropriated later (junior appropriators) may see their allotment diminished or cut off completely.

Water in western states is considered a public resource, not a private commodity. The government uses its power to regulate the uses of water in order to allocate and conserve the resource for the benefit of its citizens. Only those who apply water to a beneficial use can claim the right to use it. The property where the water is applied to beneficial use does not need to be adjacent to the natural source and in most states is not even required to be within the same basin.

The traditional elements for claiming the right to use water under an appropriative system are: the intent to apply water to a beneficial use, an actual diversion of water from a natural source, and the application of the water to a beneficial use within a reasonable time (Getches 1997). One who diverts water for flood control is not an appropriator since the diversion was not made with the intent to be applied for any use. Therefore intent has to be proved for a permit application. In Colorado, where no permits are required, proof of intent is necessary for claiming an appropriative date. Some states require water to be physically diverted in order to have an appropriation, but others recognize not-diverting uses as valid appropriations. Some methods for diverting water are: dams, reservoir, canals, ditches, flumes, pipes, pumps, and even water wheels (Getches 1997). In states where a physical diversion from the stream is not required appropriation can be recognized if intent to appropriate to a beneficial use, notice to others, and actual application to beneficial use are clearly established. When a right is granted states usually give a maximum time period, usually five years, for the construction of any diverting facility and the application of water to beneficial use. Otherwise the appropriative date (i.e. priority) can be lost.

The most important step in perfecting or acquiring an appropriation is applying the water to a beneficial use. The concept of beneficial use emerged from the desire to protect the resource from being wasted. Water uses that are considered beneficial are determined by state statute and vary from state to state. However, just because a use is listed as beneficial does not mean it will be deemed beneficial under all circumstances as the concept of beneficial use is continually refined through the judicial process (Beck et al. 1991a). Historically, the range of beneficial uses was limited to the more traditional consumptive uses. For instance, all prior appropriation states consider domestic, agricultural, municipal, and industrial uses to be beneficial. Other consumptive uses specified as beneficial on state laws are stock-watering and mining. Almost all states have now accepted some non-consumptive uses such as recreation and aesthetics as beneficial.

In addition of being used to define the right to use water, beneficial use is used to establish the amount of water an appropriator is entitled. The amount of water that can be taken is limited to the amount that is actually required for optimum beneficial use (Getches 1997). For example, the quantity of water required to irrigate a field should not include the portion required to compensate for losses due to inefficient water conveyance and/or inadequate technology.

Following the 1960s, major concerns regarding environmental issues such as water quality and ecosystems preservation became a driving force in policy. Kansas was the first state to amend its appropriation statute to accommodate for instream flow requirements in the 1980s. Since then, other nine states (Alaska, Colorado, Idaho, Montana, Nebraska, Oregon, Utah, Washington, and Wyoming) have also provided statute protection for minimum instream flows. Arizona, Nevada, and Texas have recognized instream uses as beneficial and now allow appropriations for recreation and wildlife and consider environmental impacts on flow reduction when issuing permits. However, the efficacy of these efforts in a prior appropriation system is often questioned since they appeared to have come too late. For instance, legislation for allowing appropriation for instream flow uses in the mid 1980s in Texas came after most of the state's waters were already appropriated and little water remained for environmental flows (Kaiser 2004). Therefore, the question is not whether instream needs are recognized within the permit system but how secure a minimum streamflow or instream use right is under a particular state's regime (Beck et al. 1991b).

4.4.1 Allocating Water to Permit Rights

All prior appropriation states have statutory systems to allocate water and all of them, except Colorado, have detailed administrative procedures for implementing the water allocation function of the doctrine (Carriker 1985; Tarlock et al. 2002). Only Colorado relies on the judicial system charged with administrative powers instead of an agency to deal with the details of water allocation (Goplerud 1991a, Getches 1997). Before the institution of these agencies water was allocated by the users and disputes were resolved by adjudication in court. The purpose of these administrative systems is to provide a methodology for allocating the resource and to regulate water rights. These are usually state agencies or water control boards with mixed executive and judicial powers to adjudicate water rights. However, their decisions are always subject to judicial review by the state's court.

The permit is usually the only method to acquire an appropriative right (except in Colorado). A permit can be obtained by filing an application to the administrative agency. Most permit systems will approve the permit if the applicant follows all the prescribed procedures, the state engineer determines that unappropriated water is available, and the appropriation is not detrimental to the public welfare. Following the filing of an application a notice of the filing is published and a hearing is appointed to properly address any objections to the allocation. If all the requirements are met, the time of the application filing will become the priority date and a permit is issued. A permit is not a water right until all conditions on how the water right is to be exercised are met. These conditions must be met within a sensible time frame for the permit to retain its validity.

For most permits to be approved the agency most evaluate if: water will be applied to beneficial use, unappropriated water is available, no harm will be done to prior appropriators, the means of diversion are adequate, and the proposed use is not contrary to the public interest. In addition, some states also require evidence of the financial ability of the applicant to complete the proposed work (Getches 1997).

The requirement of available unappropriated water is handled differently as some states are stricter than other in preventing overappropriation. On many streams water diversions far exceed the available streamflow. This occurs when junior rights downstream are dependant on return flows from upstream seniors or when junior rights are only entitled to use water during periods of high flows or low senior usage. Overappropriation is a sensitive subject in the arid west and proving that there is no unappropriated water is a demanding task. Historically, when courts were confronted with doubts regarding the estimates of water availability, they typically decide in favor of appropriation. However, as demands increase and most streams are already overappropriated this approach is considered inefficient and administrative agencies tend to deny the permits in such cases (Goplerud 1991a).

The concept of public interest or public trust is very important during all phases of the permit process. Public interest is not only considered when dealing with matters that may be a menace to public health, but also to protect planned uses or development of the resource. It can also be used to establish preferred uses of water. This is not to be confused with priority. Priority is related to the chronological order of water acquisition, while preferred uses refer to the relative value of a particular use that is considered during the evaluation period. In some cases, granted permits have been revoked when courts have found that the administrative agency did not responsibly consider the effects of the permits on the public interest (National Audubon Society V. Superior Court 1983). If an applicant is granted a permit, meets all institutional requirements, carry out any construction works needed for the diversion, and applies the water to beneficial use within a reasonable time, his/her water right is perfected and vested. When a right is perfected a license or certificate of appropriation is issued much like a deed that defines the extent of a property right to use water.

The administrative agency also enforces the conditions of the established rights based on the priority order of the appropriators. In most states, the overall supervision of the system is the responsibility of the state engineer. Different states have different hierarchies of enforcement divisions (Goplerud 1991a). A commissioner or water master is usually the one who physically distributes the proper quantities of water, at the right times, and to the proper users. The commissioner opens, closes, adjusts, and locks the diversion points or headgates. In times of low flows or high usage, the headgates are closed starting with the lowest priorities to ensure that senior appropriators have access to their entitled water quantity (Getches 1997). If streamflow increases, the commissioner opens the gates so that junior appropriators can use the water. The commissioner also regulates reservoir storage and reports water usage and streamflows to the state engineer.

There is a distinction between immediate use or direct flow rights and subsequent use or storage rights. A direct flow water permit is not entitled to store any water from the stream save for water conservation purposes that do not cause harm to others (Getches 1997). The storage right is not perfected until the water is applied to beneficial use either by the entity storing the water (e.g. reservoir owner) or by some joint appropriator (e.g. irrigators). Storage rights are governed by the same rules of priority as the direct flow appropriations.

However, storage gives the system more flexibility for distributing water among right holders therefore improving the overall system reliability (Wurbs 1993). For instance, exchanges among junior rights holders with storage rights and senior right holders with no storage rights can help maximize the effectiveness of water use on a stream. Senior users can allow juniors to use water in times of senior low usage in exchange for the juniors letting the seniors store water for later use. There are limits, however, in how much water can be stored in a year. Different states have different rules on how much water can be used to refill storage right. Usually, permit holders are allowed to fill its reservoir capacity just once in a given year. They are also allowed to retain their storage for future use during "dry years" (Getches 1997).

4.4.2 Transfer of Prior Appropriation Rights

Water rights can be transferred or reallocated voluntarily among water users subject to certain limitations. In general, for a reallocation to take place the water right must have been beneficially used and must continue to be beneficially used after the reallocation. In addition, the reallocation must not injure other appropriators and must be in the public interest. Thus, reallocations usually require administrative, or in some cases judicial or legislative approval (Anderson et al.1991).

Changes that may occur as part of a water right reallocation may take several forms. For instance, changes in place of use or storage, source of supply, time of use (e.g. seasonal, intermittent, or continuous), point of diversion or return, purpose of use, or a combination of changes. A common type of change that has occurred in western states since the 1980's is the reallocation of irrigation water rights to municipal, industrial, and environmental use. This trend has been the result of the diversification of the states economies, explosive urban growth, industrial development, and the consideration of environmental and recreational issues.

Although a water right reallocation may be for beneficial use, the change or changes that accompany the reallocation may cause harm to existing appropriators. Changes in use can alter stream conditions and impair the beneficial uses of other appropriators, especially juniors. Appropriators, however, have a vested right to have stream conditions maintained substantially as they existed at the time of their appropriations (Anderson et al.1991).

Therefore, courts typically apply what is known as the “no harm” or “no injury” rule, which basically states that a water right reallocation that includes a change is allowed as long as it does not injure the rights of junior appropriators. The no injury rule has been statutorily adopted in all prior appropriation states except Alaska (Anderson et al.1991). In general, injury may occur by depriving an appropriator of the initial quantity or quality of water or by increasing the appropriator’s obligations to seniors. Some examples of changes that may cause harm to other appropriators are: (1) change in the point of diversion so as to deprive the junior of water or return flows, (2) in a losing stream, changing an upstream senior right downstream of a junior right can burden the junior due to seepage looses, and (3) a change in the place of storage resulting in greater loss of water by evaporation where the burden of the additional loss is placed upon a junior.

The fact that a reallocation is likely to result in injury to other appropriators does not necessarily mean that the reallocation will be denied. Courts or administrative agencies can still approve the reallocation by imposing conditions. If it is impossible to impose conditions so as to mitigate or prevent injury, the reallocation will be denied. However, if conditions can be imposed the reallocation must be approved subject to such conditions (Anderson et al.1991). Conditions might include: (1) reduction in quantity or flow rate of the reallocated water, (2) time limits on the use of water, (3) designation of a location of use, (4) adjustment in the means of or point of diversion, and (5) conditions to maintain quality.

One alternative to facilitate water rights reallocation is the use of temporary reallocations. Temporary reallocations are expressly permitted for specified periods, commonly not exceeding one year. At the end of that period, the water right automatically reverts to the original appropriator. These transactions are also subject to the no harm rule and require administrative approval. However, temporary reallocations are subject to a more relaxed administrative process (Anderson et al.1991). It is important to note that temporary reallocations and approval does not result in the creation of a vested right.

Another method for reallocating water rights is through water markets. Water marketing refers to ways of facilitating reallocations and conservation through market-like transactions. Essentially, water marketing is the buying and selling of water rights in the manner in which one would buy or sell any commodity. A common transaction may involve a sale, lease, or exchange of a water right or an agreement not to exercise a water right (Musick 1989). These transactions are also bounded by the no harm rule.

Kaiser (1996) summarizes several types of water market transactions. Some of these transactions are: (1) sale of a water right, (2) institutional transfers, (3) option contracts, (4) subordination agreements, (5) conservation transfers, and (6) water banks. A state-vested water right may be sold or leased to different users and uses subject to state agency or court approval. In institutional transfers the actual water right is not sold but only the right to use the water. The option contract is typically used by cities to deal with dry years. A city may negotiate a dry-year option contract with a senior water right holder to acquire the right to use the water only during dry years. Subordination agreements refer to the buying of the priority date of a water right. This is typically done by junior appropriators who are seeking a higher priority. A user can acquire water in conservation transfers by financing a water project in exchange for the water that will be conserved as a result of the project. A water bank provides a means for transferring surplus water rights. The original water rights holders retain their permanent right and only sell (or lease) to the bank the right to use the water. This water can be used temporarily by other users with critical water needs.

Supporters of water markets argue that this approach gives flexibility to reflect changes in value system as compared to complicated political formulas. The water market strategy provides a means for redistributing water without building new physical systems or forcing reallocations through litigation or additional regulation, as well as promote economic efficiency (Tarlock 1987; Carter et al. 1994; Tarlock et al. 2002). Kaiser (1996) pointed out that water markets may be useful as a drought management tool, as a means to provide water to growing cities and for environmental and recreational needs, to promote efficient water use and encourage conservation, to provide an alternative to new reservoir construction, and to promote political and social harmony.

On the other hand, other investigators have pointed out that a perfect market for water cannot exist since there are few sellers and they could have the power to strategically manipulate the market behavior or even monopolize it (Griffin and Characklis 2002). Also, since water markets are subject to the no harm rule, unlike any other form of marketable commodity, water cannot be fully owned as it is subject to public interests (NRC 1992). When a water transaction occurs, the impacts of those changes spread well beyond the seller and the buyer. In other words, there are community and moral aspects of water transfers regarding third-party effects (Sax 1994) and water's ecological role that a market approach cannot fully satisfy (Freyfogle 1996). In spite of these concerns, most opponents of water marketing have favored the concept of a regulated water market (Anderson et al.1991; Oggins and Ingram 1990; NRC 1992; Sax 1994). Proponents of this strategy sustain that water marketing is what prior appropriation needs to become a flexible doctrine capable of adapting to meet new social values by creating economic incentives for conservation and reallocation.

4.4.3 Loss of Prior Appropriation Rights

There are two basic ways of losing a water right in a prior appropriation system. According to appropriative statutes a water right can be lost due to abandonment or forfeiture (Roe and Brooks 1989).

Since appropriative rights are dependant on beneficial use for its continued validity, when beneficial use ceases so does the right. A court or water agency can rule a cessation of a water right due to abandonment when a voluntary or intentional relinquishment of the water right occurs. Proving intent of non-use however, is usually a difficult task. Because of this, loss of water rights by forfeiture is more common (Goplerud 1991b).

Forfeiture, which does not require intent, can be invoked for failure to use water or for non-beneficial use (wasteful use). However, forfeiture cannot be invoked if the circumstances causing the non-usage were beyond the control of the water right holder. Forfeiture can also be an automatic action. Some states have made statutory modifications to establish a period of non-use that will cause a right to be forfeited. For instance, in New Mexico, after a period of four years the government issues a notice of non-use. If the non-use continues over one additional year, the right is automatically forfeited.

Water rights could also be lost due to prescription when a claimant who has been harmed by the wrongful usage of another water user claims rights over the offender's water right. Nevertheless, the concept of prescriptive use or adverse possession has lost favor over the years as many states are in the trend of abolishing prescriptive rights. Since the only way of obtaining this kind of rights is to take the water rights away from someone else, it is understood that this kind of rights predation should not be necessary in the presence of a comprehensive permit system (Goplerud 1991b).

4.5 DUAL SYSTEMS

There is no one definition fitting all hybrid systems, for each state has its own mixture of elements from each doctrine. Several states that originally followed the riparian system later converted to a system of appropriation. This shift occurred since prior appropriation was recognized as being more suitable for allocating water rights. Because of the aridity of the west, increasing demands to divert water for mining, irrigation, industrial and municipal uses could not be resolved satisfactorily with the reasonable use theory. However, the states also had to recognize the continued validity of vested riparian rights. These states are California, Oregon, Washington, Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas. For coastal western states and central states located between higher elevation and arid lands, neither the riparian system nor appropriation was entirely fitting (Getches 1997). Hence, they continue to recognize both types of rights and adapted to accommodate uses of water under the two rather inconsistent systems.

Giving the difficulties of coordinating the vestigial riparian rights with appropriative rights, western states have sought to further restrict riparian rights. Legislatures have abolished unused riparian rights and courts have tried to reconceptualize them in order to narrow their reach and move toward their elimination. Some courts' actions have involved narrowing the concepts of riparian land and reasonable use as well as exploding the theories of abandonment, forfeiture, and prescription (Getches 1997).

When conflicts arise between user and/or uses who claim the same type of right, resolution is straight-forward. For solving conflicts between riparian rights an *ad-hoc* application of the reasonable use theory would be used and for prior appropriators the "first in time is first in right" rule would apply. However, when conflict arise between an appropriative right and a riparian, judges and administrators face a problematic task due to the entirely different basis for decision-making of both systems. Coordination of such differences can only be obtained by treating one of the systems as primary and the other as an exception to the primary rights system (Dellapenna 1991a). Some dual system states treat prior appropriation as the primary WRS (Kansas, North Dakota, Oregon, South Dakota, Texas, and Washington) while others treat riparian rights ahead of appropriators (California, Nebraska, and Oklahoma).

Most hybrid WRS recognized prior appropriation as their primary system. Those riparian rights that have survived are usually treated as priority rights with a priority date set by the date the state made the formal transition from riparian to prior appropriation. Dellapenna (1991a) grouped the dual system states into three groups according to the transformation doctrine they applied to move away from the riparian doctrine: the California doctrine, the Colorado doctrine, and the Oregon doctrine.

California was probably the first western state to face problems regarding water allocation. Given the fact that settlements in California exploded as a result of the gold rush, water appropriation for mining purposes on federal lands became a custom. Parts of the riparian lands however, were privately owned. The California Supreme Court developed a ruling theory to solve disputes among water users that stated that appropriators are subordinate to the rights of a settled riparian but superior to any riparian settled after the appropriation. Disputes among riparians would be resolved by reasonableness of use without taking in consideration temporal priority. The state of Washington also follows this doctrine for dealing with both types of water rights.

The Colorado doctrine recognizes few rights for the owner of riparian lands. These rights however, regard to non-consumptive uses of water. Disputes over non-consumptive uses of water are resolved according to the reasonable use theory. Nonetheless, the courts do not accept riparian theory for consumptive uses. Instead, they apply the pure appropriative doctrine. Some variations of this doctrine are followed by Colorado, Idaho, Wyoming, Arizona, New Mexico, Utah, Montana, and Nevada. States such as Texas, Kansas, Nebraska, Oklahoma, North and South Dakota, and Oregon have dual WRS that follow the Oregon doctrine. The mixture of appropriative and riparian rights of these mixed climate states is characterized by statutory actions to abolish unvested riparian rights and adopt appropriative allocative systems. The legislation would set a cut-off date by which all vested riparian rights must be claimed through beneficial use. New claims to water after the appointed date would be recognized only through appropriation.

CHAPTER V

COMPUTER WATER ALLOCATION MODELS

The complexity and magnitude of many water resources problems require the assistance of computer models in order to obtain reliable and timely solutions. Computer models have been used extensively in both practical engineering applications and academic research to help solve a multitude of water related problems. Although developing efficient computer models is commonly costly and time consuming, it can be argued that it is a worthwhile effort as they facilitate and expedite the analysis of problems that would otherwise be too complex or simply too tedious to analyze by manual computations.

Computer models are typically divided into two categories, simulation and optimization models. A simulation or descriptive model is a simplified representation of a real-world system used to predict its behavior under a given set of conditions (Wurbs 1993). Typically, these models apply mass balance principles to track the movement of water through a river/reservoir system and are able to accurately represent the operation of the system. A pure simulation model is not intended to prescribe the best or optimum solution to a specific problem when flexibility exits in the operation of a system. Prescriptive optimization models have the added capability of automatically finding the optimum solution for a particular problem subject to a series of operational objectives and constraints. Labadie (2004) provides a state-of-the-art review of optimization techniques used in river/reservoir system management and describes their mathematical basis.

A computer model may be developed as a site-specific or generalized model. Site-specific models incorporate the unique characteristics of a river/reservoir system into the computer code. Site-specific models may be very detailed and efficient, but applying the model to a system other than the one for which it was developed is rather difficult. The general trend in recent years has been to shift away from site-specific models to generalized models (Wurbs 2004). Generalized models have enough flexibility to be readily applied to any river/reservoir system. The specific characteristics of a system are described in an input data file or input directly in the program interface, thereby eliminating the need for writing or modifying computer code every time a different system needs to be modeled. Generalized models have been continually growing in number and expanding their modeling capabilities. Several public-domain computer models are available for a variety of river/reservoir systems analysis applications. The U.S. Bureau of Reclamation has prepared a hydrologic modeling inventory for the United States which can be accessed via the internet at: http://www.usbr.gov/pmts/rivers/hmi/. This website also contains an on-line literature database.

The utility of computer models is undeniable, yet it must be recognized that they are only predictive tools and do not provide flawless solutions. The successful application of a computer model always relies on the ability of the user to accurately describe the system and to interpret the output data. In addition, model results are highly dependent upon the quality of the input data. The series of simplifying assumptions incorporated in the model must be carefully considered when interpreting the results. Moreover, careful inspection of the model results is always required to ensure the validity of the model. In other words, human expertise is imperative for the proper building, tuning, application, and interpretation of any computer model. Another significant limitation is that models can sometimes be so elaborate that only specialized personnel can use them and understand their results. Thus, the usefulness of the model may be drastically reduced if the results are not clearly conveyed to the public, government officials, politicians, or any other party involved in a decision making process.

A myriad of computer models and applications can be found in the water resources literature (Yeh 1985; Wurbs 1993; Labadie 1997 and 2004). Regarding water allocation systems (WAS), one of the most valuable modeling applications is generating viable new alternatives to solve water allocation problems. The series of alternatives may form the basis of negotiations to determine a new allocation. During the WAS planning and design stages, simulation models can allow decision makers to evaluate the physical and economic impacts of alternative allocation policies, demand levels, and institutional restrictions. Once a WAS is established, computer models may be used to simulate the management of the water resources of a river basin within its hydrological and administrative setting. Some models have been primarily developed to assist in the implementation, assessment, and enforcement of WAS. In general, this type of model simulates existing operating rules by tracking sequences of hydrologic input through the current system. These models are also excellent planning tools since by considering alternative scenarios of water use, they can simulate potential water management alternatives. The remainder of this Chapter provides descriptions and applications of a series of site-specific and generalized models that can support the various aspects of WAS.

5.1 SITE-SPECIFIC MODELS

Some examples of site-specific models that have been developed primarily for water allocation purposes are presented in this section. Dolan and DeLuca (1993) described the application of the Missouri River Model for the upper Missouri River basin of Montana. In general, this hydrologic model simulates a monthly water budget considering four primary system components: irrigation, municipal, dam and reservoir operation, and streamflow. The model was used by the Montana Department of Natural Resources and Conservation to help assess the hydrologic and economic impact of accepting new applications for reserving water for instream uses and new consumptive uses. A series of hypothetical water allocation alternatives representing future development scenarios that would increase water consumption and different water allocation strategies were evaluated. The allocation strategies were basically rearrangements in the priority that would be assigned to each use. Model results provided information regarding the magnitude of streamflow reductions that could occur under each alternative and the economic and environmental impacts associated with such reductions. The results were used to inform interested parties of potential impacts that could occur as a result of the decisions made regarding the new water reservation requests.

The Applied Research Institute-Jerusalem (ARIJ) published a report on the development and application of the Jordan valley Water Allocation (JOWA) model (ARIJ 2000). The model divides the Jordan Valley region into sub-regions belonging to the bordering countries of Jordan, Palestine and Israel, and thus, performs the water allocation based on the resources available in each sub-region, each country and the entire region. Water is allocated using a linear optimization algorithm that minimizes the cost of allocation to the different demanding sectors. The model constraints are, for the most part, mass balance considerations. Moreover, the model allocates water based on priority, thus introducing a hierarchy of water allocation. The water use sectors considered in the model (from highest to lowest priority) are domestic, tourism, industrial and agricultural. The model also allows water transfers. If the main supply in one sub-region does not satisfy its demand, supplementary supplies from other sub-regions will try to make up for the deficit by transferring water. However, the model also takes into account the cost of water transportation. The authors warned that since the cost value is the corner stone of the allocation process care should be taken when estimating these values.

Letcher et al. (2004) described a modeling tool based on optimization of economic-hydrologic criteria to assess water allocation issues in the Namoi River basin in Australia. The basin was divided into similar regions in terms of water policies and production type. A network flow model was used to establish the connectivity of the system. Individual model components (i.e. agricultural production, hydrology, policy, and extraction models) were developed for each region. The hydrologic model simulates daily flows at a node given a set of climatic time series inputs. This daily flow is fed through the policy model, which calculates yearly volumes of water available in a region based on the policy scenario. These volumes are input to the agricultural production model which optimizes choice of investment based on economic and hydrologic factors. The optimization routine is driven by a dynamic programming formulation and it is subject to mass balance and economic constraints. Water use decisions from the agricultural production model are fed to a daily extraction model that translates yearly use into daily water use. This daily water use is extracted from the simulated flows and the resulting ‘‘extracted flow’’ is routed to the next node downstream. Streamflow and regional farm profit are calculated at each node allowing to investigate the environmental and economic costs and benefits of policy changes in the basin.

Ringler and Huy (2004) also developed an economic-hydrologic model to assess water allocation strategies for the Dong Nai River basin in Vietnam. The model was developed as a node-link network representing the spatial relationships between the physical entities in the basin. The objective of the model is to maximize the annual net profits from water uses in irrigation, households and industries, and hydropower generation subject to hydrologic and economic constraints and the governing water allocation rules. The model performs a water balance for reservoirs, streams, and crop fields; calculates benefits from water uses; and implements the institutional rules. Water supply is determined through the water balance;

while water demand is determined within the model based on functional relationships between water and productive uses. Water benefit functions were developed for the major water uses subject to physical, system control, and policy constraints. Minimum instream flows are included as flow constraints. Water supply and demand are balanced based on the objective of maximizing economic benefits to water use.

Although actual allocations are not entirely based on economic efficiency, the models described in Letcher et al. (2004) and Ringler and Huy (2004) may be useful to identify system deficiencies and to prompt for institutional reforms that could result in a more efficient water allocation.

5.2 GENERALIZED MODELS

The analysis capabilities of a generalized computer model can be applied to essentially any river/reservoir system. In addition to simulating the system, these models typically include data management programs and tools that help interpret, summarize, and display model results. One practice that has gained popularity in recent years is to create Graphical User Interfaces or GUI's. The GUI facilitates the interaction between the user and model during the model building process and typically provides added capabilities for displaying results in graphical or tabular formats. Various generalized models are well documented and tested and have gained wide acceptance in the water resources community.

5.2.1 AQUARIUS

AQUARIUS is a computer model developed jointly by the Colorado State University and the USDA Forest Service for the temporal and spatial allocation of water among competing uses in a river basin (Diaz et al. 2000). AQUARIUS is an object-oriented model with a GUI where the system is represented as different types of water components such as reservoirs, diversions, junction points, and demand areas connected as a network. The mathematical connectivity of the components is derived automatically from the linkage of the objects in the network, which in turn reflects the hydraulic connectivity of the system. The model is driven by an economic efficiency operational criterion that calls for the reallocation of stream flows until the net marginal returns in all water uses are equal (Brown et al. 2002). The model first finds an initial solution that serves as the starting point of a sequential optimization procedure. This procedure consists of a succession of quadratic approximations of the nonlinear objective function until the optimal solution is reached. The economic criterion is used because economic demands have traditionally played a key role in water allocation decisions. However, actual allocations may have institutional constraints that impede achieving the economical efficiency modeled by AQUARIUS. Therefore, as with other previously mentioned models, the results may not be representative of the actual WAS but may be helpful in suggesting potential strategies to achieve a more efficient allocation. AQUARIUS is free for government agencies and for teaching and research purposes and it is available in the internet at http://www.fs.fed.us/rm/value/aquariusdwnld.html.

5.2.2 Environmental Policy and Institutions for Central Asia (EPIC) Model

Mckinney and Karimov (1997) reported on the development of a policy-oriented water allocation model known as the EPIC model. The model is an interface between the Geographic Information System (GIS) software ArcView and the mathematical optimization software GAMS. A mathematical model based on a network representation of the basin is used for water allocation and GAMS is used to solve this model. The original goal was to use the model as a screening tool to identify good water management alternatives for the rivers of the Aral Sea basin in Central Asia, but with the appropriate input data the model may be applied to other basins. The model objectives include maximizing flows to the Aral Sea, maximizing satisfaction of water demands, maximizing hydropower production, minimize concentration of salts in the system, and equalizing the distribution of water deficits. Some of the constraints for the model include mass balance, groundwater pumping limits, canal diversion capacities, and minimum flows. The model is based on a multiobjective decision framework in which weights are used to set the relative priority of each objective. This approach allows evaluating multiple water allocation alternatives and analyzing the tradeoffs between conflicting objectives. The authors concluded that the model provides a useful tool to develop a much needed regional water resources strategy in the Aral Sea basin. The model, documentation, and sample data may be obtained free of charge in the internet at: http://www.ce.utexas.edu/prof/mckinney/papers/aral/EPIC/EPICmodel.html.

5.2.3 MIKEBASIN

The MIKEBASIN software package, developed by the Danish Hydraulic Institute (DHI), couples ArcView with network flow hydrologic modeling to facilitate the integrated analysis of river basins (DHI 2001). The model uses a GUI which allows MIKEBASIN to use all functionality of ArcView. MIKEBASIN defines water allocation rules based on local and global priorities. Local priority rules model the distribution of water from a node on the river to users immediately connected to it, which is useful for modeling riparian rights. Alternatively, global priorities can be used to model prior-appropriation rights since they allow water to be allocated according to rules that can affect any node in the system. In addition, the model has the ability to define overall rules that can be used to maximize benefits, allowing provisions to represent the public interest (e.g. instream flow requirements). Jha and Das Gupta (2003) applied this model to the Mun River in Thailand for evaluating basin performance and recommending optimal allocation practices. This study demonstrated the usefulness of the model in establishing a decision basis for policy makers and managers regarding optimal allocation of water resources.

5.2.4 MODSIM-DSS

MODSIM-DSS, developed by Colorado State University, is a decision support system that incorporates the physical, hydrological, and institutional aspects of river basin management. The model's object-oriented GUI allows to easily create a node-link network representing the spatial relationships between the physical entities in the basin. Non-storage nodes can represent river gages, return flow sites, and river confluences. Demand nodes represent diversions and instream flow requirements. Pertinent reservoir physical and operational characteristics are incorporated in reservoir nodes. Links may represent natural or artificial flows. MODSIM-DSS solves a minimum cost network flow problem to find the required water and storage allocation to competing demands based on specified priorities and operating rules (Wurbs 1993; Dai and Labadie 2001). The model can use a monthly, weekly, or daily computational time step. MODSIM-DSS considers reservoir operations targets, consumptive and instream flow demands, evaporation and channel losses, reservoir storage rights and exchanges. The model also has a stream-aquifer module that allows to calculate reservoir seepage, infiltration, river depletion due to pumping, and aquifer storage

(Dai and Labadie 2001). Graham et al. (1986) used an earlier version of the model to simulate the allocation of water supplies in the Rio Grande basin following the prior appropriation water rights doctrine and interstate compact agreements. More recently, the model has been applied to the Nile River in Africa (El-Beshri and Labadie 1994) and the Piracicaba River in Brazil (Azevedo et al. 2000) for evaluating innovative water allocation schemes. The model may be downloaded free of charge at: http://modsim.engr.colostate.edu/download.html.

5.2.5 OASIS

The Operational Analysis and Simulation of Integrated Systems (OASIS) program, developed by HydroLogics (http://www.hydrologics.net/), simulates the routing of water based on a linear optimization algorithm. The program uses an operations control language (OCL) for defining operating rules. OCL is a programming language patented by HydroLogics similar to a scripting or macro language. OASIS's GUI provides user-friendly controls to build, modify, and run the model and to view model results. Operating rules are expressed as goals or constraints. The user indicates which goals have a higher priority by assigning relative weights to each goal. OASIS obeys all constraints and tries to meet competing goals. The developers refer to this approach as a goal-seeking behavior which differs from most modeling approaches in that competing goals are not modeled as a complex set of "if-then" type rules. An excellent capability of OASIS is the OCL views other programs (ex. databases and other simulation models) as external modules and allows to import and export data between them. Both OASIS and the external modules can run simultaneously and react to each other.

5.2.6 RiverWare

RiverWare is an object-oriented river/reservoir simulation model with multiobjective modeling capabilities (Zagona et al. 2001). The model was developed at the Center for Advanced Decision Support for Water and Environmental Systems at the University of Colorado under joint sponsorship by the U.S. Bureau of Reclamation and the Tennessee Valley Authority. In this model, basin components are represented as objects and categorized by object-type. Each object is modeled according to the physical processes and operating rules associated with its object-type. Operating rules are expressed separately through a special rule language that allows the use of mathematical functions, loops, and logical statements. A syntax-directed editor with a series of operations and functions is provided to guide the construction of syntactically correct rules (Zagona et al. 2001). Thus, operating rules can be easily created and modified to customize the model. The rules can also be prioritized which allows the simulation of water allocation based on prior appropriation. RiverWare can perform pure simulation runs or it can use rule-based simulation and optimization. Pure simulation and rule-base simulation are used to provide descriptive solutions to "what if" scenarios. When multiple conflicting objectives need to be evaluated, the optimization routines can provide prescriptive solutions. RiverWare's optimization capabilities make it suitable for screening and evaluating multiple water allocation schemes. Wheeler et al. (2002) applied this model for the Colorado River basin. The model was used to explore the effects of changes in several water management policies including gradual reductions in California's dependency on other states unused water, water reallocation between purposes, and inadvertent overrun withdrawals. The authors concluded that the flexibility of this model offers hope of a less litigious process for reaching compromise among participating parties.

5.2.7 The State of Colorado's Stream Simulation Model (StateMod)

StateMod is a river/reservoir system simulation model with water allocation simulation capabilities. This model was adopted as the water management modeling tool in the Colorado's Decision Support System (CDSS) developed by the Colorado Water Conservation Board and the Colorado Division of Water Resources. StateMod follows the prior appropriation doctrine of water allocation and it can use a monthly or daily time step. The model recognizes five types of water rights: direct flow, instream flow, reservoir storage, well, and operational. StateMod consists of four major modules: baseflow, simulation, report, and data check. In the baseflow module, the effects of human intervention with the river system (i.e. historic diversions, return flows, well pumping, and reservoir storage, releases, evaporation, and seepage) are removed in order to estimate the natural streamflow condition in the system. The impact of new or modified water rights may be assessed by comparing the simulation results with the natural streamflow condition. The

StateMod model, users guide, and sample data may be downloaded free of charge at: http://cdss.state.co.us/ftp/statemod.asp.

5.2.8 WaterWare

WaterWare is an integrated, model-based information and decision support system for water resources management developed by Environmental Software and Services, an Austrian consulting firm. WaterWare is an object-oriented model that integrates databases, GIS, models, and analytical tools into a common framework. The model includes a number of simulation and optimization models and related tools, such as a daily rainfall-runoff and water budget model, irrigation water demand model, a dynamic an stochastic water quality models, groundwater and transport model, and a water allocation model. The latter is based on a heuristic (genetic algorithm) module that finds cost-efficient water allocation strategies. The model computes a daily water budget for all nodes in the river network and provides monthly, seasonal, annual, and sectoral demands summary statistics. Model documentation and sample applications are available in the internet at: http://www.ess.co.at/WATERWARE.

5.2.9 WEAP

The Water Evaluation and Planning (WEAP) model, is a water balance accounting model that allocates water from surface and groundwater resources. WEAP is developed by the Stockholm Environment Institute (http://www.weap21.org). This model may be used as a policy analysis tool for evaluating water management options taking into account multiple and competing water uses. A network flow model is used to establish the connectivity of the river/reservoir system. WEAP operates on a monthly time step and uses a linear optimization algorithm to optimize the supply of demands and instream flow requirements, subject to supply priorities, mass balance and other constraints. The model also contains a pollution mass balance routine which evaluates loadings and treatments of pollutants on receiving water bodies. Hydropower generation and water delivery costs are also incorporated in the model. WEAP may be used to address several water resources issues including reservoir operations, water rights and allocation priorities, pollution tracking, and benefit-cost analysis. Lévite et al. (2003) applied the model to assess alternative water allocation scenarios in the Olifants River basin in South Africa. The authors concluded that

WEAP is a user-friendly model that is useful for the rapid assessment of water allocation decisions and for locating the regions of the basin where water scarcity problems are likely to occur.

5.2.10 WRAP

The Texas Water Availability Modeling (WAM) System has facilitated the assessment of hydrological and institutional water availability and reliability through the use of the Water Rights Analysis Package (WRAP) model. The model is used for planning purposes and for evaluating water right permit applications. WRAP is a generalized model, developed at Texas A&M University, designed to simulate a river basin under a priority-based WAS (Wurbs 2005). WRAP evaluates the ability of the river/reservoir system to meet demands during a hypothetical repetition of historical hydrology. The spatial connectivity of the system is modeled as a set of control points. The computational algorithms are based on the location of each control point related to the others as defined in the input data. Simulation results include regulated flows (i.e. physical flows at a location), reservoir storage contents, diversions, water right shortages, unappropriated flows, reliability indices, and other variables (Wurbs 2003). WRAP has been used to simulate water allocation and management in all Texas river basins, including the international Rio Grande basin (TCEQ 2005b). The WRAP modeling capabilities will be described in more detail in Chapter VIII.

CHAPTER VI

WATER ALLOCATION IN TEXAS

6.1 HISTORICAL DEVELOPMENT OF WATER RIGHTS IN TEXAS

The current surface water allocation framework in the state of Texas is the result of an evolutionary process guided by political transitions, court decisions, and legislation. Water rights in Texas have been granted under Spanish, Mexican, Republic of Texas, and State of Texas laws. In essence, the riparian doctrine was first introduced, then the prior appropriation doctrine was adopted and coexisted with riparianism, and finally the riparian rights were merged into the prior appropriation system.

During the Spanish and Mexican rule, grants of land and the water rights of property owners were governed by civil law. In 1840, the Republic of Texas adopted the English common law, and with it acquired the English riparian doctrine which was somewhat different from the Spanish. Between 1840 and 1895 extensive tracks of public lands were transferred to private owners. Riparian owners were granted with the right to use water for irrigation and other purposes. However, as early as 1868, the Texas Supreme Court indicated that riparian rights did not apply to the drier parts of the state and suggested legislation to impose the prior appropriation system (Dellapenna 1991a, Templer 2001). The prior appropriation doctrine became effective with the enactment of the appropriation statutes of 1889 and 1895.

Subsequently, the Texas courts and legislature began to restrict the scope of riparian rights. In 1913, a water code was adopted that extended appropriation laws to the entire state and barred riparian rights on lands that passed to private owners after July 1, 1895 (Dellapenna 1991a). Pre-existing riparian rights, however, were honored. Between 1895 and 1913 water rights could be obtained by simply filing a sworn statement with the county clerk and describing their use. Under this simplistic system, water-rights claims often overlapped and people claimed more water than the stream could possibly supply (Templer 2001). After 1913, a much more elaborate administrative procedure has been followed which involves filling an application and obtaining a permit from a centralized state agency.

Although prior appropriation was the official allocation doctrine after 1895, riparian rights were not totally eliminated. Having mixed types and often conflicting water rights and the fact that there were many unrecorded water rights (for which there was no record of the amount of water that was diverted) greatly hindered the coordination and management of the state's surface waters. The 1950's drought prompted the state legislature to tackle this situation and in 1967 the Water Rights Adjudication Act (WRAA) was enacted. The objective of the WRAA was to require a recording of all water rights claims, to limit those claims to actual use, and to provide for the adjudication and administration of water rights (Wurbs 2004). All unrecorded water right claims were required to be filed by 1969. Over 11,600 unrecorded claims were filed and they were limited to the maximum amount of water used between 1963 and 1967 (Templer 2001). Most claims were for riparian rights since most appropriative rights were already recorded. More than half of the claims were rejected since they did not show water use during the established period (Wurbs 2004). The approved permits were also subject to cancellation for non-use. During this adjudication process, all riparian rights were merged with the prior appropriation system forming the current permit system applicable to all of Texas save for the Lower Rio Grande. The process started in 1968 and was completed in the 1980's.

6.2 TEXAS WATER RIGHTS SYSTEM

The Texas Water Code of 1963 is based on the prior appropriation doctrine. Under this doctrine, water rights are granted on a "first come – first served" basis and older water rights have priority during times of shortage. A water right permit is required in Texas in order to use surface water. Anyone can submit an application to the Texas Commission on Environmental Quality (TCEQ) to obtain a permit. As of August 2005, there were 9,464 active water rights permits and 130 pending applications (TCEQ 2005b). Water rights permits are held by cities, river authorities, water districts, public and private agencies, and individual citizens. The permits with the largest amounts of water are usually held by cities and river authorities. These entities hold the water right permit and sell water to their customers who are not required to hold a water right.

Water rights permit applications are carefully scrutinized by the TCEQ before the permit is granted. The TCEQ approves the application if there is unappropriated water available, a beneficial use is contemplated, water conservation will be practiced, existing water rights are not impaired, and the water use is not detrimental to the public welfare (Wurbs 2004). The TCEQ examines the proposed monthly water demand and the monthly river flows or reservoir levels over a period of time. The availability of unappropriated water requirement is satisfied if the historical record suggests that most of the water being requested will be available most of the time it will be needed. The TCEQ follows three rules of thumb to determine if there is enough water to meet the demands of a new permit (TCEQ 2005a):

(1) For most users, if the record shows that at least 75% of the water can be expected to be available at least 75% of the time, the TCEQ will usually issue the permit.
(2) For municipalities, the TCEQ will issue a permit only if the record shows that 100% of the water can be expected to be available 100% of the time, unless a backup source is available.
(3) For a municipality that has access to a backup supply, the TCEQ may decide to issue a permit to use water that can be expected to be available less than 100% of the time.

The requirement of beneficial use is easily satisfied in most applications. The Texas Water Code lists beneficial uses, in order of priority, as follows: domestic & municipal, industrial, irrigation, mining, hydroelectric, navigation, recreation and pleasure, and others (Texas Water Code §11.024). The only real inquiry is whether the volume of water requested is excessive in light of the intended use (Caroom 1997). Notice that water appropriation for environmental uses is not considered a beneficial use. However, since 1985 the TCEQ is required to consider the impacts of new water permits on aquatic, terrestrial and riparian habitats, as well as bay and estuary inflows (Texas Water Code §11.047, §11.150, §11.152). The water conservation requirement promotes the efficient use of water and avoidance of wasteful use. The TCEQ may deny an application if the applicant has not provided evidence that reasonable diligence will be used to avoid waste and achieve water conservation (Caroom 1997). Computer modeling is used to determine whether new water uses will affect existing senior water rights under a variety of hydrologic conditions (see Section 6.5). If the model results indicate that senior rights may be impaired, the TCEQ may deny the application or set restrictions on the new diversion. The public welfare requirement can include consideration of environmental, social, and economic impacts of the proposed water use.

A water right permit authorizes the applicant to use a specific amount of water in the manner described in the application. The permit allows the user to impound that water, divert it, or both. Impoundment rights specify the location of the users dam and the capacity of the reservoir. Diversion or "run-of-the-river" rights specifies the diversion location and the rate at which water can be diverted. Most permits are issued in perpetuity, but they can be cancelled if water is not used over a 10 year period. Two types of short term permits are also available: term and temporary. The rationale for these permits is to maximize the use of water in basins where waters are fully appropriated but not yet being fully used (TCEQ 2005a). Term permits are typically issued for agricultural, mining, and industrial uses for a period of 10 years. Temporary permits are valid for up to three years and are commonly issued for road construction projects.

Some water uses are exempted from the permitting process. For example, water can be used without a permit for domestic and livestock (D&L) purposes if the water is diverted by persons living adjacent to a stream. Persons can also store in their property up to 200 ac-ft of water for D&L uses. The right to use water for these purposes is a property right attached to the land. State water can also be used without a permit for wildlife management, fish and shrimp farming, drilling and extracting oil, sediment control in surface coal mines, and for emergency purposes by fire departments and other similar services (TCEQ 2005a).

Once approved, a priority date is assigned to the water right which corresponds to the time of the application filing. The priority date governs the water allocation sequence. In essence, if water is insufficient to meet all needs, earlier users (senior appropriators) will obtain all their allotted water while those who appropriated later (junior appropriators) may see their allotment diminished or cutoff completely. Special stipulations, however, were added to this basic priority system in order to handle water rights that do not have priority dates. For instance, the allocation sequence begins with D&L uses. These uses are considered senior to any kind of appropriated water right. Conversely, holders of short term permits are junior to all other users.

With regard to the protection of water rights, there are two basic mechanisms that are adopted: the honor system and watermaster programs. Most of the state relies on the honor system, which assumes that users will abide to the water allocation rules without supervision. One advantage of this system is that there is no ongoing cost for enforcing the law. However, it is difficult for users to know how much water they must let pass for downstream senior users and how much they can divert or impound. In case of illegal diversions, water right holders can resort to civil courts, or they can report them to the TCEQ. The TCQE can set up a temporary streamflow monitoring program to stop the unauthorized water use but it cannot restore the water that was illegally used by others (TCEQ 2005c). Under a watermaster program, streamflows, reservoir levels, and water use in a basin are continually monitored to ensure proper use of the water. The watermaster is an officer appointed by the TCEQ which coordinates the allocation process and has the authority to enforce the law. Under this system, all water releases and diversions must be pre-authorized and if an illegal diversion is discovered the watermaster can lock up the diversion pumps of the infractor. Another benefit is that watermasters are usually able to settle disputes, thereby avoiding costly litigation. Two watermaster programs operate in Texas, one in the Rio Grande basin and the South Texas watermaster which serves the San Antonio, Guadalupe, Nueces, and Lavaca basins.

6.2.1 Lower Rio Grande Water Allocation System

The allocation process of the Texas share of the waters of the Lower Rio Grande basin is significantly different from that of the rest of the state. The primary difference is that the allocation sequence is governed by water use type instead of priority date. In accordance with a court decision in the Lower Rio Grande Valley Water Case, water uses are divided into three groups: 1) domestic, municipal, and industrial (DMI), 2) Class A irrigation, and 3) Class B irrigation. DMI uses have the highest priority followed by the irrigation uses. Of the total agricultural land in the Lower Rio Grande Valley supplied by the Rio Grande, 86% was assigned with Class A rights and the remaining 14% with Class B rights. Each water right is limited by its permitted annual diversion amount and by the water available in storage. Once the available storage has been allocated, the Rio Grande Watermaster makes daily requests to the International Boundary and Water Commission (IBWC) to make the necessary releases to satisfy the needs of the water right holders. The Watermaster keeps record of water releases and storage allocated to each water right account.

Every month, the IBWC informs the Rio Grande Watermaster of the total volume of water allocated to the US in the international Amistad and Falcon Reservoirs. The storage allocation between Mexico and the US is explained in Section 6.4. The monthly allocation procedure of the US share of the water is depicted in Figure 6.1 and summarized below based on the 1977 Texas Administrative Code, Title 30 – Chapter 303 (30 TAC – 303).

Out of the total volume in storage available to the US 4,600 ac-ft is considered dead storage. The remaining storage constitutes the usable storage. From the usable storage, 225,000 ac-ft is reserved for DMI uses. That is equivalent to one year's average diversions for all municipal demands below Amistad for Texas users (TCEQ 2005d). The size of the DMI reserve has not been updated since 1986. Since then, the number of DMI rights has grown to approximately 320,000 ac-ft and thus a reevaluation of the DMI reserve size may be warranted (Griffin and Characklis 2002).

After the DMI allocation, the total end-of-month account balances for all Class A&B water right accounts are deducted. Next, 75,000 ac-ft are allocated to an operating reserve (OR). The OR provides for water loses due to evaporation, seepage, and conveyance; for emergency requirements; and for adjustments in storage that may be necessary in the provisional IBWC computations. If water is still available after all deductions, the surplus is distributed among the Class A&B rights. The storage is allocated in proportion to permitted annual diversion amounts, but Class A rights receive 1.7 times as much water as that allotted to Class B rights. Consequently, Class B rights suffer greater shortages on water-short years. If the OR is less than 75,000 ac-ft but greater than zero, then that amount will be allocated to the OR. If, however, the OR is less than zero ac-ft, a negative allocation process is adopted in which water is deducted from the Class A&B accounts until the OR is restored to 48,000 ac-ft.

Some additional stipulations regarding water rights account balances and permits are as follows:

(1) Account balances cannot exceed 141% of their annual permitted storage capacity.
(2) Accounts are reduced to zero if water has not been used in two consecutive years.
(3) No allocations are made to water right holders that do not specify place of use.
(4) Accounts are reduced to zero due to non-payment in a one year period.
(5) Water rights may be cancelled if not used over a period of ten consecutive years.

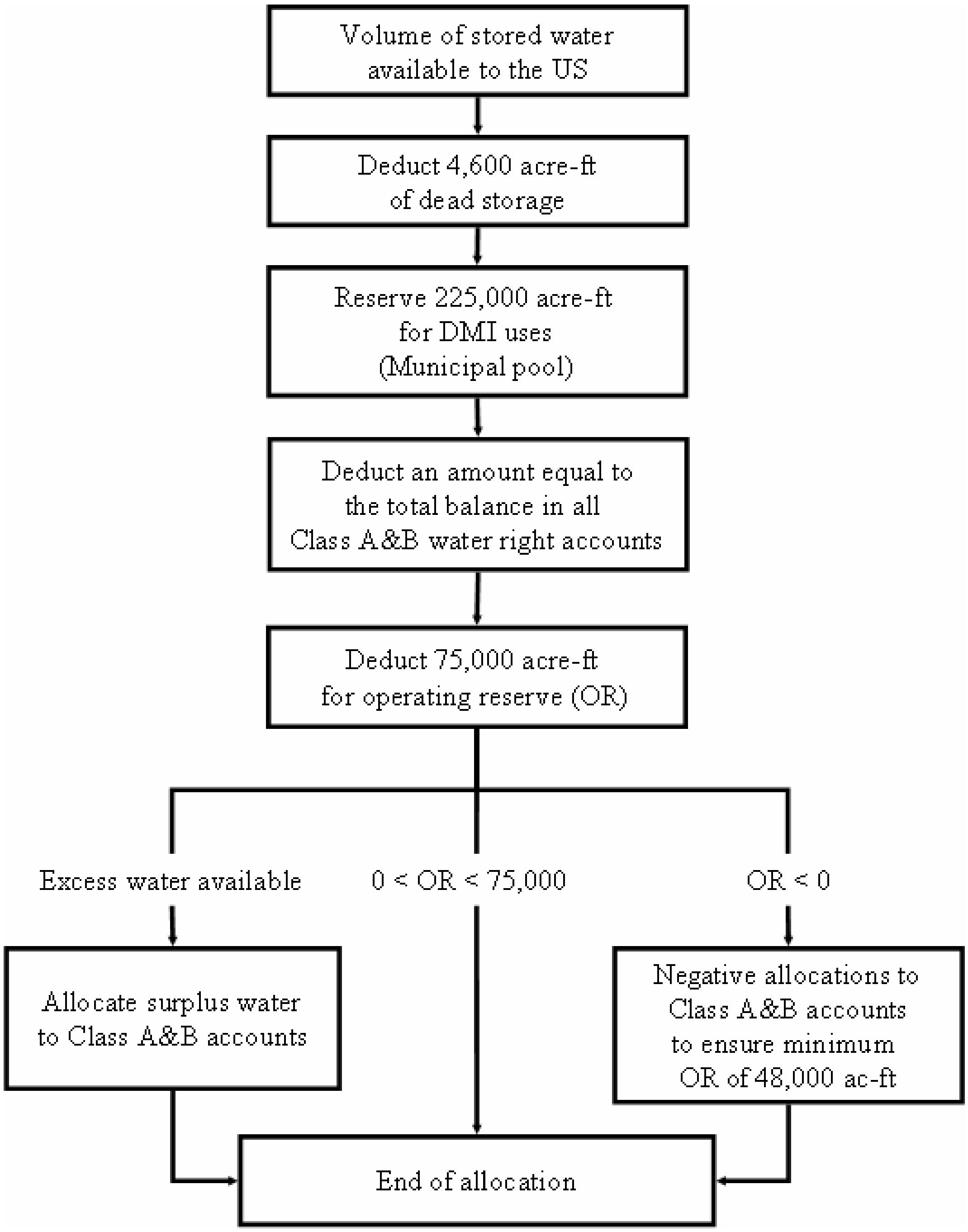


FIGURE 6.1. Monthly Allocation of the US Share of Conservation Storage in the Amistad and Falcon Reservoir System

6.2.2 Texas Water Markets

Water markets represent an alternative means of acquiring the right to use water. Water marketing refers to ways of facilitating reallocations through market-like transactions. Although water right holders do not have the actual title to the water, a water right can be sold, leased, or transferred to another person.

The Rio Grande has been over-appropriated for many years with no new rights for additional water use being granted (Wurbs 1997). However, water market transactions are frequently used in this region to help resolve water supply needs. The most common transaction has been municipalities buying water rights from agricultural users, with municipalities acquiring in the order of 10,000 ac-ft of additional rights per year (Griffin and Characklis 2002). One important specification in these transactions is that, in accordance with the 30 TAC – 303, if a Class A water right will be acquired for a DMI use it has to be converted to 50% of the existing water right. If it is a Class B right, it has to be converted to 40% of the existing water right.

Another common transaction is a temporary (one year) lease of water. These transactions are also known as contractual sales of water. Contractual sales account for a great deal of market activity with 20,000 to 80,000 ac-ft changing hands annually (Griffin and Characklis 2002). In contrast to permanent water sales, contractual sales are only approved for same-type use of water. Other possible transactions are the dry-year option contracts and the transfer of conserved water (TWDB 2005). The dry-year option contracts are typically used by municipalities to increase their water supply during times of drought. This allows municipalities to meet their needs during droughts and the water right holder gains financial benefits from the contract while keeping the right to use the water during normal periods. The transfer of conserved water option is typically used by industries or municipalities to acquire water by financing the modernization of irrigation systems in exchange for the right of using the water that is being conserved.

As opposed to the Rio Grande region, water market transactions are not so common in the rest of Texas. In 1993, the Texas Legislature established a statewide water bank, managed by the Texas Water Development Board (TWDB), with the intention of encouraging and facilitating water marketing (Wurbs 1997). However, usage of the water bank has been sparse. Griffin and Characklis (2002) identified four reasons for this trend.

First, they pointed out that water scarcity is not as big of an issue in the eastern basins of Texas as it is in the Rio Grande. The second reason is that Texas does not have the appropriate infrastructure to convey water from water-rich to water-short basins. Third, since protection of water rights is based on the honor system, people are hesitant to buy something they can take for free or buy something that can be easily taken away from them. Finally, the authors suggest that the presence of river authorities hinders water markets because they tend to purchase water rights from lesser public and private water districts in order to extend their domains within their licensed service areas which results in a monopolistic power that makes water marketing infeasible. Further information regarding water markets in general can be found in Chapter IV, Section 4.1.2.2, and in Chapter VII, Section 7.2.1.

6.3 INTERSTATE RIVER COMPACTS

Interstate river compacts are negotiated agreements entered into voluntarily by two or more states. Compacts have become the most common venue for transboundary water allocation between states, especially among western states. The primary purpose of interstate compacts is to provide a means for the equitable allocation of water between states. Interstate compacts typically create compact commissions composed of representatives from the parties entered in the compact (i.e. states and/or the federal government) to administer the compact. The different types of interstate compacts, their legal basis, and their allocation and conflict resolution mechanisms are expounded in Chapter III, Section 3.3. The State of Texas participates in five interstate river compacts that allocate the waters of its major interstate rivers; the Canadian, Pecos, Red, Sabine, and Rio Grande rivers (Figure 6.2).

6.3.1 Canadian River Compact

The Canadian River Compact is an interstate compact between Texas, New Mexico, and Oklahoma. In essence, the compact divides the waters of the basin and it sets maximum amounts of conservation storage allowed to each state (Texas Water Code – Chapter 43). Oklahoma is allowed free and unrestricted use of all the Canadian River waters in the portion of the basin that lies in Oklahoma. New Mexico is allowed free and unrestricted use

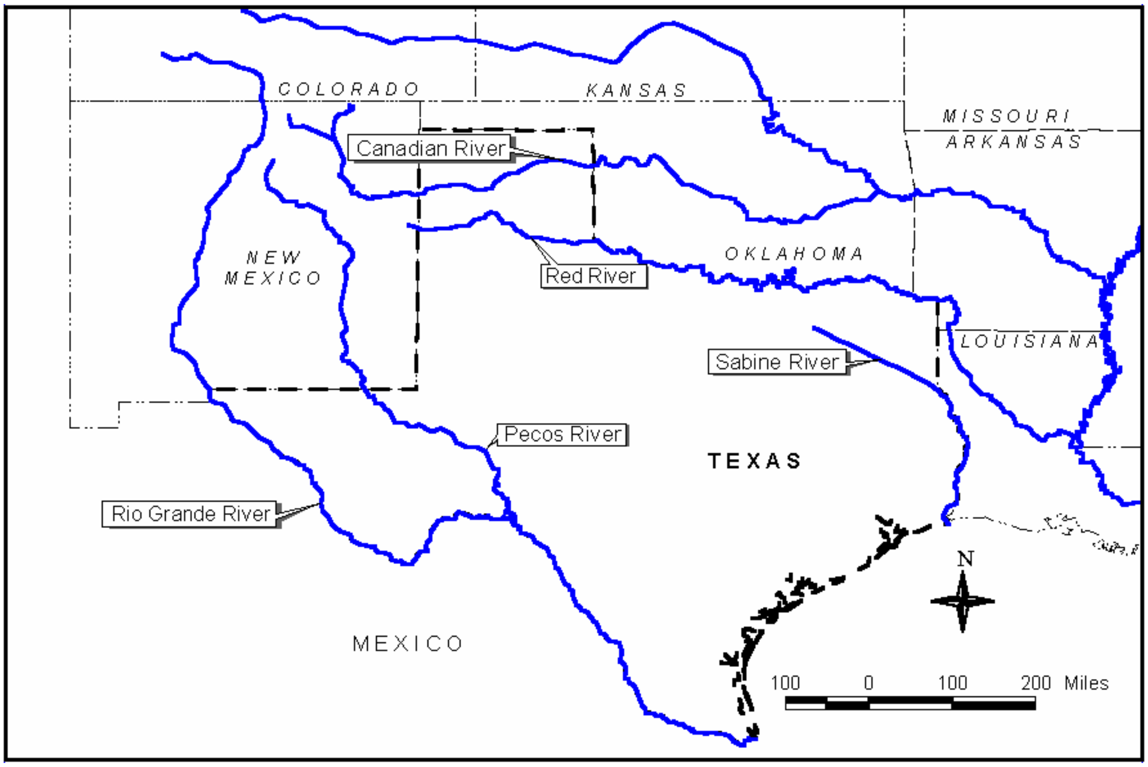


FIGURE 6.2. Texas Interstate Rivers

of the runoff generated in the drainage basin of the Canadian River in New Mexico below Conchas Dam, however it cannot store more than 200,000 ac-ft in the reservoirs below said dam. The compact states that the water that Texas is allowed to store can only be used for municipal, household, livestock, and small scale self-subsistence irrigation uses. The right of Texas to store water is limited to 500,000 ac-ft, until Oklahoma has been provided with 300,000 ac-ft of conservation storage. These values exclude storage on reservoirs in the North Canadian River for Texas and Oklahoma, and east of the 97th Meridian for Oklahoma. Once Oklahoma has received 300,000 ac-ft, the limit for Texas switches to 200,000 ac-ft plus whatever amount of water Oklahoma has in conservation storage during the same time period. In other words, the amount of water that Texas can store in excess of 500,000 ac-ft is the same amount of water that Oklahoma is storing over 300,000 ac-ft.

The Canadian River Compact Commission (CRCC) administers this compact and performs an annual accounting of water stored in each state to determine compact compliance. For example, to verify if New Mexico is in compliance with Texas the actual amount of storage in Texas reservoirs is divided by 350,000 ac-ft and its converted to a percentage. The 350,000 ac-ft value represents the amount of water that Texas normally has in storage during an average runoff year and with New Mexico complying with the compact (CRCC 2004).

Some legal issues have emerged over the years between the Canadian River Compact signatory states. In 1987, Texas and Oklahoma filed suit in the US Supreme Court against New Mexico alleging violations of the compact. The final resolution of the suit occurred seven years later in 1994. The resolution included a finding that New Mexico violated the compact and required a repayment of water to Texas for past compact violations, and a payment of $200,000 to both Texas and Oklahoma (CRCC 2004). More recently, Oklahoma has been considering filing suit in the US Supreme Court regarding the construction of the Palo Duro Reservoir in the North Canadian River Basin in Texas. Oklahoma asserts that they have a higher priority than Texas for using the water from this reservoir and that Texas is using the water for purposes other than those authorized by the compact. The CRCC is still trying to resolve this matter without litigation (CRCC 2004).

6.3.2 Pecos River Compact

The Pecos River Compact is an interstate compact between Texas and New Mexico created in 1948. Basically, the compact requires New Mexico to maintain water deliveries to Texas of an amount equivalent to what was reaching the state line under the 1947 natural conditions. The compact also created the Pecos River Compact Commission (PRCC), which has the responsibility to adopt rules and regulations, perform water supply studies, keep track of streamflows, storage, diversions, and water use, and oversee the deliveries of water from New Mexico to Texas, among others. The most prominent specifications of the compact include the following (Texas Water Code – Chapter 42):

(1) New Mexico cannot deplete the flow of the river below an amount which will give to Texas a quantity of water equivalent to that available under 1947 conditions.

(2) Of the water salvaged in New Mexico (i.e. water made available for beneficial use) through the construction and operation of water projects, 43% is apportioned to Texas and 57% to New Mexico.
(3) Any water salvaged in Texas is totally apportioned to Texas.
(4) The unappropriated flood waters are apportioned 50% to each state.

For years, Texas considered New Mexico to be deficient in living up to the terms of the contract and in 1974 filed suit. The US Supreme Court ruled in June 1987 that New Mexico owned Texas 340,000 ac-ft of water for the period between 1950 and 1983, and ordered the New Mexico repay with deliveries of 34,000 ac-ft of water a year for ten years (Hayter 2005). The Court also appointed a River Master to perform the annual accounting of water deliveries to Texas. Since completion of the litigation, New Mexico has taken measures to comply annually with the Pecos River Compact. New Mexico spent approximately $40 million appropriated by their legislature to take existing water rights out of production to ensure water deliveries to Texas (PRCC 2004).

6.3.3 Red River Compact

The Red River Compact is an interstate compact between Texas, Oklahoma, Arkansas, and Louisiana created in 1978. The compact divides the Red River basin into five reaches and establishes specific allocations for topographic sub-basins within each reach (Texas Water Code – Chapter 46). Article IX of the compact creates the Red River Compact Commission (RRCC) for the administration of the compact. The RRCC has the power to adopt rules and regulations governing the operation of the compact and to enforce its terms.

6.3.3.1 Red River – Reach I

Reach I includes the Red River and tributaries from the New Mexico-Texas state border to Denisom Dam and it is divided into four sub-basins. Sub-basin 1 and 3 are entirely within Texas; Sub-basin 2 is entirely within Oklahoma; and Sub-basin 4 includes all of Lake Texoma and the Red River from the Texas-Oklahoma boundary to Denisom Dam. The compact apportions the water in each Sub-basin as follows:

- The annual flow within Sub-basin 1 is apportioned 60% to Texas and 40% to Oklahoma.
- Oklahoma has free and unrestricted use of the water within Sub-basin 2.
- Texas has free and unrestricted use of the water within Sub-basin 3.
- Oklahoma and Texas are apportioned 200,000 ac-ft, which include existing allocations and uses. Additional quantities are allocated 50% to each state.

6.3.3.2 Red River – Reach II

Reach II begins at Denisom Dam and continues until the river reaches the Arkansas-Louisiana state boundary. All the tributaries that contribute to the flow of this portion of the river are also included in Reach II. This reach is divided into five sub-basins.

Sub-basin 1 is completely within Oklahoma. The compact states that Oklahoma can have unrestricted use of the water in this sub-basin. Similarly, Texas has unrestricted use of the water in Sub-basin 2, which lies entirely within the said state. Sub-basin 3 is divided almost in half between Oklahoma and Arkansas and they both have free and unrestricted use of the water within their states. However, Oklahoma is required to allow 40% of the total runoff generated below certain dams to flow into Arkansas. The waters from Sub-basin 4, which is primarily composed of the Sulphur River Basin, are apportioned 100% to Texas.

Sub-basin 5 is the portion of the Red River from Denisom Dam to the Arkansas-Louisiana state boundary excluding all tributaries included in the other sub-basins. In this sub-basin, all four states are entitled to 25% of the water, so long as the flow of the river at the Arkansas-Louisiana border is 3,000 cfs or more. If the flow is between 1,000 and 3,000 cfs, Texas, Oklahoma, and Arkansas are required to allow 40% of the total weekly runoff from Sub-basin 5 and 40% of undesignated water flowing into Sub-basin 5 to flow into Louisiana. However, this does not entail any state to release stored water. If the flow is less than 1,000 cfs, Texas, Oklahoma, and Arkansas are required to allow 100% of the total weekly runoff from Sub-basin 5 and 100% of undesignated water flowing into Sub-basin 5 to flow as required to maintain 1,000 cfs. Other special provisions regarding minimum flows and exceptions to the allocation rules are also included in the compact.

6.3.3.3 Red River – Reach III

The majority of Reach III lies in Texas and Louisiana at and it is divided into four sub-basins. Sub-basins 1 and 2 lie entirely within Texas and Arkansas, respectively. Sub-basin 3 is divided between Texas and Louisiana. Sub-basin 4 lies entirely within Louisiana. The compact apportions the water in each Sub-basin as follows:

- Runoff from Sub-basin 1 is apportioned 60% to Texas and 40% to Arkansas.
- Runoff from Sub-basin 2 is apportioned 60% to Arkansas and 40% to Louisiana.
- Texas and Louisiana have unrestricted use of the water of Sub-basin 3 within their respective boundaries. Conservation storage is allocated 50% to each state.
- Louisiana has unrestricted use of the water of Sub-basin 4.

6.3.3.4 Red River – Reaches IV and V

Reaches IV and V lie entirely within Arkansas and Louisiana, respectively. Reach IV is divided into 2 sub-basins. The waters of Sub-basin 1 are apportioned 100% to Arkansas, and the waters of Sub-basin 2 are distributed 60% to Arkansas and 40% to Louisiana. Other provisions regarding minimum flow requirements are also stated in the compact. Reach V lies entirely within Louisiana and said state is entitled to 100% of the flows in that reach.

6.3.4 Sabine River Compact

The Sabine River Compact is an interstate compact between Texas and Louisiana created in 1953. In essence, the compact apportions the waters of the Sabine River 50% to Texas and 50% to Louisiana, regardless of the origin of the water (Texas Water Code – Chapter 44). The compact also requires a minimum streamflow requirement of 36 cfs at the point where the river touches for the first time both Texas and Louisiana. With regard to reservoirs constructed in the portion of the river that flows along both states, the compact establishes that the storage is to be divided in proportion to their contribution to the cost of storage.

The compact also created the Sabine River Compact Administration (SRCA). The main functions of the SRCA include adopting the rules and regulations of the compact, collect and analyze streamflows, storage, diversions, and water use data, and maintain an account of the water used by each state. The SRCA also has the duty of investigating any violation of the compact and report recommendations to officials in the affected state.

Currently, Texas' uses in the Sabine River basin are such a small proportion of its total share of the Sabine water that the compact imposes little more than a theoretical limitation that may become applicable at some point in the future (Caroom 1997).

6.3.5 Rio Grande Compact

The Rio Grande Compact is an interstate compact between Colorado, New Mexico, and Texas, approved by Congress in 1939 (Texas Water Code – Chapter 41). The main purpose of the compact is to apportion equitably the waters of the Rio Grande above Fort Quitman, Texas, among the signatory states. A depiction of the Rio Grande Basin is shown in Figure 6.3.

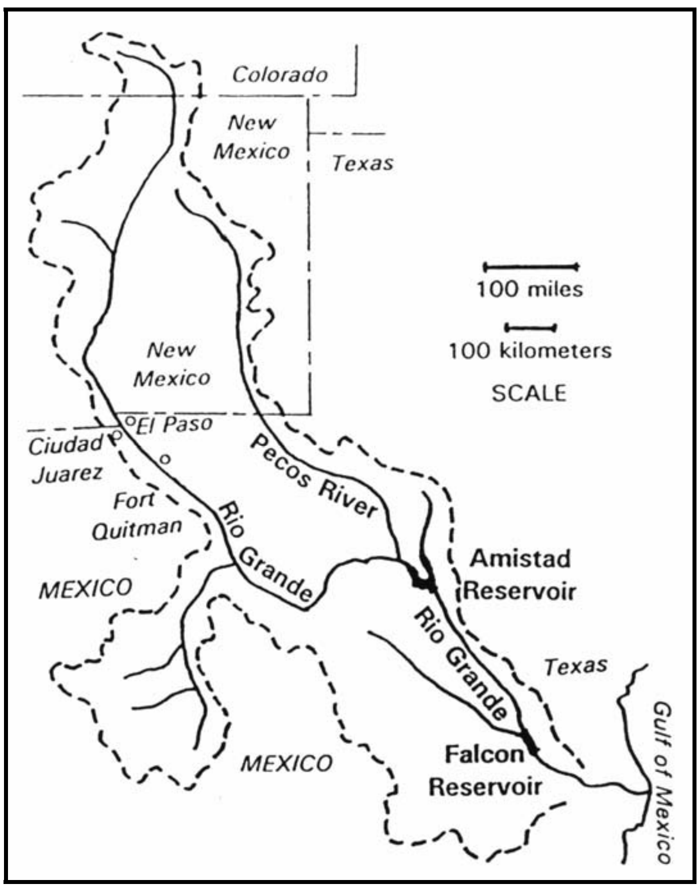


FIGURE 6.3. Rio Grande River Basin (source: Wurbs 1997)

The compact also established the Rio Grande Compact Commission (RGCC) to administer the terms of the compact. A critical responsibility of the RGCC is to maintain and operate a series of stream gaging stations and keep the flow records required for carrying out the compact allocations as explained below.

The allocation mechanism in this compact is based on a series of tables that indicate the water deliveries that Colorado and New Mexico are obligated to make. The tables establish relationships between the annual flows at one or more inflow index gaging stations and the quantity of water that needs to be delivered downstream. An example of this mechanism is presented in graphical format in Figure 6.4. This figure represents the obligation of New Mexico

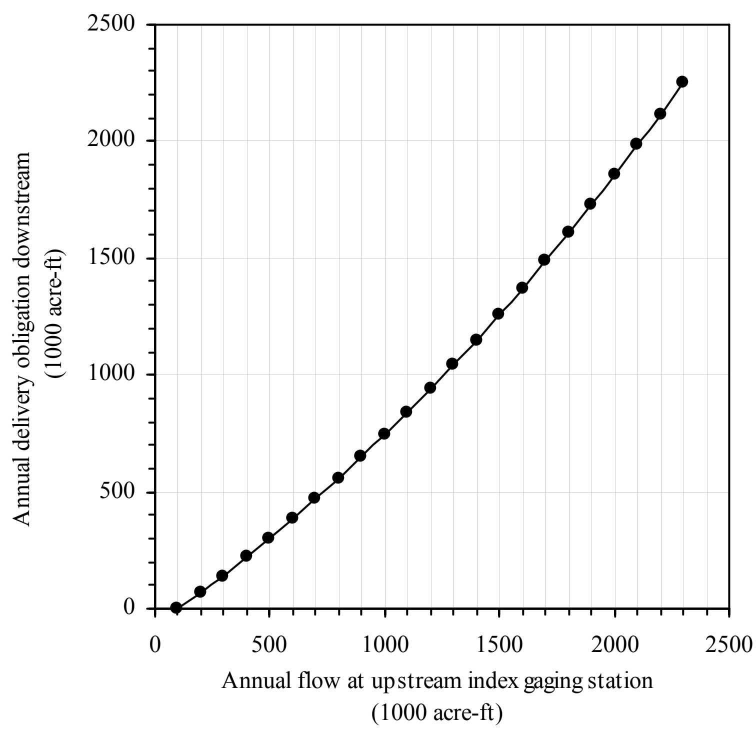


FIGURE 6.4. Example of Rio Grande Compact Allocation Mechanism. Relationship between Annual Flows at Otowi Index Supply (Upstream) and Delivery Obligations at San Marcial Index Supply (Downstream)

to deliver water in the Rio Grande at San Marcial (downstream index station) during each calendar year as a function of the annual flow quantity at the upper index station (Otowi Index Supply). Similar relationships are established for different river reaches. Another important aspect of the compact is the system of debit and credit accounts. Debits are the amounts by which actual deliveries fall below scheduled deliveries, while credits are the amounts by which actual deliveries exceed scheduled deliveries. Both credits and debits are determined in annual cycles and they accrue over time. The compact does however set maximum limits for the accrued debits and sets stipulations for the repayment of accrued debits from reservoir storage. For example, during the month of January, the Texas representative at the RGCC can demand of Colorado and New Mexico releases from storage to the amount of the accrued debits of said states at a practical rate.

6.4 INTERNATIONAL ALLOCATION OF THE RIO GRANDE

The Rio Grande defines the boundary between Texas and Mexico from Ciudad Juarez/El Paso to the Gulf of Mexico. The Rio Grande waters are shared in accordance with two international treaties: the 1906 Convention between Mexico and the United States for the distribution of waters of Rio Grande, and the 1944 Treaty for the Utilization of the Waters of the Colorado and Tijuana Rivers and of the Rio Grande. The 1906 Convention apportions the waters of the river reach between Ciudad Juarez/El Paso to Fort Quitman, Texas. The 1944 Treaty defines the allocation of water between Fort Quitman and the Gulf of Mexico.

6.4.1 Allocation of the Rio Grande above Fort Quitman (1906 Convention)

The 1906 Convention allocates the waters of the Rio Grande in the international reach above Fort Quitman between Mexico and the US (Figure 6.3). Basically, Mexico is granted 60,000 ac-ft of water annually, without cost, from the US. The water is to be delivered at the Acequia Madre or Old Mexican Canal in accordance with a monthly schedule. The Convention establishes provisions for “extraordinary drought” or serious accident to the US irrigation system. Under such conditions water deliveries to Mexico are to be reduced in the same proportion as deliveries to the US. Elephant Butte Reservoir in New Mexico is the primary storage facility for providing this water. The delivery of this water, however, does not entail recognition of claims to that water on the part of Mexico. This Convention has worked relatively well since its inception (Combs 2004).

6.4.2 Allocation of the Rio Grande below Fort Quitman (1944 Treaty)

The 1944 Treaty allocates the waters of the Rio Grande in the international reach from Fort Quitman to the Gulf of Mexico between the two countries (Figure 6.3). The treaty allocates the water that reaches the Rio Grande based on a series of allocation rules outlined in the treaty. In general, the rules allot all or a portion of the water reaching the main stream to each country based on the geographical origin of the flows (i.e. Rio Grande tributary sub-basins). The allocation rules set in Article 4 of the treaty are summarized here as follows:

Water allocated to Mexico:

(a) All waters reaching the Rio Grande from the San Juan and Alamo Rivers as well as their return flows from irrigated lands.

(b) Half the flow in the main channel of the Rio Grande below the lowest major international dam (Falcon Reservoir).

(c) Two-thirds of the flow reaching the main channel of the Rio Grande from the Conchos, San Diego, San Rodrigo, Escondido and Salado Rivers and Las Vacas Arroyo.

(d) Half of all other flows not otherwise allotted occurring in the main channel of the Rio Grande, including contributions from all the unmeasured tributaries.

Water allocated to US:

(a) All the waters reaching the main channel of the Rio Grande from the Pecos and Devils Rivers, Goodenough Spring, and Alamito, Terlingua, San Felipe, and Pinto Creeks.

(b) Half of the flow in the main channel of the Rio Grande below the lowest international dam (Falcon Reservoir).

(c) One-third of the flow reaching the main channel of the Rio Grande from the Conchos, San Diego, San Rodrigo, Escondido, and Salado Rivers and Las Vacas

Arroyo, provided that this third shall not be less as an average amount, in cycles of 5 years, than 350,000 acre-feet annually.

(d) Half of all other flows not otherwise allotted in the main channel of the Rio Grande, including contributions from all the unmeasured tributaries.

The Treaty also makes provisions for paying water deficits. In the event of “extraordinary droughts” or serious damage to the hydraulic systems on the Mexican tributaries that may impede the delivery of the annual 350,000 acre-feet, deficiencies existing at the end of a 5-year cycle can be made up in the following 5-year cycle with water from the same measured tributaries. If the conservation capacities assigned to the US in at least two of the major international reservoirs are filled with waters belonging to the US, a 5-year cycle is considered terminated, all debits fully paid, and a new 5-year cycle commences.

The Treaty also authorized the construction of two international dams (Amistad and Falcon) for flood control, water conservation storage, and streamflow regulation for the benefit of both countries. Falcon, located approximately 275 river miles upstream from the mouth of the river, was completed 1953. Amistad was completed in 1969 and it is located approximately 299 river miles upstream of Falcon. Amistad is the second largest reservoir in Texas and Falcon is the fifth. These reservoirs are operated as a system by the IBWC. The IBWC is the administrative body created by the Treaty for overseeing treaty compliance and operating the international reservoirs. According to the IBWC, the combined conservation storage capacity in these reservoirs is 5,804,706 ac-ft (3,151,242 ac-ft in Amistad and 2,653,464 ac-ft in Falcon). It was the determined by the IBWC that the conservation storage in the reservoirs was to be divided between the two countries in accordance with their monetary contribution to the construction project: in Amistad, 56% to the US and 44% to Mexico; and in Falcon, 59% to the US and 41% to Mexico.

The IBWC operates the reservoirs according to the operational rules set forth in Article 8 of the Treaty. These rules are summarized as follows:

(1) Storage of upstream reservoirs (Amistad) shall be maintained at the maximum possible water level, consistent with flood control and other uses.

(2) Inflows to the reservoirs must be credited to each country.
(3) When the conservation pool of a particular country is full, any water in excess of that needed to keep it full shall pass to the other country given that it has unfilled conservation capacity. An exception to this rule is that one country may decide to temporally use the conservation capacity of the other country in any of the upper reservoirs, provided that if a flood or spill occurs this country will be charged for that amount and all inflows shall be credited to the other country until the flood discharge or spill ceases or until the capacity of the other country is filled with its own water.
(4) Losses in storage are charged in proportion to the ownership of the water in storage.
(5) Releases from reservoirs are proportionally divided between the countries unless it is otherwise approved by the IBWC in case the other country is not using them.
(6) Either country can avail itself of its share of stored or diverted water as long as it is for a beneficial use.

Evidently, water accounting is an integral part of the reservoir system operation. The IBWC keeps records of reservoir inflows, releases, evaporation, and storage, and assigns them to each country. The IBWC schedules releases requested by each country and deducts them from their total water allocation. This procedure allows the IBCW to compute the amount of water that each country has in storage at any time and provides the basis for evaluating if the countries are in or out of compliance with the established agreements. Other IBWC functions include planning and regulation of water quality and sanitation activities, flood control, and resolution of conflicts.

6.5 WATER AVAILABILITY MODELING IN TEXAS

In 1996, the state of Texas experienced a severe drought that caused serious losses in crop and livestock production and decreases in surface and groundwater that affected public water supplies and water-based recreational activities (Wilhite and Svodoba 2000). These losses were estimated at nearly $5 billion. This drought turned water resources management into the primary public concern and therefore, the number one issue on the 1997 state's legislature agenda. The 1997 Senate Bill 1 (SB1) addressed a wide range of issues and concerns including state, regional, and local planning for water conservation, water supply and drought management; administration of state water rights programs; interbasin transfer policy; groundwater management; water marketing; state financial assistance for water-related projects; and state programs for water data collection and dissemination. SB 1 defined a new direction for Texas water management. Water resources were now to be planned and administered with a regional, "bottom up" approach. Previous to SB1, the TWDB performed all the water planning process. SBI created 16 Regional Water Planning Groups (RWPG) that represent all local interests and develop regional water plans for water conservation, management, and mitigation for the next 50 years (Masloff 2002). The TWDB oversees the planning process and provides administrative and technical support to the RWPG (Wurbs 2005).

SB1 addressed a wide range of water management issues and authorized funds to expand the water availability modeling capabilities for the entire state. An integral part of the SB1 was the creation of Texas Water Availability Modeling (WAM) System. The WAM System is used to develop the RWPG and TWBD planning studies and to support the TCEQ water rights permit program. The WAM system consists of the following components:

(1) The Water Rights Analysis Package (WRAP) model.
(2) Databases for existing surface water rights, water use, streamflows, and other pertinent data for the 23 Texas river basins.
(3) Geographic Information System (GIS) tools for determining hydrologic parameters and establishing the river/reservoir system connectivity.
(4) Program management and complete documentation of the WAM System.

The WRAP model is the principal tool of the WAM System. WRAP is a generalized model, developed at Texas A&M University, designed to simulate a river basin under a priority-based WAS (Wurbs 2003). The WRAP model provides the flexibility to simulate alternative water availability and management scenarios (e.g. new water right permits, changes in operating practices, addition of water supply facilities, limited water supplies) and evaluate the system-wide effects of such alternatives. WRAP evaluates the ability of the river/reservoir system to meet demands during a hypothetical repetition of historical hydrology represented by monthly sequences of naturalized flows (unregulated flows) and reservoir evaporation rates. The spatial connectivity of the system is modeled as a set of control points. The computational algorithms are based on the location of each control point related to the others as defined in the input data. Model input includes the priority date and authorized annual water use for each water right, monthly water use distribution coefficients, return flow specifications, and pertinent reservoir storage data. Key simulation results include regulated flows (i.e. physical flows at a location), reservoir storage contents, diversions, water right shortages, unappropriated flows, and reliability indices, (Wurbs 2003). WRAP has been used to simulate water allocation and management in all Texas river basins (TCEQ 2005b).

6.5.1 WAM Applications to International and Interstate WAS

The multiple features of the WRAP model allowed considering the peculiarities of interstate and international river basins, where water allocation is influenced by treaties or compacts, to the extent necessary to assess water availability in Texas. Generally, compliance with the respective treaty or compact is assumed, especially for the assessment of long-term availability. In the WRAP model, inflows at the various control points are defined as naturalized flows. Naturalized flows represent the natural flows that would have occurred in the absence of the water users and water management facilities and practices. When incorporating inflows, the streamflow of transboundary rivers at the points of diversion are adjusted so that only Texas water allotment is available to Texas water right holders. If historical data showing deviations from the treaty/compact specifications is available, the naturalized flows can be further adjusted to account for the deficits or surplus in water available to Texas. Some specific modeling strategies used to incorporate the treaty/compact provisions in the WRAP models are discussed below.

The Canadian River Compact states that the right of Texas to store water is limited to 500,000 ac-ft, until Oklahoma has been provided with 300,000 ac-ft of conservation storage (section 6.3.1). However, as of 1993, the actual Oklahoma storage was 12,091 ac-ft and there are no plans to substantially increase this storage capacity (Espey Consultants Inc. 2002). Therefore, the total storage available to water rights in Texas is limited to 500,000 ac-ft. The actual storage amount authorized to water rights in Texas is 509,111 ac-ft. For modeling purposes, the additional 9,111 ac-ft are subtracted from one water right that accounts for more than 98% of the conservation storage.

The Pecos River Compact apportions the Pecos River waters between New Mexico and Texas (section 6.3.2). Texas' share of water delivered under the Pecos River Compact is based on the flow measured at the streamflow gage on the Pecos River near Red Bluff, New Mexico. Therefore, the historical flow at the Stateline gage has been adjusted to reflect the over/under deliveries as documented in the historical accounting records from the TCEQ and the Pecos River Commission for the period that compact accounting has been in place (1952-2000). Unadjusted records were used for the 1940-1951 period (R. J. Brandes Company 2005).

The Red River Compact has specific provisions for different reaches of the river system. Several modeling strategies were implemented in the Red River WAM model (Espey Consultants Inc. 2002). For instance, the waters of Subbasin 1 (Reach I) are apportioned 60% to Texas and 40% to Oklahoma. To account for this, only 60% of the naturalized inflows computed in WRAP's hydrology data program (WRAP-HYD) were incorporated into the WRAP allocation model (WRAP-SIM). In the case of Subbasin 2 (Reach I), the entire flow is allocated to Oklahoma. However, historical records indicate that Oklahoma does not utilize all the flow, and thus, some water reaches the Texas portion of the subbasin. This amount of water was computed based on drainage area ratios and were input in the model using flow adjustment factors. The flow adjustment option in WRAP allows additional inflows to be added as a time-series at pertinent control points. In the case of Subbasin 5 (Reach II), the flows at certain diversion locations are adjusted to maintain the instream flow requirements set forth in the compact as a function of certain streamflow and storage conditions (section 6.3.3.2). These conditions are defined in WRAP as triggers that activate the instream flow requirements in the simulation. Reaches III, IV, and V are not included in the model since they are completely within co-riparian states and do not contribute flows to Texas.

The Sabine River Compact apportions the Sabine River waters equally between Texas and Louisiana, and it requires a minimum streamflow requirement of 36 cfs at Texas-Louisiana Stateline. The division of water is simulated in WRAP using instream flow and target option features (Brown & Root Services 2001). The 50/50 instream flow requirement is set at the mouth of the river at Sabine Lake and applies to all water rights downstream of Toledo Bend Reservoir. Return flows are also subject to the 50/50 split. The 36 cfs minimum flow requirement at the Stateline is set senior to all downstream water rights. This requirement does not involve any releases from storage and only applies to water rights with priority dates junior to January 1, 1953.

The waters of the Rio Grande are allocated between US and Mexico according to the 1944 Rio Grande Treaty. In addition, the flow is allocated between Colorado, New Mexico, and Texas according with the Rio Grande and Pecos Compacts and the Rio Grande Project. The strategies used in the WAM model of the Rio Grande will be discussed in Chapter VIII.

6.5.2 WAM Applications to Intrastate WAS

Intrastate water allocation in Texas involves complex system configurations of policies, practices, and administrative institutions. As part of SB1 stipulations, all entities involved in managing the state's waters must use the modeling tools provided by the WAM System. This has resulted in greater consistency in the development of water management plans and the evaluation of water right permit applications.

6.5.2.1 WAM System and Water Management Plans

The TWDB is the primary water resources planning agency in Texas. TWDB is in charge of developing the state's comprehensive water masterplan and to provide leadership, technical services, and financial assistance to the 16 RWPG for the development of their regional water plans. To perform the myriad of studies required for supporting these planning activities, all agencies involved utilize the WAM System administered by TCEQ. The TCEQ has developed modeling guidelines for applying the WRAP model under varying conditions and assumptions. To assure consistency in the model development process, the TCEQ has stipulated eight model runs and an additional run for firm yield analysis. Each run reflects a specified combination of premises regarding:

(1) Return flow estimates – Consideration of 0, 50, and 100% of return flows.
(2) Water use – Full authorized amounts of water rights or maximum annual amount of water used recorded over the last 10-year period.

(3) Reservoir sedimentation conditions – Full reservoir capacity or under year 2000 sedimentation conditions.
(4) Water rights permits – Inclusion of term and perpetual rights.

Runs 1–3 are called the "Re-use" runs and they reflect varying return flow amounts. Water use in these runs is set to the full amounts, reservoirs are considered to have full capacity, and only perpetual rights are included. Runs 4–7 are called the "Cancellation" runs and they combine varying water use amounts with 0 or 100% of return flows, reservoirs have full capacity, and they only include perpetual rights. Run 8 is the "Current conditions" run. This run uses 100% of the return flows, the reservoirs are under the year 2000 conditions, and both term and perpetual permits are included in the simulation. Each model run is performed under two hydrologic conditions: 1) normal flows and 2) drought-of-record flows. The objective of these runs is to determine the projected amount of water that would be available under normal and drought-of-record conditions, project the amount of water that would become available if water rights cancellation procedures are implemented, and investigate the potential impact of municipal and industrial return flows on existing water rights, instream uses, and freshwater inflows to bays and estuaries (TCEQ 2005e).

6.5.2.2 WAM System and Water Right Permit Applications

As explained in section 6.2, water right permit applications are carefully scrutinized by the TCEQ before the permit is granted. Two key requirements that must be met in order to approve a permit application are that unappropriated water must be available and that existing water rights will not be impaired. The TCEQ relies on the WRAP capabilities for evaluating these requirements.

Two alternative scenarios are modeled in WRAP to evaluate the aforesaid requirements and help determine whether or not the permit can be granted (Wurbs 2005). Permanent permits are evaluated using what is referred to as the "Full authorization" scenario (Run 3). This scenario assumes the following conditions: 1) all water rights are using their entire allocation, 2) 0% return flows, 3) reservoirs have full capacity, and 4) term permits are not included. Using any other run which simulates quantities less than the full amount authorized to each permit may result in water over-appropriation by issuing additional water rights based upon water that has already been allocated to senior water right holders. Alternatively, the “Current conditions” run (Run 8) is used for evaluating term permit applications. These simulations are used to determine if unappropriated water is still available at a desired reliability (see section 6.2) and if the reliability of existing senior water rights is not decreased as a result of the proposed permit. Failure to meet any of these requirements would result in rejection of the permit application.

Wurbs (2005) evaluated the Texas experience and highlighted two significant contributions of the WAM System to the state’s water management. First, the WAM System has helped integrate planning efforts at all management levels and brought greater consistency to the administrative and regulatory processes. Second, as the different planning and regulatory scenarios are considered, important water management issues have arisen regarding acceptable levels of reliability, reservoir storage priorities, environmental flow needs, water permits for multiple reservoir systems, and accounting of return flows. These key issues are being addressed in new WAM studies and some of them may define the criteria for the refinement of guidelines and regulations that will further improve water resources management.

CHAPTER VII

SYSTEMATIZATION OF WATER ALLOCATION SYSTEMS

Efficient allocation of water is increasingly a central issue for the economic well-being of individual regions and countries. The allocation of water resources is typically accomplished within the framework of water allocation systems (WAS). Robust WAS facilitate the achievement of economic and social goals. On the other hand, inadequate WAS encourage misuse of the resource ultimately leading to inefficiency and loss to individual users who need to compensate for obsolete practices. In general, a WAS sets priorities, applies rules, and organizes responses to a range of water allocation scenarios.

The development of WAS has become a central issue in water resources management, for an effective WAS can help to ensure peace, stability, and prosperity at the local, national, and international levels. The primary objective of a WAS is to codify arrangements to maximize the efficient use of water resources by (1) distributing water equitably among users, (2) protecting existing users from having their supply diminished by new users, (3) establishing rules for sharing limited water resources during drought periods, (4) protecting the long-term reliability of the resource by avoiding over-exploitation (Wurbs 2004), and (5) adapting to changes in the societal values of water by accommodating new users and uses. Accomplishing this, however, is a challenging task for the institutions that mediate access to water.

7.1 THREE-DIMENSIONALITY OF WATER ALLOCATION

WAS are defined by multiple overlapping legal systems and levels of water management policies and practices. The specific rules for allocating water reflect continual adaptations to different water needs and are molded to the hydrologic and socio-economic characteristics of a region. Among nations, water is allocated by means of treaties, decrees, and other agreements. The principles and doctrines that have historically governed such agreements are commonly known as international water law (Chapter II). In the United States (US), water is allocated among states through interstate river compacts and other legal means (Chapter III). Within states, water is distributed among water service and supply organizations or individual users through water rights systems (Chapter IV).

7.2 SYSTEMATIZATION OF WATER ALLOCATION SYSTEMS

While the importance of effective water allocation is well recognized, methodologies are extremely disparate and somewhat obscure. From past experiences it is safe to say that there is a mismatch between normative prescription of water policy, actual practices, and institutional mechanisms. For instance, although most international treaties define general water allocation objectives, usually they neither clarify the allocations among specific users nor set priorities under emergency shortages. Also, when the water allocation mechanisms in interstate compacts are vague, and thus subject to conflicting interpretations, they may lead to lengthy disputes and waste of resources on litigations and Supreme Court appeals. The manner in which water rights systems have evolved in each state has resulted in a lack of uniformity in water allocation rules and policies. This lack of specificity at all levels may preclude selecting effective allocating mechanisms, which in turn may lead to inconsistencies among actions and inefficient performance and incompliance of the system objectives (Frederiksen 1992, Wolf 1997). For these reasons, there is a growing interest in the field of developing, improving and administering WAS.

In this Chapter, a conceptual model for the systematization of WAS is presented. WAS are addressed from a hierarchy of water management levels that include:

(1) International river basins involving water allocation among nations.
(2) Interstate river basin compacts and other interstate allocation arrangements in the US.
(3) Intrastate water allocation based on water rights systems in the US.

Following this hierarchy, the voluminous compilation of treaties, compacts, and scientific and engineering literature are reviewed and researched from the perspective of eight major areas fundamental to any WAS: water rights, determination of water allotment, administrative systems, reservoir storage considerations, system reliability, multiple uses, instream flow requirements, and drought management. A summary of the researched issues and the mechanisms used to address them is presented in Table 7.1. The systematic scrutiny of these areas at all three management levels will define a conceptual framework for assessing water allocation.

Table 7.1. Summary of Mechanisms Used in the Implementation and Administration of Water Allocation Systems

Water Allocation Aspect	Mechanisms and/or Strategies		
	International	**Interstate**	**Intrastate**
Water Rights	Equitable utilization	Interstate water compacts Watershed management agencies	Certainty: Permit systems, Court rulings, Priority Flexibility: Permit duration, Water markets
Determination of Water Allotment	Equitable utilization Avoidance of significant harm	Interstate water compacts Equitable utilization Allocation by fixed amounts Allocation by percentage of stream flow	Reasonable use Beneficial use Permit systems
Administrative Systems	United Nations organizations International river commissions Intergovernmental committees	Interstate water commissions Federal role: Regulatory agencies, laws	State agencies Federal role: Regulatory agencies, laws River authorities Special water districts
Reservoir Storage Considerations	Water accounting Coordination of reservoir operations with established agreements Storage allocation	Water accounting Coordination of reservoir operations with established agreements Storage limits	Water accounting Hedging rules (laws, operational rules)
System Reliability	Storage-yield relationships Reliability indices	Storage-yield relationships Reliability indices	Storage-yield relationships Reliability indices (for permit evaluation)
Multiple Uses	Equitable utilization No-harm rule Cooperation	Pre-established priorities Economic criteria Equity Sustainability Cooperation Court rulings	Beneficial use Preferred uses Equity Sustainability Pre-set priorities Economic criteria

Table 7.1. Continued

Water Allocation Aspect	Mechanisms and/or Strategies		
	International	**Interstate**	**Intrastate**
Instream Flow Requirements	Community of riparian states doctrine Avoidance of significant harm Allocative provisions in treaties Establish seasonal minimum flows Administrative bodies	Interstate water compacts Interstate water commissions Establish seasonal minimum flows Federal laws	Establish seasonal minimum flows Incorporated in Water Rights Systems Water markets Federal laws
Drought Management	Regional mitigation and response planing General treaty allocative provisions during droughts	Regional mitigation and response planning General compact allocative provisions during droughts	Triggers: drought index, storage and streamflow conditions, percent of precipitation Water transfers, water banking, water use/withdrawal restrictions, instream flow protection, conjunctive use.

7.3 WATER RIGHTS

Scope: What are the rules for determining who has the right to use water and in what priority?

The fundamental element of a WAS is the water right. Water rights systems (WRS) give structure to the water allocation process by regulating who has the right to use the water. A robust WRS gives order and security to support economic progress while facilitating the achievement of society's goals for water. A non-comprehensive WRS hinders the effective use of the resource and water is wasted in order to compensate for the inadequacies of the system. Designing sound comprehensive WRS is important because they define the appropriate structure that guides the use of water.

7.3.1 Intrastate Water Rights Systems

The framework of policies and rules that administer water rights is usually developed at the national or state level. Different WRS have different set of rules and mechanisms for defining who has the right to use water. Two important concepts can be used to analyze such differences: certainty and flexibility. Certainty can be defined as the level of security water right holders can have that water will be available to supply their demands. Flexibility refers to the provisions of a WRS that enables it to supply the water needs of water right holders under changing water availability and demand circumstances.

Water is a highly variable resource, thus its availability cannot be completely ensured. Therefore, it can be said that a WRS rather than allocating an amount of water, it allocates the probability of obtaining that amount of water or the risk of not obtaining it. In other words, WRS determine how the risks of shortages are distributed among users.

Tarlock (2000) defines WRS as systems of winners and losers. Well-developed WRS clearly declare who are the winners and losers in times of water shortages. This not only gives security and promotes investment (i.e. certainty), but also provides mechanisms for the reallocation of water during times of severe shortages from winners to losers (flexibility). Tarlock (2000) suggests that property rights are needed for providing enough incentive for future development, reallocation in the face of changing circumstances, and conservation.

Most WRS rely on the permit system for establishing certainty. Once a permit is issued and water right is vested, the user will have some level of certainty that, if water is available, he/she can use water for the pre-approved purposes. Certainty of water usage is probably the most important criteria for water development. When a water right holder decides to develop the resource, in all likelihood, an economic investment is required to put the water to beneficial use. If there is high uncertainty of water availability for a particular water right, investors are more reluctant to develop the resource and the water right holder chances for financing or supporting any water related enterprise are small. The degree of certainty WRS give to their water rights holders vary with the system and doctrine of appropriation since different types of WRS have different ways of defining how risks are to be distributed among users.

Pure riparianism is a system based on common property and is dependent on torts, therefore it does not declare winners and losers in advance but instead provides some mechanism for compensation of losers. In pure riparian states the use of water is attached to the ownership of the riverside land, and as long as an individual owns the land, he/she also has the right to use the water. However, this certainty is limited because a riparian user is always at risk of having his/her water right scrutinized, modified, or even deemed unreasonable in relation to other riparian rights (Chapter IV). Since land property is the main criteria to determine right and there is usually no priority established among water rights holders, if conflict arises, even a new use can affect the terms of an existing riparian right. Also a riparian land owner's right to use water does not expire and can be claimed at any time. Moreover, reasonableness of use is determined by judicial action, thus the outcomes of disputes are very difficult to predict and can take a long time to resolve. In other words, even though riparian rights are inherent to the waterfront property and cannot be lost by non-use, there is uncertainty in the system due to weaknesses in the reasonable use doctrine. On the other hand, it could be argued that riparianism is a flexible doctrine because it allows the system to accommodate preferred uses by dimming them more reasonable and therefore adapting to society's evolving values of water. However, due to the system's dependence on torts this flexibility may be overshadowed by the problems mentioned above, especially during periods of drought where disputes among water users are more likely to occur.

Even though efforts have been made in many eastern states to firm up their WRS the rest of the states that still rely on pure riparianism still do so because they assume a continuous abundant supply of water. Eastern states that have adopted regulated riparianism have moved from this assumption and have developed measures, to different degrees, for establishing a permit system that clearly defines the terms and limitations of water rights under regular circumstances and shortages. Being a system of public rights (or semi-private property rights), it tries to reconcile the protection of private values and the furtherance of public values. Even though in regulated riparianism the right to use the water is judged on whether the use is reasonable, this criterion is applied very differently than in traditional riparianism. In regulated riparianism reasonableness of use is determined based on the general social policy and prior to the issuance of a permit. The requirement of permits provides certainty in the case of investments since once the permit is granted it cannot be curtailed save for cases of water shortage, noncompliance, or termination of the permit's period of validity.

The amount of water the water right holder is to receive is variable. Most regulated riparian states have systems based on proportional water rights. The water is allocated based on percentages or fractions of the available streamflow or storage. Therefore the amount of water received by the user varies from year to year and is affected by any new water right holders in the system. To reduce this uncertainty, when shortages are imminent, some states (e.g. Arkansas) enforce pre-establish priorities for certain uses, usually protecting domestic uses and distributing the shortages among other uses. Most commonly, this prioritization obeys the following order: human consumption, agriculture, and other uses. Other states under regulated riparianism allocate risks equitably among all users by reducing all diversions by the same rate regardless of the type of use.

Since the right to use the water in regulated riparianism is not dependent on riparian land ownership but on the criteria established by a state's overseeing agency, permits can be terminated regardless of continued land ownership. As a result, regulated riparian states have established permit systems where water rights have a prescribed duration period. This gives a high degree of flexibility to the system since it allows to accommodate newcomers and reallocate water to more desirable uses once a permit has expired. However, short duration periods may not allow the users sufficient time to payoff capital equipment or recover from losses during dry years, thus adding uncertainties that may promote economically inefficient decisions. Therefore, the degree of certainty in regulated riparianism is dependent upon the duration of the water permit.

The prior appropriation doctrine is a private property WRS. These systems provide a clear and complete risk allocation scheme in advance of shortages. In times of low supply, water allocations follow a priority schedule based on the dates the appropriations started (Chapter IV). In this case, senior water appropriators have greater certainty of receiving their full water right allotment and lower risks of shortages than junior appropriators. The principle of "absence of damage" states that new appropriations cannot occur unless it is shown that they do not damage existing water rights in any way. Most prior appropriation states rely on permitting systems for recording and monitoring water use. Once a prior appropriation water right is vested it cannot be terminated except in the case of non use. This "non use" rule is intended to prevent "sleeper rights" that may be claimed later and introduce uncertainty into the overall system (Livingston 1995). However, this can be seen as an incentive for the user to use his/her entire entitlement regardless of need in order to avoid loosing the permit. This high degree of certainty offers little flexibility to accommodate different scenarios of water supply and demand.

A special case of water rights allocation can be observed in the case of the Rio Grande where the system was created by court adjudication. The Rio Grande water rights system allocates water and risks based on the type of water use (Chapter VI). Municipal uses receive the greatest protection against shortages by receiving their allotment first. Agricultural uses bear all the risk by having to reduce or curtail their supply first and having their storage rights honored only when there is a water surplus after all other rights and operational needs of the system have been satisfied.

WRS must be flexible and allow water allocations to change in order to adapt to changing physical, economic, and social circumstances. Water reallocation not only occurs within the context of administrative reallocation but also through voluntary reallocation or transferability of water rights. Voluntary reallocation usually occurs within the context of water markets. This transferability of water rights within and between user-groups is to be driven by economic efficiency, where water is transferred from low valued uses to the highest valued use.

As water demands increases and water supplies are more likely to decrease due to pollution and potentially climate change (Miller et al. 1997; Tarlock 2002) water markets are the most likely source of new supplies. However, the question of whether the redistributions commanded by the market are fair and consistent with social and ecological values is not easy to answer. The value society puts on its water resources can not always be expressed in monetary terms and therefore the highest economically valued use is not necessarily the most desirable. Overseeing institutions are crucial for ensuring the protection of non-quantifiable values of water and enforcing binding contracts between individuals. Thus, a mix of market and administrative mechanisms are usually required. The best combinations of such mechanisms vary somewhat depending on local circumstances. In 1992, California established an emergency water bank for the reallocation of water rights as a respond to a five year drought. The water bank allowed market transfers of water rights but with a significant amount of state control. The water bank program was highly successful in transferring water from less (i.e. agriculture) to more economically sensitive sectors (i.e. municipal and industrial) of the state.

7.3.2 Water Rights in Interstate Basins

WRS in interstate rivers can present an administrative challenge, especially between states following the prior appropriation doctrine. These difficulties arise in cases where water users in the downstream state have appropriation dates well ahead of appropriators on upstream states. In this case, since water compacts override state water rights law, those early downstream appropriators might lose water during times of low flows or if their state's water allocation is not large enough. This situation has been avoided by some states by taking a different approach and addressing this issue in the compact. For instance, the Belle Fourche, Yellowstone, and Snake Rivers Compacts all have made clear that compact allocative terms apply only to post-compact diversions and uses and pre-compact rights are preserved as if there were no compacts.

Another approach has been adopted by some eastern states to avoid conflict between water users of a basin on different sides of states' lines. Watershed management and planning agencies with water rights granting capabilities determine who within the interstate watershed has the right to use the water. The criteria used to determine the right to use water is guided primarily by the agency's comprehensive plan for the basin regardless of the state in which the water users reside or where the diversion is being made (Sherk 1994). The best example of this trend is the Delaware River Basin Commission which has quasi-judicial powers that allow it to determine the validity of rights and resolve disputes.

7.3.3 International Water Rights

Usually, determining who has the right to use water at the international level is not a difficult task. International law recognizes that all riparian counties have the right to use the resource regardless of their economical and political power status. Defining the terms and extent of such right is more complicated. International water rights as defined by international water law are an evolving concept modeled after the prior appropriation system and the doctrine of equitable utilization developed in the US (Chapter IV). But unlike the US where the Supreme Court can determine the extent of a state's right to use a common resource, international law lacks such an institution and international water rights are defined by vague concepts that in practice have little meaning. In addition, intranational or intrastate WRS allow the creation of semi-exclusive private rights (i.e. property rights) which is not yet seen in the international setting.

An international water right has no clear definition of control rights. In other words, the extent of an international water right in terms of the right to exclusion (who will have access to the resource and who will not), management (regulation of usage patterns), and alienation (right to sell, lease, etc.) are unknown (Schlager and Ostrom 1992). Therefore, even though water can be seen as a commodity within a country's borders, that same country may not recognize water as such commodity outside its borders.

Countries usually invoke state sovereignty over its water resources making it more difficult to efficiently manage the resource. Recently, a model of "community property" has been advocated in which rivers an associated water resources are to be managed jointly regardless of international borders (Dellapena 1994b). However, this concept has not been adopted in any international agreement nor has been implemented in any international water project besides the formation of committees for riparian cooperation. The weakness of the definition of water rights is probably the major reason of the international water law shortcomings in being a major factor for stabilizing and securing international relations over shared water resources.

The need for stronger definitions for international water rights has been stressed in recent years with political changes such as the dissolution of the Soviet Union. Former Soviet countries in Central Asia have been struggling to reconstruct an economy from severely depleted resources, especially water. The environmental devastation in the Aral Sea and the many social conflicts that have resulted from it has left the counties of the region competing for an ever decreasing resource. In the Middle East, longstanding conflict between Turkey, Iran, and Iraq over the Euphrates-Tigris basin and Palestine and Israel have drawn attention to problems with the international water law doctrines of absolute sovereignty (hydrography) and absolute riverain integrity (chronology)(Chapter II, section 2.1).

In these water-stressed regions these contradicting concepts have caused decades of deadlocks and hostilities. It has been argued that a more efficient approach would be to manage the resources according to needs rather than rights. In other words, it would be easier to reach agreements based on sharing the socio-economic benefits of water rather than address the right to share a particular amount of water. Basis for this, come from the experience of international treaties were "baskets of benefits" have been included as part of treaty provisions. For instance, the 1909 agreement between Canada and US allocates the water based on equality of benefits. The Lesotho Highlands Treaty grants South Africa water for conservation and to Lesotho hydropower from the same reservoir project. A recent example of this management mechanism is the Southern Anatolia Project (GAP from its Turkish acronym) in the Euphrates-Tigris basin. After decades of deadlocks between the riparian countries based on Turkey's claim of absolute sovereignty rights and Syria and Iraq claims of prior use and riverain integrity rights, the countries appear to be cooperating in establishing dialogue and investigation pertinent to the region needs and socio-economic development.

Kibaroglu (2002) argues that using needs rather than rights as the basis for allocation is the new paradigm for international water management. The author states that the doctrine of equitable utilization is the correct mechanism to establish needs-based allocation because it provides flexibility to integrate multiple issues. Currently, the GAP project operates on the basis of an agreement between Turkey and Syria to cooperate on technical trainings, studies' development, technology and data exchange, and conduction of joint projects. The agreement has neither water allocation stipulations nor any specific provisions for the recognition of water rights. Even though this new approach is extremely promising for resolution of future water conflicts and to further improve international water law and management, several important issues must be considered.

First, at the international level, equitable utilization has also displayed the same shortcomings of absolute sovereignty and riverain integrity doctrines, (i.e. vagueness, impracticality and contradiction). Flexibility for reaching comprehensive agreements is found in the US application of the doctrine, where strong and impartial institutions (i.e. US Supreme Court or basin commissions) oversee, mediate, rule, and enforce allocations. International water law has not such an institution and in the case of the Euphrates-Tigris conflict, the countries have been reluctant to create an institution with enough power to make such decisions.

Second, a country's need for water has no relationship with the amount of water available for use. Currently the riparian countries of the Euphrates-Tigris basin have water claims that exceed the Euphrates supply by 50% (Recknagel 2005). A needs-based approach would necessarily require creating some criteria for deciding whose need should have priority and that in itself creates a legal dilemma almost impossible to solve at the current stage of international law.

Third, there is the fact that needs for water change overtime and at different rates in different countries according with the economic development stage of each country. This presents a worrisome scenario in regions with great disparity between riparian states and a history of unwillingness for cooperation and compromise exist. Water rights systems protect countries in time of scarcity against overuse by other more powerful countries. In the case of the Euphrates-Tigris basin, both conditions exist. Turkey is a more economically advance country than Iraq and Syria and is relying of its surface water resources to support its growing economy. Moreover, Turkey has repeatedly show disregard for its neighbor's claims as well as for international intervention by curtailing the flow of the Euphrates. International organizations have intervened by threatening to curtail funds for water development projects in order to resolve these crises. Moreover, when the GAP project is completed by 2010, Turkish irrigation projects will consume 50% of the Euphrates flows giving little margin for considering other needs. More recently, the countries have been opened to dialogue and cooperation and have formed a Joint Technical Committee (JTC) for investigating future agreements on water rights. The countries however, have refused to give any significant power to the JTC or to make any definite commitment for joint integrated management. Meanwhile this massive water management project grows nearer its completion date without an agreement in place and the potential for conflict increases, with every passing day having the potential to be the first of the next drought.

7.4 DETERMINATION OF WATER ALLOTMENT

Scope: What are the hydrological and policy criteria used for assigning diversion and storage quantities to water users?

7.4.1 International Allotment

During international negotiations the determination of a nation's water allotment has been mostly governed by the principles of equitable utilization and avoidance of significant harm. Equitability of utilization is not necessarily interpreted as the division of water into equal portions but as equality of right to use the water for beneficial purposes. The manner in which a nation's "equal right" to use the water is determined has been categorized in the UN Convention on the Law of Non-Navigational Uses of International Watercourses. The Convention identifies a list of as much as seven factors that should be considered as a whole and none is paramount (UN 1997):

(1) Geographic, hydrographic, hydrological, climatic, ecological and other factors of a natural character.
(2) The social and economic needs of the watercourse states concerned.
(3) The population dependent on the watercourse in each watercourse state.
(4) The effects of the use or uses of the watercourses in one watercourse state on other watercourse states.
(5) Existing and potential uses of the watercourse.

(6) Conservation, protection, development and economy of use of the water resources of the watercourse and the costs of measures taken to that effect.
(7) The availability of alternatives, of comparable value, to a particular planned or existing use.

Besides this, no other guidelines are given on how to weight each factor against each other than "the weight to be given to each factor is to be determined by its importance in comparison with that of other relevant factors". Moreover, the lack of specificity in the definition of such factors makes the process highly ambiguous and overall impractical (Elmusa 1998, Utton 1998, McCaffrey 2001). For instance, one of the factors calls for consideration of the physical and natural attributes of the international watercourse but gives no further insight on how to incorporate them into the consideration process. If we are to take drainage area and streamflow contribution as the main physical attributes for determining equitable apportionment: how do we use them for determining a nations share? Is total drainage area more relevant than streamflow contribution? How do these factors compare in importance with other factors such as population dependent on the watercourse or existing uses of the watercourse?

Perhaps not giving any hierarchy to these factors, more than giving flexibility to the process, has made political power the more significant factor in the determination of a nation's water share. However, this is not to say that the factors proposed by the Convention are not relevant or useful to the process of international water allocation. When one considers other alternatives, it would be highly improbable that a nation would agree to consider other more technically specialized approaches such as economic maximization and game theory that are not well anchored in international law. It is mostly the lack of guidance in how to evaluate these factors what makes the process of equitable apportionment somewhat ambiguous and obscure.

Elmusa (1998) has suggested that socioeconomic and environmental factors should have priority over the others since they are the ones that better define "relative justice" and facilitate compromise among riparians. According to the author, the history of political negotiations and conflicts shows that countries based their rights to use watercourses on their socioeconomic and environmental needs. Others have taken a more physically oriented approach for determining equitable utilization. Pherry (2000) evaluates different scenarios for allocating the waters of the Zambezi River between Zambia and Zimbabwe. The author used mean annual flows and each country's flow contribution as criteria to determine equitable allotment assuming two administrative scenarios: allocation among user-groups irrespective of their location and total volume allocation to each sovereign state. Both allocation alternatives are expressed as net annual flows and percentage of mean annual runoff. The author concluded that given the political characteristics of the Zambezi region, using flow contributions to determine water allocation while managing the basin as a whole and assigning allocations according to user-groups would give more water to the countries and therefore is the most equitable and beneficial scenario of allocation.

International water allocation sometimes includes storage allocation especially when international dams are constructed. In these cases, economic considerations are also taken into account into the allocation process. Such was the case in the 1944 Rio Grande Water Treaty between the US and Mexico. Even though the main purpose of the treaty is to divide the flows of the river, it made provisions for the construction of international dams and their management by the International Boundary and Water Commission (IBWC). The IBWC was to determine the details and allocation of storage in accordance with the treaty water provisions and water accounting of their allotted flows. Two international dams were constructed Amistad and Falcon. It was the determined by the IBWC that the conservation storage in the reservoirs was to be divided between the two countries in accordance with their monetary contribution to the construction project: in Amistad, 56% to the US and 44% to Mexico; and in Falcon, 59% to the US and 41% to Mexico.

7.4.2 Interstate Allotments

In the US, interstate water compacts allocation provisions usually do not discuss the rationale for proportioning the flows between states. However, in the case of the 1947 Pecos River Compact, it is known that the adopted allocative methodology was intended to provide Texas with an amount of water equivalent to what was reaching the state line under the 1947 natural conditions. Also, the 1929 Rio Grande River Compact allocation was intended to preserve the allocation of the river as of 1929 by developing a series of curves relating inflows and outflows to Elephant Butte Reservoir. This suggests that the allocative criterion used in these compacts was to protect the pre-compact level of beneficial use (i.e. existing uses) established in the corresponding states. Due to the lack of detail given on the compacts' text, other criteria such as runoff contribution are more difficult to identify. However, equitability is always the main purpose or objective of the allocation.

The majority of compacts specify that water originating in a specific state belongs to that state, and only waters from shared sections of the steam are divided. A smaller number of compacts divide the water regardless of where the water originated (e.g. Sabine River Compact). Whatever the underlying principles for determining an equitable allotment have been, allocations are usually defined as fixed amounts or as percentages of the stream flow. The flow amounts specified can be annual (e.g. South Platte River Compact), monthly (e.g. Big Blue River Compact) or daily (e.g. La Plata River Compact). The total water availability is determined from flow measurements at specific gauge stations or estimated flows from site-specific hydrologic models.

Storage allocations in compacts are much simpler. They are basically limitations on the amount of water that can be stored by upstream states. In parts of the country where the regime of inflows are in mismatch with the regime of water use or where there are great variability of flows, upstream states require storage to be able to use their fair share of the resource while downstream states require some assurance that some flows will reach the state line. The storage limits can be expressed as fixed storage quantities or storage elevation levels or they can be a series of storage amounts that vary depending on the season or stream flow conditions. In these types of compacts the downstream state will receive only what is left of inflows after the upstream state has had its allotment, therefore assuming most of the risk of water shortages.

The major advantage of storage allocation compacts is that they are relatively easy to implement, monitor and enforce since the level of water in storage at a dam is openly visible. Most problems arise from the drafting of the compact, especially regarding if the compacts limits or not the construction of new dams (McCormick 1994). For instance, the Canadian River Compact was the center of litigation from 1987 to 1994 between Oklahoma, Texas and New Mexico due to differences in interpretation of compact language. Finally the Supreme Court decided in favor of Oklahoma and Texas interpretation of the compact stipulations. Recently, Oklahoma has expressed its resolution to sue Texas for breaching the

Canadian River Compact by constructing the Palo Duro Reservoir and increasing Texas' storage capacity, an interpretation the state of Texas disagrees with. Since the Canadian River Compact Commission does not have any effective mechanism for conflict resolution and/or enforcement, this conflict will most likely end in the Supreme Court.

7.4.3 Intrastate Water Allotment

The criteria for determining the allotment size of individual users within a state varies according with the state's allocation philosophy. In states following pure riparianism, a riparian user is entitled to take as much water as he/she need as long as it does not negatively impact other riparian's water uses. If conflicts arise, a court suit must follow to determine the riparians fair share of water as well as any possible compensation for damages caused. The specific criteria a state court uses to determine if a particular riparian user has used more than his/her fair share of water vary from state to state but it is always based on the concepts of reasonable use and equitability (Chapter IV). However, several generalizations can be made regarding the courts' criteria for determining equitable apportionments. Some of the criteria used are: priority of appropriation, physical and climatic conditions, consumptive usage, rate of return flows, extent of established uses, availability of storage, and damage to upstream areas as compared to benefits downstream.

Regulated riparianism has built on these rules and added other of its own in its permitting structure. The influence of the "natural flow" theory (Chapter IV) is still evident in more regulated eastern states where instream flow uses have historically been considered more important than in western states. For that reason, a minimum flow is usually established and given priority over most uses. From the remainder flow individual water rights diversions are assigned. There are different methodologies for determining the water allotment size of individual rights. In general, the permit size is related to the size or value of the land, especially if it is riparian land. The amount allocated is usually in proportion to the landholding, the length of riparian streamfront or the operational size of the user operation (Chapter IV). Some states use a more *ad hoc* approach where proposed water rights are evaluated and its size determined based on the use compatibility with the state's development interest, water use policy, historical water consumption, and/or other concerns such as economic value of the use.

In the prior appropriation system the amount of water allocated to an individual use is directly related to the concept of beneficial use. In the early days of the system the amount a user was entitled to was whatever amount of unappropriated water he/she can put to optimal beneficial use (i.e. consumptive uses). As water has become scarcer and western water administration more structured and regulated, states have become more stringent in determining the size of a water permit.

Additional criteria factored into the process vary from state to state. Several additional factors are: harm to current appropriators, regional economic interests, preferred water uses, water conservation technology, the public trust, and environmental concerns among others. For instance, since 1985 the state of Texas requires the Texas Commission on Environmental Quality (TCEQ), formerly known as the Texas Natural Resource Conservation Commission, to consider potential environmental damages to aquatic and terrestrial habitats before conceding new water right permits. Nonetheless, the most important factor is water availability. Many states have declared certain river basins to be fully or even over appropriated and have prohibited the concession of additional water rights. Therefore, only unappropriated water is available for appropriation.

Four considerations arise when determining if there is water available for appropriation: (1) the geographical source of the water relative to the proposed diversion, (2) the existence of prior claims (e.g. other water rights, federal rights, international or interstate commitments, Indian rights, etc), (3) exclusivity of the water body (e.g. preservation), and (4) the potential for re-appropriation of water (e.g. return flows, irrigation seepage, runoff from excess application etc.) (Beck et al. 2001b). In many states it is not unusual for new potential water users to be required to prove that there is still water available for appropriation at the desired water body. If it is established that there is enough water available, then intent of using the water for beneficial use must be proved (Chapter IV) and water is allocated accordingly with the user's need. It is important to note that no water is allocated to compensate for losses due to inefficient water conveyance and/or inadequate technology.

7.5 ADMINISTRATIVE SYSTEMS

Scope: What are the roles and jurisdiction of the multiple administrative institutions that mediate access to water?

Effective governance is a requisite to achieve successful management of water resources. Water systems are equally impacted by the availability of water as it is by the institutional framework that mediates access to water. It is therefore important to examine the institutional mechanisms used to facilitate effective development and management of the resource.

7.5.1 International Transboundary Administration

There is no one overseeing international water entity with real administrative powers. Instead, several international councils, commissions, and organizations perform different aspects of regional or watershed-level water management. The institutions listed in Table 7.2 are examples of the various kinds of administrative entities created for managing international waters. The functions and powers of these institutions vary. In general, the institutions may have legal, operational, and/or regulatory functions (Frederiksen 1992). Legal functions typically include resolutions of law, authorization of funds, and policy making. Operational functions consist mostly of project planning, design, construction, and maintenance, data collection and sharing, and professional assistance. Regulatory functions include resource apportionment, determination of harm, dispute settlement, and assessment of compliance with established laws, regulations, and agreements.

International administrative entities can be divided into two main categories: (1) those that deal with international waters in general and (2) those that were created for overseeing a specific transboundary water system. International organizations sponsored by the UN, international law committees, and the International Court of Justice (ICJ) (Table 7.2) are examples of the first category. These entities typically serve as advisors in coordinating efforts for water development, policy improvement, and maintaining and promoting cooperation and good will among co-riparian countries. Perhaps the major contribution of these entities has been made in the fields of policy-making and conflict resolution. For instance, the most influential documents on international water law, namely the *Helsinski Rules* and the UN Convention on the Law of the Non-Navigational Uses of International

Table 7.2. International Administrative Entities

Administrative Entity	**Examples**	**Primary Function**	**Water Resources Responsibilities**
International Law Committees	International Law Association International Law Commission	Legal	Advisory functions for the development of international policies
Courts of Justice	International Court of Justice	Legal	Advisory opinions on specific conflicts. Settlement of legal disputes. No enforcement capabilities.
International Organizations	World Bank UN Environment Programme UN Development Programme	Operational	Financing, mediation, professional assistance.
International Commissions	International Boundary and Waters Commission (US and Mexico)	Operational and Regulatory	Treaty enforcement. Water accounting. Research and planning. Construct, operate, and maintain water works. Dispute settlement.
	Mekong River Commission (Thailand, Laos, Cambodia, and Vietnam)		Create policy. Development and enforcement of water plans. Dispute settlement. Monitoring and information sharing.
	International Joint Commission (US and Canada)		Evaluate new water diversions and projects. Dispute settlement. Agreement enforcement. Monitoring and information sharing.

Table 7.2. Continued

Administrative Entity	**Examples**	**Primary Function**	**Water Resources Responsibilities**
Intergovernmental Committees	Nile Basin Initiative (Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda)	Operational	Policy direction for cooperation. Resource planning and management.
	Intergovernmental Coordinating Committee of the La Plate River Basin Countries (Argentina, Bolivia, Brazil, Paraguay, and Uruguay)	Operational	Promotion of mutual projects. Infrastructure improvement. Conservation efforts. Resource management.

Watercourses, were drafted by the International Law Association and the International Law Commission, respectively. UN international organizations have played a crucial role in the resolution of conflicts and subsequent development of management efforts in some international river basins. For example, the World Bank intervention in the India and Pakistan dispute over the Indus River was probably the most critical factor in the formulation of the Indus Waters Agreement. Similarly, the intervention of the UN Environmental Programme in the Zambezi River and UN Development Programme in the Mekong River as mediators and financial partners was the catalyst for the formation of international agreements. However, the role of these organizations is limited since these success stories can be attributed more to the interest and effort of individuals, than the actual role and jurisdiction of the international organizations themselves (Nakayama 1997, Biswas 1999).

Perhaps the only international organ with any kind of leverage for resolving disputes over international waters is the ICJ. The general functions of the ICJ are to settle, in accordance with international law, the legal disputes submitted to it by states, and to give advisory opinions on legal questions referred by duly authorized international organs and agencies. However, cases in the ICJ are entered into voluntarily and only recognized nations can bring their cases to the Court consideration. Furthermore, like all other international entities aforementioned, the ICJ has no practical mechanism to enforce its decisions.

International River Commissions and intergovernmental committees exemplify the second category of international administrative entities. These entities are usually created by treaties for managing and enforcing water allocation as defined in international agreements for specific transboundary river basins.

Three of the most comprehensive river commissions are the IBWC, the International Joint Commission (IJC), and the Mekong River Commission (MRC). The IBWC was created pursuant to the 1944 Treaty that allocates the Colorado, Tijuana, and Rio Grande rivers between US and Mexico. The main role of the IBWC is the joint operation of the Amistad and Falcon international reservoirs and to regulate streamflows in accordance with the 1944 Treaty rules. Water accounting is an integral part of the system's operation. The IBWC keeps records of reservoir inflows, releases, evaporation, and storage, and assigns them to each country. The IBWC schedules releases requested by each country and deducts them from their total water allocation. This procedure allows the IBCW to compute the amount of water that each country has in storage at any time and provides the basis for evaluating if the countries are in or out of compliance with the established agreements. Other IBWC functions include planning and regulation of water quality and sanitation activities, flood control, and resolution of conflicts. Even though the IBWC is probably the most efficient international administrative institution in terms of reservoir management, it is not a model of comprehensive basin-wide management. As with many other international institutions, the IBWC was created for the management of joint water infrastructure. Therefore it lacks adaptation mechanisms as it is bounded by the provisions established in the treaty and does not have the power to implement alternative basin-wide management strategies.

The IJC administers the 1909 Boundary Waters Treaty between US and Canada. The jurisdiction of the IJC is limited to the boundary waters, mostly the sections of the Niagara and Mary-Milk rivers and the Great Lakes. Each country retaining exclusive control over the tributaries to boundary waters within its territories. However, the IJC has stronger judicial and investigative powers than the IBWC, especially for conflict resolution. The IJC has judicial power to approve projects affecting boundary waters, water flowing from boundary waters, and transboundary waters below the boundary (Utton 1991b). The countries are required to obtain approval from the IJC before taking any action that may affect the flow or level of boundary waters. The IJC makes decisions based on a set of priority preferences according to use type as established in Article VIII of the treaty:

(1) Uses for domestic and sanitary purposes
(2) Uses for navigation
(3) Uses for power and irrigation purposes

The IJC decisions are binding and are made based on majority of votes, each country having three votes. The secret of the IJC success lies in the fact that the treaty established that in the case of a deadlock, the dispute is to be referred to an umpire appointed by the parties. The umpire's conclusion will render the IJC decision, which is adjudicatory in nature. The IJC investigative powers are also extensive. Either country may request an investigation on potential issues that may cause conflict. The IJC has developed a reputation of impartiality, objectivity, and efficiency that has been a key factor in preserving the tradition of goodwill and cooperation that exist between the two countries. Nonetheless, the lack of basin-wide management capabilities has been problematic. This has made very difficult for the IJC to successfully perform some of its responsibilities such as environmental protection, especially in the Great Lakes (Utton 1991b).

The MRC was created through the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin of 1995. In contrast to the IBWC, the MRC was created for "the integrated management" of the Mekong River basin, which aimed at optimized utilization of the water resources in the basin by dealing with it as a unit, regardless of the borders among riparian countries (Nakayama 1997). The principal functions of the MRC are represented in its four core programs: Basin Development Plan, Water Utilisation Programme, Environment Programme, and the Flood Management and Mitigation Programme. This agreement, however, does not specifies water allocations. Instead, it vested power to the MRC to formulate water utilization rules. As of 2005, an accord has not been reached on the actual water allocation mechanisms. However, the MRC is a relatively young institution and major advances have been made in other areas such as data collection and sharing, professional training, research cooperation, and conservation planning.

Intergovernmental Committees are also entities created for overseeing specific transboundary water systems but their functions are mostly directed toward improving cooperation and dialogue among co-riparian countries. Burchi and Speij (2003) provide further information regarding commissions and committees for the administration of bi- and multinational river basins.

7.5.1 Interstate Transboundary Administration

The water resources responsibilities of administrative entities at the interstate level are summarized in Table 7.3. About two thirds of all interstate water allocation compacts create commissions to administer the compact. There is a difference in power and structure among commissions created by interstate compacts and those created by federal-interstate compacts. In the case of the former, the functions of interstate water commissions (IWCs) are usually more limited. Generally, the purpose of IWCs is to accumulate information, facilitate communication, and negotiate during changing circumstances (Copas 1997).

In Texas, there are five IWCs that administer the Pecos, Red, Sabine, Canadian, and Rio Grande basins compacts (Chapter VI). In this region, accusations of non-compliance arise regularly, many of them resulting in lengthy and costly Supreme Court litigations (e.g. Pecos, Canadian, and Rio Grande). Only the Rio Grande Compact Commission (RGCC) has water accounting capabilities as specified in the compact. In 1987, the Pecos River Compact Commission added a River Master office for water accounting as a result of a Supreme Court resolution after 30 years of disputes between Texas and New Mexico. On the other hand, federal-interstate compacts (e.g. Delaware and Susquehanna River Basin Compacts) have established commissions with extensive planning, regulatory, and enforcement powers. The Delaware River Basin Commission (DRBC) has the authority to approve or reject any project that may have a substantial effect on the water resources of the basin. Approval decisions are guided by the comprehensive plan for the basin developed by the DRBC itself. The Susquehanna River Basin Commission has powers and duties similar to the DRBC but they are also in charge of water quality permits and floodplain management

Table 7.3. Interstate Administrative Entities

Administrative Entity	Water Resources Responsibilities
Interstate and Federal-Interstate Compact Commissions	Administer water compacts specifications. Manage and operate interstate rivers and reservoirs at different degrees.
*US Army Corps of Engineers	Construction, operation and maintenance of water infrastructure. Some resource management and regulatory functions.
*US Bureau of Reclamation	Monitoring an development of irrigation projects in the West. Construction, operation and maintenance of water infrastructure.
*Environmental Protection Agency	Administers and enforces the Clean Water Act and other federal environmental protection programs.
*US Fish and Wildlife Service	Administers and enforced the Endangered Species Act. Declares critical habitat areas for species protection.
*US Geological Survey	Monitoring and collection of data. Preparation of technical reports. Financing of water resources research. Mediation in some interstate water compact commissions.

* Federal Agency

regulations. Water commissions also function as forums for resolving disputes. The most common mechanisms for conflict resolution are voting and arbitration (McCormick 1994).

Voting can occur among commission members in order to use a majority criterion to reach a decision. Several commissions have non-voting federal representatives (e.g. US Geological Survey) and some allow these members to vote when a tie needs to be broken (e.g. Yellowstone and Snake River Compact Commissions). In reality, only the DRBC has enough power to make and enforce independent decisions. This commission has the authority to allocate the waters of the basin among the signatory states in accordance with the Supreme Court's doctrine of equitable apportionment and impose penal sanctions to compact violators (Muys 2003, Copas 1997).

The federal role in the administration of interstate water resources is also important. During the first part of the 20th century, the federal construction agencies and congressional public works committees fostered countless water projects around the nation and guaranteed federal involvement in the development and management of water. Currently, the US Bureau of Reclamation and the US Corps of Engineers operate and manage several reservoir and water infrastructure projects in many interstate basins. Nonetheless, federal funding of water projects has been greatly reduced and a new pattern of greater cost sharing by project beneficiaries has emerged (Cortner and Auburg 1988).

Federal regulation, on the other hand, has become increasingly influential on the set of institutions that mediate access to water. This federal influence is shaped by the federal jurisdiction over navigable waters, federal laws (e.g. Clean Water Act, Safe Drinking Act, Endangered Species Act, National Environmental Policy Act, etc.), and Supreme Court cases. Federal agencies such as the Environmental Protection Agency and the US Fish and Wildlife Service can set restrictions on water use and establish management efforts to ensure compliance with federal regulations. In addition, the federal government has reserved water rights for Native American lands. When the federal government established Native American reservations, it implicitly reserved sufficient water to serve the purpose of the reservation. Even though these reserved rights have not been exercised, they have the potential for future conflict, especially in times of water shortage (Miller et al. 1997; Tarlock et al. 2002).

Other federal reserved water rights are created when the federal government withdraws land from the public domain (e.g. for parks, military bases, etc.). These rights could represent large amounts of water considering that about half of the western states lands are under federal ownership. For instance, the federal government owns 80% of the lands in the state of Nevada and 72% of the Colorado River basin (Kenney 2003). Even though most compacts include this recognition of federal water rights, most of them do not include the federal government as a signatory party. For this reason federal-interstate compacts such as the Delaware River Basin Compact of 1961, by including the federal government as a signatory party and as member of the DRBC, had made provisions for linking federal and state planning and imposing significant constraints on both the state and federal government. Based on the experience in the Delaware River Basin, the National Water Commission (1973) recommended the federal-interstate compact approach as the preferred institutional strategy for water resources planning and management in multi-state water sharing regions.

7.5.3 Intrastate Water Administration

Water resources administration at the intrastate level is carried out by a myriad of federal, state and local agencies (Table 7.4). These administrative bodies interact to make up multi-level water allocation frameworks. The purpose of these administrative systems is to provide a methodology for allocating water and to regulate water rights. These are usually state agencies or water control boards with mixed executive and judicial powers to adjudicate water rights. Some states have very comprehensive agencies administering the management of all natural resources while others have a particular agency devoted exclusively to water management. The level of authority vested by the state in its water administering agency also varies. Some agencies have broad powers that allows for comprehensive authority while others are more limited, being authorized only to issue water permits. In Texas, the Texas Commission on Environmental Quality and the Texas Water Development Board have statewide jurisdiction for the implementation of water laws and administration of the water rights system (Chapter VI).

Two states have taken a different approach for their water management institutions. Instead of having an agency for dealing with the details of water allocation, Colorado relies on the judicial system charged with administrative powers (Gloperud 1991a; Getches 1997). Colorado's Water Court system is composed of water divisions that correspond to seven major basins, each been overseen by a water judge, a water engineer, a water referee, and a water clerk. Water judges are district judges appointed by the state's Supreme Court and have jurisdiction in the determination of water rights, the use and administration of water, and all other water matters within their jurisdictions (Hobbs 2004). In Florida, regulatory authority is divided between five regional water management districts (WMDs) corresponding to major river basins. Some of the functions of the WMDs include: establishing minimum inflows, declaring water shortages emergencies, evaluating new permits

Table 7.4. Intrastate Administrative Entities

Administrative Entity	Water Resources Responsibilities
State Water Agencies	Administration of federal water programs. Different levels of authority for resource management, regulation, issuance of permits, and resolution of conflict among water users.
Municipal and county water authorities or districts	Planning, construction, maintenance and operation of local water projects.
*US Army Corps of Engineers	Construction, operation and maintenance of reservoirs
*US Bureau of Reclamation	Construction, operation and maintenance of reservoirs

* Federal Agency

for consumptive uses, comprehensive planning, and constructing and operating water development works.

The implementation of state and federal water resources legislation at the local level is typically accomplished through river authorities and municipal and/or county water districts. In Texas, there are 19 river authorities in charge of the development and management of major river basins (Wurbs 2004). A variety of specialized districts have been established for the planning, construction, and maintenance of local projects. The legislature authorizes each district by special legislation that specifically defines the powers, duties, and limitations upon the district. Some special districts found in Texas include: water control and improvement, groundwater conservation, irrigation, fresh water supply, drainage, and municipal utility districts (Caroom 1997).

As previously discussed, the institutional arrangement for intrastate water administration in the US cascades from bureaucratic management to self-governing local institutions. This branching framework results in a de-centralized management structure. Although federal and state involvement is necessary to accomplish large-scale water management objectives, self-governing institutions at the local level allow for a greater degree of adaptability to local conditions and needs, provide for faster response to changing circumstances, and facilitate cooperation among participants (Tang 1992). On the other hand, this approach increases the complexity of water management and could result in duplicity of efforts that may translate into higher operational costs and other system inefficiencies. In 1997, Senate Bill 1 (SB1) provided for this approach to water supply planning in Texas. In the past, the TWDB had been responsible for determining what strategies and projects each region or city should implement to meet future water supply needs. SB1 changed that to a "bottom up" planning process that calls for local representatives from all interest groups, called Regional Water Planning Groups (RWPG), to develop strategies to meet water supply needs over a 50 year time period. The TWDB oversees the planning process and provides administrative and technical support to the RWPG (Chapter VI).

Four key aspects in the administration of water resources were identified from the evaluation of administrative water agencies at all management levels. Administrative agencies must have the power and capability to conduct and lead efforts in the areas of: (1) data collection, (2) planning, (3) resource management and regulation, and (4) conflict resolution. Data collection involves conducting and supporting water resources monitoring and research (e.g. streamflow, water use patterns, system performance, etc.). The agency must also be a conduit for information sharing and dialogue. Long-term planning of water development projects and policy formulation are crucial elements for ensuring the effectiveness of the system in meeting future needs, especially under water scarcity conditions. An important aspect of this process is the evaluation of potential scenarios of water demand and availability. Adopting watershed scale management strategies, in which watershed boundaries rather than political boundaries are the basic unit of analysis, may be beneficial as they provide a more hydrologically correct view of the water resources of a region. The agencies also need the authority to manage and operate water resources systems (i.e. reservoirs, channels, diversions, etc.) and regulate water allocations. The extent of this authority should be in accordance with their position within the hierarchy of management levels. Water accounting methodologies are a critical aspect of resource management as it provides a mechanism for assessing compliance of agreements and the enforcement of regulations. Finally, these agencies must provide the necessary framework and mechanisms for conflict resolution (e.g. voting, arbitration, mediation, etc.) and define courses of action in the case of non-compliance (e.g. water debt repayment, monetary compensation, storage provisions, etc).

7.6 RESERVOIR STORAGE CONSIDERATIONS

Scope: How reservoir storage considerations can be incorporated into WAS to support its administration and for meeting present and future demands?

Streamflows and water demands are typically characterized by great temporal variability. Thus, reservoir storage is necessary to regulate streamflow fluctuations and provide a more dependable water supply. In general, for reservoir operation purposes the storage capacity of a reservoir is subdivided into the following pools: inactive, conservation, flood control, and surcharge. The water stored in the conservation pool is the only portion of the storage available for allocation, thus in the context of this discussion the term "reservoir storage" refers specifically to the conservation pool.

Reservoirs provide an added measure of security by storing water during wet periods and making it available during periods of seasonal low streamflows, high demands, or long-term droughts. Reservoir storage is commonly shared by many users for a variety of purposes. Municipal demands are highly dependent upon storage to ensure the consistent supply of water necessary for basic human needs. Other uses like agricultural irrigation do not usually require a continuous supply of water, but they need the security of having enough water to meet the demands for growing crops during particular seasons. Releases from storage can also be used to meet instream flow needs during periods when streamflows are significantly diminished. Consequently, incorporating reservoir storage considerations in a WAS is essential for the efficient use and conservation of water resources. This section presents some key issues regarding reservoir storage within the context of international, interstate, and intrastate WAS.

7.6.1 Water Accounting

The primary objective of international treaties and interstate compacts is to establish policies and mechanisms for the proper allocation of water resources between nations and states (Chapters II and III). These legal agreements are used to determine how much water a nation or state is entitled to from the total amount of water available in a specified timeframe. In addition, they serve as binding documents that protect the parties involved from being deprived of their fare share of the water.

Once water has been allocated, the management and enforcement of the treaties or compacts relies on proper water accounting procedures that allow to evaluate if the parties are in compliance with the established agreements and to provide a better basis for evaluating and solving conflicts. Incorporating reservoir storage in the water accounting procedure allows to obtain a more accurate estimate of the water used by each party and the remaining portion of their allocated supply that may be carried over in storage if the agreement allows to do so. Moreover, coordination between actual reservoir operations and the administration of the treaties or compacts is recommended in order to manage the reservoir storage in a manner that reflects the established agreements and meet demands more efficiently.

The 1944 Rio Grande Treaty between the US and Mexico is used here to illustrate how reservoir storage provisions may be used to facilitate delivery of the allocated waters and to verify compliance with the international treaty agreements. The treaty allocates the water that reaches the Rio Grande between the US and Mexico based on a series of allocation rules outlined on Article 4 of the treaty. In general, the rules allot all or a portion of the water reaching the main stream to each country based on the geographical origin of the flows (i.e. Rio Grande tributary sub-basins). The treaty also authorized construction of two international dams, Amistad and Falcon, to serve as storage facilities that would regulate flows from the upper Rio Grande basin. These reservoirs are located in series and are operated as a system by the IBWC to meet the provisions of the agreement.

The IBWC is responsible for the water accounting procedures of the river/reservoir system. For such purposes, the IBWC keeps records of reservoir inflows and releases, and evaporation and storage volumes allocated to each country. Reservoir inflows are credited to each country following the Article 4 allocation rules. If a country has a full conservation pool, the treaty contains a stipulation that allows transferring the excess flows to the other country if such country has unused conservation storage capacity. Releases from storage may be requested at any time and they are subtracted from the water available in the conservation storage of the country requesting them. The rationale for the allotment of conservation storage to each country was explained in section 7.2.1. The estimated volume of water lost due to evaporation is proportionally allocated to each country's share of the reservoir storage.

This procedure allows the IBCW to compute the amount of water that each country has in storage at any time and provides the basis for evaluating if the countries are in or out of compliance with the established agreements. For example, the treaty requires Mexico to make available an annual average of 350,000 acre-ft of water from six Mexican tributaries to the US over five year cycles. The treaty also indicates that in the event of extraordinary drought water debts shall be made up in the next five year cycle. In 1992, Mexico began a 10-year cycle of failing to meet this requirement claiming to be in an extraordinary drought condition (Combs 2004). Failure to comply with this aspect of the treaty resulted in intense political tension between the nations. The IBWC's water accounting procedures allowed to keep a record of the water owed by Mexico, which amounted to a high of 1.5 million acre-ft in 2002. As of October 1, 2004, Mexico's deficit stood at 716,670 acre-ft. The present status of this issue is that Mexico has delivered the required amount of water in the first two full years of the current cycle and an understanding between the two nations was reached in 2005 for Mexico to pay its entire water debt by September 2005 (IBWC 2005). A weekly water accounting data sheet of Mexico's water deliveries to pay off the deficit is available at the IBCW website (http://www.ibwc.state.gov/html/mexico_deliveries.html).

Some interstate compacts in the US also have explicit reservoir storage considerations in their water allocation rules. The Canadian River compact between New Mexico, Texas, and Oklahoma, besides dividing the waters of the basin it sets maximum amounts of conservation storage allowed to each state in the reservoirs of the system. For instance, New Mexico is allowed free and unrestricted use of the runoff generated below Conchas Dam, however it cannot store more than 200,000 acre-ft in the reservoirs below said dam. The right of Texas to store water is limited to 500,000 acre-ft, until Oklahoma has been provided with 300,000 acre-ft of conservation storage. These values exclude storage on reservoirs in the North Canadian River for Texas and Oklahoma, and east of the 97th Meridian for Oklahoma. Once Oklahoma has received 300,000 acre-ft, the limit for Texas switches to 200,000 acre-ft plus whatever amount of water Oklahoma has in conservation storage during the same time period. In other words, the amount of water that Texas can store in excess of

500,000 acre-ft is the same amount of water that Oklahoma is storing over 300,000 acre-ft. Although the compact does not specify a rationale for establishing these limits, this type of practice helps prevent an unbalanced use of the available water in the system. The Canadian River Compact Commission (CRCC) administers this compact and performs an annual accounting of water stored in each state to determine compact compliance. For example, to verify if New Mexico is in compliance with Texas the actual amount of storage in Texas reservoirs is divided by 350,000 acre-ft and its converted to a percentage. The 350,000 acre-ft value represents the amount of water that Texas normally has in storage during an average runoff year and with New Mexico complying with the compact (CRCC 2004).

7.6.2 Hedging Methods

Another critical aspect of managing conservation storage is the determination of how much water should be used for meeting present needs and the amount to be carried over in storage to meet future demands. This aspect can be better evaluated within the context of intrastate WAS. Once water has been allocated to a state, it must be distributed between individual users to meet demands. The tradeoffs between how much water to withhold from immediate use and retaining that water in storage for future use is known as hedging.

Hedging rules allow for some water to be stored even if there is enough water to satisfy present demands in order to provide insurance for high-valued uses when there is a low potential for refill or high uncertainty of inflows (Draper and Lund 2004). The rationale is that having small shortages more frequently is preferable than coping with the risks and costs or larger shortages (Loucks et al. 1981). The most common methods to incorporate hedging into a WAS are based on: (1) legal considerations (laws) and (2) operational rules.

The allocation of the US share (Texas share) of the Lower Rio Grande waters follows the rules established in the Texas Administrative Code. Title 30 – Chapter 303 of this state legislation specifies procedures for allocating the Texas share of water stored in Amistad and Falcon Reservoirs. These procedures are carried out by the TCEQ Watermaster. The allocation procedure performed each month by the Watermaster is outlined in Chapter VI, section 6.2.1, and summarized here as follows:

(1) From the total amount of usable storage, reserve 225,000 acre-ft for domestic, municipal, and industrial uses. This reserve is referred to as the "municipal pool".
(2) From the remaining storage, deduct the total-end-of-month account balances for all Lower and Middle Rio Grande irrigation and mining allottees.
(3) From the remaining storage, deduct 75,000 acre-ft for an operating reserve.
(4) The balance is allocated to irrigation and mining allottees.

This procedure places the highest priority to maintaining the municipal reserve full. This reflects the importance of meeting current and future municipal demands since even if agricultural or mining shortages are occurring in the present month and there is plenty of water available in the municipal pool, this water cannot be used to meet those current needs but rather it is reserved for future municipal uses. In other words, storing enough water to meet current and potential future municipal needs is favored at the expense of having shortages for other uses that may have been avoided by using water from the municipal pool. The Water Code also has provisions for storing water for future irrigation uses. If there is excess water after the aforementioned allocation steps are completed, irrigation rights may store water for future use (if the water right permit allows it), but storage cannot exceed more than 1.41 times its authorized diversion right (Chapter VI).

The second approach for incorporating hedging into a WAS is by means of operational rules. Operational rules are guidelines for determining the quantities of water to be stored or released from a reservoir under various conditions. Operational rules are commonly expressed as rule curves which specify reservoir releases as a function of storage content and time of year. Rule curves provide greater flexibility in managing storage and releases since, in contrast to treaties and compacts, it is fairly easy to modify them over time based on experience and changing conditions.

For water supply systems, the standard operating policy (SOP) is to supply current demands and store water only after demands have been met. Hedging operating policies modify the SOP by setting storage levels that serve as triggering mechanisms to start and resume water rationing. The storage levels may be defined based on multiple runs of simulation models in which various storage levels can be tested to see whether or not they are sufficient to meet forecasted demands considering the expected inflows. Water rationing can be applied to specific water demands or all demands may be curtailed by certain percentage. Bayazit and Ünal (1990) tested different combinations of storage triggers for a water supply reservoir and concluded that the performance of reservoirs under hedging operational policies are more stable and the potential for large shortages are significantly reduced compared to those following the SOP. The US Bureau of Reclamation incorporates hedging into the operation of California's Central Valley Project (CVP) reservoirs in order to retain sufficient carryover storage to reduce the risks of large shortages (USBR 2000). Carryover storage in CVP reservoirs is used to provide reasonable assurance that minimum storage, instream flows, diversions, and hydroelectric demands are able to be sustained. Additional considerations for fish restoration and wildlife habitat are required by the CVP Improvement Act of 1992.

Basic hedging rules are more suitable for single purpose reservoir systems. However, when dealing with multi-purpose reservoir systems, which involve more complex operations, these basic rules may become too simplistic. Therefore, an optimization procedure that can consider the system objectives and constraints may be required. Mathematical programming techniques have been used in the academic field to address this problem (Oliveira and Loucks 1997; Draper and Lund 2004), yet its implementation in real-world applications has been limited (Duranyildiz et al. 2000).

7.7 SYSTEM RELIABILITY

Scope: How can reliability considerations be incorporated into WAS to provide a better basis for decision-making?

7.7.1 Reliability Theory

River/reservoir systems are characterized by great variability of streamflows, climatic patterns, reservoir evaporation rates, and other pertinent factors. Because of these uncertainties regarding the future hydrologic character of the system, water supply capabilities must be viewed from a reliability, probability, or percent-of-time perspective (Wurbs 1996). Reliability (R) is a measure of dependability and can be used to assess the capabilities of a river/reservoir system to satisfy specified water use requirements. Reservoir reliability is an indication of the probability of meeting a given demand. Alternatively, reservoir reliability can be expressed as the percent of the time that a given demand can be met. Also, reliability may be interpreted as the complement ($R = 1 - F$) of the risk of failure (F), which expresses the probability or the percent of the time that the demand will not be met. Incorporating reliability considerations into a WAS may be therefore beneficial as it can provide an improved basis for decision making.

Reliability indices, such as period reliability and volume reliability, provide a mechanism for evaluating and comparing alternative reservoir storage allocations and operating plans in terms of their capabilities for meeting system demands (Wurbs 1996). Reliability indices can be computed from the results of a water supply simulation study based on either the historical record flow series or on multiple synthetically generated flow sequences which preserve selected statistical characteristics of the historical data.

Period reliability (R_p) represents the percentage of time periods in which demand targets were met. R_p is calculated as:

$$R_p = (n/N)\ 100\% \qquad \text{(Eq. 7.1)}$$

where n is the number of time periods that the system was able to meet the target demands, and N is the total number of time periods in the simulation. R_p can also be interpreted as the probability of a specified demand target being met in any randomly selected time period. The risk of failure F_p, which is the compliment of R_p, reflects the frequency of shortages in the simulation. A period during which all or a specified percentage of the demand was not met is considered a shortage or failure. Alternatively, a failure state may be defined as any period in which the reservoir storage falls below pre-specified levels.

Volume reliability (R_v) is the ratio of the volume of water supplied (v) to the total volume target (V):

$$R_v = (v/V)\ 100\% \qquad \text{(Eq. 7.2)}$$

R_v reflects the magnitude and the frequency of shortages. In terms of R_v, a failure state occurs when v is less than V or less than a specified percentage of V during a given period. The shortage magnitude or volume is the difference between V and v.

It should be recognized that in reality a reliability of 100% does not necessarily mean that the system will always be able to supply all demands without failure. Reliability indices do not provide a perfect appraisal of the system capabilities as they are influenced by modeling assumptions and are based on historic hydrologic data that does not necessarily reflect the entire range of possible future inflow sequences.

7.7.2 Reliability Applications

One of the key aspects of WAS in which the benefits of incorporating reliability considerations can be observed is in the planning and design of water supply systems. A primary objective in many international water allocation treaties is to allow the construction of dams and other pertinent water supply projects (e.g. 1944 US and Mexico Treaty; Lesotho Highlands Treaty). Also, some interstate compacts made provisions for future development of shared projects (e.g. 1929 Rio Grande Compact).

One of the fundamental hydrologic analyses in the planning stages of reservoir design is the development of storage-yield relationships. Basically, this analysis is used to determine the reservoir yield given a storage allocation, or to determine the storage required to attain a desired yield. The reservoir storage-yield relationship can also be used to determine the quantity of water that a given storage can supply at different levels of reliability.

The maximum amount of water that can be supplied continuously with a R_p and R_v of 100% is commonly referred to as firm yield. Most designs of reservoir storage for municipal and industrial water supply are based on supplying the firm yield during the most critical drought of record (USACE 1997). This conservative design practice is based on building a sufficiently large reservoir so that the risk of shortages is theoretically zero. This practice however may not be optimal if water development costs are high.

Tolerating a relatively small risk of shortage may significantly reduce the storage required to provide the desired yield rate and thus reduce the related construction costs (USACE 1997). Therefore, an understanding of system reliability can provide greater flexibility in the design process and allows for the evaluation of tradeoffs between costs and system dependability.

Considering reliability concepts can also be beneficial in the assessment of water availability. The process of allocating water between nations, states, or users has an inherent element of uncertainty. It is impossible to make absolute guarantees of supplying a specified amount of water without having any shortages. Reliability indices are useful to provide an estimate of the risk of future shortages. Different types of water uses can tolerate different levels of risk, thus a reservoir can supply water to various users at different levels of reliability. Greater quantities of water become available as the level of risk increases. Certain water users require high levels of reliability, while for others obtaining a relatively large quantity of water with some risk of shortage may be preferable over obtaining a supply of greater reliability but smaller quantity. The level of reliability assigned to each water user or water right can be used as a rationing mechanism during shortages. Storage triggering mechanisms can be implemented to progressively curtail uses according to their level of reliability. When a shortage occurs the first uses to be curtailed are those with lower reliabilities, hence they absorb the initial effects of droughts and higher reliability uses would only be curtailed under the most severe drought conditions. Drought management is further discussed is section 7.2.8.

Evidently, there is qualitative judgment in determining acceptable levels of reliability, but in general higher reliabilities are needed for municipal and industrial uses than for agricultural, environmental, and recreational uses. For instance, in evaluating water right permit applications in Texas, the TCEQ has applied the general rule that municipal supplies should have a R_p and R_v of 100%, and for agricultural supplies, 75% of the permitted demand should be met at least 75% of the time (Wurbs 2005). Requiring a reliability of 100% for municipal supplies is common practice since shortages are considered intolerable for purposes such as drinking water. Small shortages may be tolerated without serious economic impact by reducing the less important uses such as lawn watering, car washing, refilling pools, etc. However, a shortage of 10% of the demand may cause serious hardship. For agricultural purposes shortages are usually acceptable under certain conditions. A shortage of 10% usually has a negligible economic effect, but shortages as large as 50% can be disastrous (USACE 1997).

It is important to recognize that the long-term reliability of a river/reservoir system in meeting system demands can be significantly different from the short-term (i.e. several months) reliability. Salazar and Wurbs (2004) investigated this consideration and developed the Conditional Reliability Model (CRM). The CRM is defined as the process of determining the likelihood of meeting water use requirements (reliability) after a specific instance of storage or inflow (the condition) has occurred. The model evaluates the likelihood of historical hydrologic sequences based on storage conditions using conditional frequency duration curves (CFDC). A CFDC represents the probability distribution of flows after the occurrence of the storage within specified intervals (e.g. high, medium, or low storage). The objective is to capitalize on the storage-flow relationship, which basically shows that low storage is likely to be followed by low flows, and high storage is followed by higher flows. Some applications of the CRM methodology include evaluating short-term reliabilities for water diversions, designing short-term drought management strategies, and administering curtailment of water rights; all of which are highly dependent on the current conditions of reservoir storage.

Another important aspect of the relationship between reliability and water availability is how to manage the tradeoffs between how much water to commit for beneficial use and the level of reliability that can be attained. Certainly, in many occasions there will be more water available than the quantity associated with 100% reliability.

Wurbs (1997) stated that if water commitments are limited as required to assure an extremely high level of reliability, the amount of streamflow available for beneficial use is constraint, and a greater proportion of the water flows into the ocean or is lost through reservoir evaporation. In this study, the Brazos River in Texas was used to demonstrate that yields can increase greatly with relatively small reductions in reliability. A yield-reliability relationship was developed for a particular diversion in the river. It was found that the firm yield rate could be increased by 71.3% and the reliability would only decrease from 100 to 96.2%, which is still a relatively high reliability. Thus, the amount of water supplied at this diversion by the Brazos River basin can be increased significantly by tolerating slightly higher risks of shortages. It should be noted here, however, that this diversion is supplied by a system of nine reservoirs. Multiple-reservoir system operations can significantly increase reliabilities, as compared to operating the reservoirs independently. Coordinated releases from multiple reservoirs increases reliability by sharing the risks associated with individual reservoirs not being able to meet their individual demands (Wurbs 1996).

As previously stated, reliability considerations may bring flexibility to a WAS. Reliability concepts can be used to aid in the planning and design of reservoirs, to assess the water supply capabilities of a system, to evaluate the effects of new water right permits on other users, to provide a measure of the risks of shortages, and to establish priorities between competing uses, among others. Proper understanding of the relationship between reliability and water availability also improves water management strategies as significant quantities of water may be "liberated" for beneficial use by tolerating relatively small risks of shortages. Incorporating these reliability considerations also require certain flexibility in the administration of WAS.

At the international and interstate levels this could be a challenge due to the lack of commissions or other management agencies with enough enforcement and administrative power to incorporate these concepts. When these legal agreements are created with the intention of building water supply projects, a fixed, perpetual water supply and flow allocation regime is generally assumed. Typically, no provisions are made for improving allocation schemes in response to newer and more precise hydrological studies or unforeseen changes in water availability. An institutional inertia exists as the parties involved are likely to insist in maintaining the status quo in spite of known system inefficiencies. Moreover, in the case where treaties or compacts protect certain uses or users against shortages, any modification to the water allocation scheme based on a redistribution of risk of shortages would be illegal. For instance, the Yellowstone River Compact protects pre-compact water users by applying the compact's allocation scheme only after those water rights are fully satisfied.

Perhaps, greater applicability can be achieved at the intrastate level. In river basins where water rights have not been adjudicated, water management is more flexible as decisions are typically based on operational policies that can be modified in response to experience, new management practices, improved hydrologic information, and changes in water demand and availability.

7.8 MULTIPLE USES

Scope: What water uses are recognized within the WAS? What are the provisions within the WAS for dealing with conflicting water uses?

The value given by society to the quantity, reliability, quality, location and timing of water resources differ across competing user groups and countries, and these relative values change over time. Thus, decisions about water use may involve a multitude of claimants whose desires may increasingly come into conflict, especially when water availability conditions worsen. The increased potential for conflict warrants closer examination of the ways in which institutions manage multiple uses to facilitate effective water allocation.

7.8.1 Recognition of Multiple Uses

In any particular region, the use of water by a community is multi-purpose and intended to meet the requirements of different users. WAS must then reflect this multi-dimensionality from the policy design to the management level. At the policy level, a WAS needs to recognize as legitimate those water uses valued by society and define how conflicts among those water uses are to be resolved. At the management level, water supply systems should be designed to include all sectors of water users.

The recognition of legitimate water uses does not depend on engineering or scientific considerations but on the socio-economic, cultural, and political characteristics of a country. In the US, the federal government has placed that responsibility on the individual states. Water uses that are considered legitimate vary according to the appropriation doctrine and even among states following the same doctrine.

In the prior appropriation doctrine, legitimate uses are defined based on the concept of beneficial use (Chapter IV). Some states have general definitions of beneficial uses while others contain specific listings. In North Dakota, a beneficial use is simply defined as a use of water for "purposes consistent with the best interest of the people state" (Beck et al. 1991a). On the other hand, other states have drafted lists of beneficial uses which typically include: domestic and municipal, industrial, irrigation, mining, hydroelectric power, navigation, recreation, fish and wildlife, among others.

Some state statues also specify that some uses are more beneficial than others and establish priorities within the recognized uses. Typically, domestic and municipal uses have the highest priority, followed by irrigation and livestock, power and mining, and recreation and wildlife. These priorities are applied in the evaluation of competing permit applications and, in a few states, in the case of insufficient supplies (e.g. Nebraska, California). Other states have recognized less traditional uses like appropriation for avoiding pollution (Nevada), and groundwater recharge (Idaho, Utah, California). Some states also specify non-beneficial uses. For example, California prohibits the use of potable water in cemeteries, golf courses, residential landscaping, and cooling towers.

Riparian water law is restrictive in nature. This means that a person is legally allowed to use the water in any way for any legal and reasonable purpose until a court restricts that use. However, there have been precedents or statues acknowledging specific uses of water. There is a preference for "natural" uses over other uses which the courts referred to as "artificial". The term "natural" refers to domestic uses (i.e. household, livestock, gardening) and "artificial" to those that produce comfort and prosperity (e.g. irrigation, manufacturing, mining). In regulated riparian states, administrative officials have the power to determine preferred uses as well as to choose between competing uses. However, some statutes do set priorities for allocation in the time of permit issuance or when there is not enough water for all needs. These priority schemes give highest priority to direct human consumption (i.e. domestic and municipal) followed (with some exceptions) by agricultural and other uses. Some states, like Arkansas, give minimum streamflows the highest priority after municipal uses. Only Massachusetts and New York do not give any preferences among uses.

7.8.2 Solving Conflicts

Accommodating multiple uses brings a range of benefits but also costs. When properly considered, multiple-use water systems can address the users needs better than single-use schemes, lead to improved cost recovery, promote sustainable development, and help integrate the different institutional aspects of water management and administration. On the other hand, multiple-use systems are more difficult and expensive to manage and can lead to conflict between different users, overloaded systems, and tail-end problems where those at the end of under-designed systems receive nothing due to overuse by others (Smits *et al.* 2004).

In general, water institutions can use several criteria for solving conflicts among the different sectors of water usage: pre-established priorities, economic criteria, equity, and sustainability considerations. Most WAS in countries, states, and/or river basins are established by the acts of legislation or judicial adjudication. In several of these cases the law that establishes the allocation and management framework also establishes priorities for conflicting uses. For example, in 1969 the Texas Supreme Court adjudicated the Lower Rio

Grande and established a system of allocation by use. The water obtained from the US multipurpose pool at Amistad and Falcon was to be used in such a way that if water is insufficient, municipal uses are to be satisfied first. Agricultural uses are completely satisfied only when there is enough surplus of water (Chapter VI).

Economic criteria can also be used for resolving conflict. Different economic values are assigned to each water use according to market or institutional standards. In case of conflict, water uses with higher economic value can be favored by institutions or market mechanisms can be used to reallocate water from low valued uses to higher valued ones. Care must be taken when assigning the appropriate value to the use. Low values can result in inefficient use of the resource, water hoarding, wastefulness and damage to water ecosystems. When properly used, economic criteria can be used to encourage reallocation of water as well as to discourage unnecessary or inefficient uses.

An equity criterion refers to the concepts of social fairness, justice, and impartiality. Therefore, it is dependent on society's principles of ethic and fair play. This is much like the doctrine of equitable utilization, where water users stand on the same level in power and right to benefit from the resource. Nancarrow and Symeb (2004) describe the issues that affect the perception of fairness in allocation among conflicting uses: self interest; efficient uses of water; business investments; viable communities and prior rights to water. People's opinions on such issues change over time.

Historically, many water systems were designed to support certain uses that were deemed very important for sustaining economy. For example, in many states of the US there are still laws and policies that favor outdated uses such as mining and highly consumptive agricultural practices. However, society's needs and values have change and these policies are inefficient and unfairly protected. To resolve this, legislative action might be required. Also some uses such as ecological preservation, recreation, and scenic beauty have low economic values and those groups that advocate environmental uses are fewer than other more economically empowered user-groups. Water uses valued by minority groups, such as native tribes and small-scale community enterprises, would be in disadvantage in an economic water allocation framework. Therefore, government intervention is usually necessary to ensure the consideration and protection of these public interests.

Economic efficiency and equity are centered on fundamental human needs. However, other values, such as ecological health, are not necessarily related to such needs. Ecological sustainability recognizes the value of ecological components in promoting and advancing important public interests. Perhaps the best example of this mechanism has been the application of federal laws, such as the Endangered Species Act, which prohibits any federal action that might threaten the survival of species considered in danger of extinction.

Sustainability also refers to the concept of equilibrium in the development of water resources. The question is not only if there is enough water for a particular use without conflicting with other uses, but also without hindering future ones. In other words, equilibrium relates to supplying current needs while conserving enough resources for future benefits. This requires comprehensive planning of policies and proactive measures such as basin development plans and integrated water resources management (IWRM). The purpose of IWRM is to manage multiple sources and uses of water so that, over time, more efficient water resource supply systems and use patterns emerge, while maintaining or improving ambient water quality. IWRM has been the management approach recommended by international organizations (World Bank 1993).

Formal international institutions of water law encourage the multi-purpose development of water resources. Both the body of international water law and recommendations from international advisory committees emphasize the need for considering multiple uses in the different aspects of water allocation. The Agenda 21 of the UN Conference on Environment & Development at Rio de Janerio, Brazil (1992), which establishes the UN policy for sustainable development, states that "water-supply infrastructure … should be expanded for multiple uses" in order to assist in developing the economy and ensure the reduction of poverty. Also, international organizations in charge of the financing of water projects have recently required that countries interested in utilizing the organization resources must incorporate multi-purpose water projects and policies (Solanes and Getches 1998).

In the case of conflicting uses, international water law gives priority to water uses necessary to sustain human life such as drinking and the production of food to prevent starvation (UN 1997). The concept of equitable utilization and the no-harm rule are also invoked; however, these concepts frequently contradict each other making it difficult to reach resolution. McCaffrey (1999) argues that these conflicts are more likely to be resolved by cooperation and compromise, than by rigid insistence on rules of law. This suggests that probably the most effective strategy for solving conflict among uses at the international level is the joint management of the resource.

Multi-use strategies have been mostly applied in managing specific international water projects. This is also true for interstate WAS. In the past, large scale projects were typically designed with a sub-sectoral focus for domestic or irrigation uses, with no overlap between the two. As the economic and/or social values of water change from one use to another or to new uses; these single-purpose systems might not be able to cope efficiently to sustain progress. Although these systems were designed for single use development, their operation could be modified to incorporate multiple use objectives. However, this change in operational policies may fall short from fully providing for multiple needs.

Systems that are fully designed for multiple purposes are based on comprehensive assessment of needs and resources and are intended to make the most effective use of water (Smits et al. 2004). A typical multi-purpose reservoir project designates storage for flood control and conservation. The operation of these reservoirs is typically based on satisfying the conflicting objectives of maximizing conservation storage while maximizing the empty space required for flood control.

The multiple purposes that depend on the conservation storage are sometimes complementary but often conflicting (Wurbs 1996). Water that is stored primarily for water supply can also be used for uses such as recreation and fisheries while in storage, and then, as it is released, it can be used for hydropower generation and streamflow augmentation before it reaches the diversion location. However, when the available water is not sufficient for satisfying all uses, conflicts arise between consumptive and instream or in-reservoir uses. As previously explained, the criteria for solving these conflicts are specified in treaties or compacts and administered by international or interstate agencies. In other situations where no agency has been created, courts have the responsibility to resolve such disputes and establish mechanisms for weighting the users' claims for water.

In the US there are two major conflicting water allocation scenarios: conflicts between traditional agricultural practices and growing municipal needs; and conflicts between highly-consumptive economy-driven uses and environmental needs. Demands from these groups are not only for a particular water quantity but also for a required standard of quality, reliability, and cost. Competition among these uses is not only dependent on water availability but also on politics, culture, and the economic history and expectations of that particular region (Kenney 2003).

For the most part, agriculture is the greatest water consumer accounting for 80 percent of the nation's consumptive water use (ERS 2004). Nonetheless, the agricultural contributions to the economy continues to decline and the value of water in agriculture is several orders of magnitude less than that used for municipal and domestic uses (National Research Council 1992). The competition between economic and environmental uses of water is very problematic in the sense that it is often centered in the fact that environmental uses of water are often not recognized as legitimate uses or are deemed less important than consumptive uses. For instance, the prior appropriation system does not generally recognize obligations to the environment. Moreover, by punishing non-use of water it can actively encourage environmental degradation. Also, the history of the development of the western US is filled with the development of major water projects that have had significant negative impacts on water ecosystems.

In the US more and more frequently water markets have provided a way to address these issues. Markets compensate farmers for temporarily or even permanently transferring their water rights to municipal purposes. However, these transfers can have significant economical and social impacts on agricultural communities. In the western US, where water rights are private property rights, compensation for water transfers go entirely to the farmers while other members of the community receive no compensation (Kenney 2003). This suggests that some sort of regulation of water markets is needed in order to mitigate these impacts. Water markets have also assisted in economic/consumptive uses and environmental uses (see section 7.2.7). In addition to market mechanisms, the eastern US has used their permit system for dealing with conflicting uses. Some states have pre-established priorities based on type of use that apply only under water scarcity conditions. Also, their permit duration periods are used for reallocating water to new uses in accordance with the water regulatory agency's evolving vision of water use.

7.9 INSTREAM FLOW REQUIREMENTS

Scope: What are the strategies used to incorporate non-traditional instream uses of water into a WAS scheme?

Adequate instream flow is vital for the comprehensive utilization and protection of water resources. As economies develop, the consumptive use of water usually increases and more pressure is put on taking water out of the channel. However, as society progresses, the social values of water also change and other non-consumptive uses of water are expected to be protected.

Over the last decades, worldwide, more attention has been placed on increasing streamflows to improve water quality, protect fish and wildlife habitat, provide for recreational activities, and maintaining the aesthetic integrity of water systems. In the US, the Clean Water Act and the Endangered Species Act have further stressed the importance of providing for the non-consumptive uses of water and exerted more pressure on water regulatory agencies to provide adequate flows for environmental protection. In addition, even in the more arid west, outdoor recreation such as hunting, fishing, and environmental tourism has grown to a multi-billion dollar industry that is greatly dependent on healthy water systems.

7.9.1 International Provisions

At the international level, instruments of law (e.g. treaties, conventions, etc.) seldom address environmental and other instream uses in any specific provision. The concept of environmental flows is explored only in the more recent international doctrine of integrated water resources management or community of riparian states. For instance, the 1996 United Nations Convention on the Non-Navigational Uses of International Watercourses requires countries to protect and preserve the ecosystems of international watercourses and control the sources of pollution. In the text, states located within an international watercourse have an obligation to cooperate in the regulation of the watercourse flows. Also, the long standing doctrine of not causing significant harm, confirmed by both the Helsinski Rules and the UN Convention, defines terms to reduce transboundary impacts including adverse effects resulting from a change in conditions of transboundary waters. As explained in Chapter II, the Helsinski Rules have never been completely accepted and the Convention of Non-

Navigational Uses has not yet been ratified. Therefore, even though these agreements, collectively, may provide a basis for a comprehensive international regime for instream uses (mainly environmental flows) they are ambiguous and give ample margin for implementation to the parties involved.

Perhaps more practical insight can be discovered from the study of bilateral and multilateral agreements. Although very few of these treaties specifically address instream non-consumptive uses of water, the few that do have used one of two approaches. Treaties either set very specific allocative provisions and limitations or establish an administrative body which, among other duties, will determine how these uses are going to be addressed. For instance, the Niagara River Water Diversion Treaty of 1950 between Canada and the US curtails diversions during specific times and dates in order to maintain adequate flows for the protection of scenic beauty and recreational uses. The flow rates specified in the treaty are mandatory minimums and all excess waters are then divided equally between both countries.

The International Joint Commission is the administrative body for the Niagara River which manages the Treaty's provisions and provides an instrument for conflict resolution. Probably the only treaty that has any meaningful provision for the protection of environmental flows is the 1995 Mekong River Agreement. The agreement creates the Mekong River Commission (MRC) which is in charge of creating a framework for the management and sustainable development of the Lower Mekong River basin. The agreement states that the signatory parties are to protect the environment of the basin by minimizing and mitigating pollution and other harmful effects resulting from development plans and uses of the waters. The agreement also requires the establishment of minimum monthly natural flows during the dry season. A Joint Committee which is the implementation branch of the MRC is appointed to adopt the necessary guidelines for the location and levels of the flows. Currently, the Committee has developed a hydrological model of the Lower Mekong River with the support of the World Bank. Alternative development scenarios are being evaluated as part of a bigger study to determine the environmental flows component required in the treaty.

7.9.2 Interstate and Intrastate Provisions

In the US, instream flow needs have been included in WAS in several ways. Among states, instream needs are usually not considered separately from the other water needs and it is left to the individual states to consider and provide for them from their water allotment as established by ratified interstate compacts and in accordance with the state's water administration policy. More recently a different approach has been taken in eastern states in which state's borders are ignored and administration of water rights and uses within a transboundary basin, including instream flows, are regulated by policies established by a commission.

At the intrastate level, states either define instream flows as guaranteed minimum flows reserved prior to allocation or incorporate them within their water rights system. In the eastern US, where the riparian doctrine evolved, instream uses have historically been considered important due to the natural flow tradition (Chapter IV). Nonetheless, in the traditional riparian states, expanding municipal and other out-of-river demands have exposed the weakness of the reasonable use rule to balance and much less protect conflicting water rights.

In more regulated eastern states, minimum stream flows are usually established for the protection of environmental ecosystems rather than for ensuring natural flow to other riparians. These minimum flow rates are maintained at particular stream gauges and usually have specifications on how minimum flows may vary throughout the year. This specificity can be used to facilitate trade-offs between competing uses. For instance, when a minimum flow is established for habitat protection and fisheries, it can be increased during the spawning season and decreased during winter. Also, in areas of aesthetic and recreational interest, higher minimum flows can be established for the peak season of tourism and later be reduced.

Western prior appropriation states emphasize the private property nature of water that has been physically put to use and the historically preferred uses of water have been consumptive in nature. In contrast to the riparian natural flow theory, prior appropriation laws were designed to promote traditional economic uses of water, which besides hydropower were mostly out-of-stream. As environmental awareness grew, many western states revised their water laws to allow for the recognition and establishment of instream water rights for environmental, recreational and aesthetics purposes. For instance, the state of Texas now recognizes recreation and pleasure, stock raising, public parks, and game preserves as beneficial uses of water. However, the concern about environmental flows has come at a time when consumptive uses of water such as municipal, industrial and irrigation are also increasing.

Due to the fact that instream water rights in the west are relatively recent, they are junior to most consumptive rights and therefore their recognition as beneficial uses has little practical significance. For instance, in Texas environmental instream water rights have only been recognized since 1985 and with most of the state's surface waters already allocated little water remains for environmental flows. In most cases, public agencies own most instream rights which make these efforts dependent on the state's economic and political will.

Some states' legislations have also incorporated concerns for instream needs by requiring water administrative agencies to review the effects of proposed water rights on the instream uses of water. In Texas, this process usually entails revision of stream gauges near the area where the diversion is proposed, quantification of median flows needed for sustaining the aquatic habitats, and consideration of potential impacts on terrestrial wildlife and wetlands (Rochelle 2004). The effectiveness of such practices, however, is dependent on the level of development of the river system. In overappropriated rivers this practice has come too late to make any significant impact on ensuring healthy aquatic ecosystems.

For these reasons, water markets have become the most effective mechanism for accommodating instream needs since organizations interested in ensuring instream flows for environmental protection and other non-consumptive uses can purchase rights from more senior users. Landry (1998) reported that water sales for environmental and other instream uses have occurred in nine of the eleven western states with several federal and state water acquisition programs of agencies such as the New Mexico Interstate Stream Commission. Nonetheless, relying on water markets alone for protection of instream uses may not be enough to ensure a comprehensive protection of instream values of water.

It must be considered that most established water market mechanisms, especially in western states are designed for reallocating water from one consumptive use to another (i.e. agricultural to municipal) and have worked sometimes exclusively for that purpose. Also, water banking is not a permanent solution since it only works when and where there is money available for such purposes. Reliance on markets shifts the responsibility of environmental protection from the government to the private sector which creates uncertainty, especially when considering that most success in environmental flows protection has been obtain through legislation and governmental programs. Therefore, when designing strategies to use this mechanism, provisions must be made for assuring a high level of long-term protection and security at least comparable to those obtained by more traditional mechanisms such as legislation.

Major concern for instream uses of water has prompted stronger pressure for instream flow protection in Texas. Texas ranks first among the states in hunting opportunities and second in fishing, activities that amounted $4 billion in annual revenues in 1993 alone (TPWD, TCEQ, and TWDB, 2003). It has been considered the number one destination in the world for birdwatchers (Sansom 1995). In 2001 the Texas Senate Bill 2 instructed the TWDB, the Texas Parks and Wildlife Department (TPWD), and the TCEQ to develop a state program for instream flows on priority rivers by the end of 2010. In response, the agencies drafted a proposed instream flow program that is described in two documents: the Programmatic Work Plan (PWP) (TPWD, TCEQ, and TWDB, 2002) and Technical Overview Document (TOD) (TPWD, TCEQ, and TWDB, 2003). The PWP outlines the scope, timeframe, and methodology for planning and conducting priority studies while the TOD details scientific and engineering methodologies for data collection and analysis that will be needed to develop such studies. Priority basin instream flow studies were identified based on potential water development projects, water rights permitting issues, and other factors. Among the priority basin studies are the Trinity, Lower Colorado, Sulphur, Brazos, San Antonio, Guadalupe, and Sabine Rivers. Additional basins to be considered later on are the Neches, Red, and the upper subbasins of the Guadalupe and Sabine Rivers. This program is still in a study and development phase and regulatory implications have not yet been determined.

7.10 DROUGHT MANAGEMENT

Scope: What are the special conditions defined within WAS for declaring a drought state? What are the adjustments to normal allocation rules and/or implementation of new rules used to cope with drought conditions?

A key component of a WAS, particularly in arid regions, is to establish methodologies to respond to periods of water scarcity. Drought periods are the ultimate test for a WAS, for effective water allocation becomes critical as reliable supplies diminish. However, drought periods are difficult to detect as they develop slowly and usually cover large regions and can last for years. Droughts are natural disasters and their severity is dependent not only on physical factors such as precipitation, temperature, and moisture but also on social components. When WAS are well prepared to withstand water scarcity, the impacts of droughts are less severe.

7.10.1 Definitions of Drought

In general, droughts are defined as recurrent climatic events characterized by a lack or dramatic reduction of precipitation for an extended period of time. The factors used to define if a drought is occurring or about to occur vary from region to region. The manner in which WAS define droughts are important because they determine drought policies and response actions. There is no universally accepted definition of a drought. Droughts are insidious and their effects accumulate gradually over time, which makes difficult to determine whether or not it exists and how severe it could be. Moreover, since droughts occur in all regions of the world regardless of climate and economic background, a single mechanism to determine if a drought is in progress might not be a viable expectation.

Droughts have been defined based on different characteristics: meteorological, agricultural, hydrological, and socioeconomic (Wilhite and Glantz 1985). Meteorological droughts are defined by the decline in climatic moisture as compared to normal conditions. The standard of comparison for this definition is site-specific as moisture conditions vary greatly from region to region. Agricultural droughts are defined based on yield losses in agricultural production. Hydrological droughts are defined based on the effects of low precipitations on surface and sub-surface water supplies rather than lack of precipitation itself. A hydrological drought downstream of a river can be caused by changes in precipitation, land use, or water use patterns upstream that result in diminished streamflows regardless of precipitation downstream. Socioeconomic droughts are defined based on the economic effects of the reduction of precipitation and/or streamflows (supply) on water users (demand). In other words, a socio-economic drought occurs when demands exceeds supply.

In the US, the national drought policy has incorporated two basic drought definitions: stored water and natural water droughts. Stored water droughts occur when stored resources in man-made reservoirs, natural lakes and groundwater aquifers are depleted for unusually prolonged periods of time due to low precipitation. This type of droughts are rarely affected by regular periods of less-than-normal rainfall and only very prolonged periods of low precipitation and increased water use can have significant impacts. Natural water droughts on the other hand, react quickly to short periods of below-normal rainfall. These affect mostly people depending on direct precipitation and unregulated streamflows for agriculture and other water-dependent businesses.

Due to the many intricacies and interconnections between the physical and socioeconomical aspects of droughts, the aforementioned compartmentalized definitions of droughts are more difficult to practically integrate into the water management system. For that reason, public declarations of droughts are often triggered by specific and well-defined conditions. These triggers then become the practical definition of drought for a particular region or for specific sectors such as agriculture or municipal water supply (National Drought Policy Commission 2000). For instance, in more humid areas a drought can be declared only after a couple of months without rain. In more arid areas, a couple of months without rain might be considered normal and only when reservoir levels start to drop dramatically, a state of alarm may be reached.

Some water resources management systems like the Australian, use rainfall triggers to guide their drought mitigation programs. Australia water management has identified a range of triggered drought definitions based on percentages of normal precipitation. If the accumulated rainfall over three successive months (or six months for the most arid regions) is 10% or less of what normal precipitation should be, a drought watch is issued in the affected region. A serious deficiency is declared when rainfall over a three month or longer period falls within the lowest 5 to 10% of historical records. Conversely, if rainfall is in the lowest 5% of records for three months or more, a severe rainfall deficiency is declared. The drought is considered to have ceased when plentiful rainfall returns. Plentiful rainfall is defined as well above average rainfall for one month or above average rainfall over a three-month period (Australian Government 2005).

One of the most common mechanisms for defining droughts is droughts indexes. These drought indicators are objective measures of the system that can help agencies identify the onset, increasing or decreasing severity, and conclusion of a drought (Werick and Whipple 1994). Most water-supply planners find it useful to evaluate one or more indices before making a decision.

The most widely used index is the Palmer Drought Severity Index (PDSI) (Palmer 1965). The PDSI uses temperature and rainfall data to determine dryness. One of its major strongholds is that it can determine long-term droughts by identifying long-terms trends that are not affected by abnormally wet months. Only a long enough wet spell would mean the drought is over. The PDSI is a meteorological drought index and does not consider non-meteorological aspects such as streamflow, lake levels, and snowpack in determining when a drought starts and ends. The PDSI provides measures of moisture conditions that are standardized for comparison.

The Crop Moisture Index (CMI) is an index within the computations of the PDSI that evaluates short-term moisture conditions and can be used to monitor impacts on crops. The PDSI follows a 4 to -4 scale with 0 as normal conditions and negative numbers as drought conditions (-2 moderate, -3 severe, -4 extreme). Even though PDSI has become the semi-official drought index for drought monitoring in the US, it has been argued that it does not properly depicts drought conditions in mountainous lands or in regions of frequent climatic extremes (Smith et al. 1993, Hayes 2005). Also, the PDSI was designed for assessing impacts mostly in agriculture and does not accurately represent other hydrological impacts of droughts (Mckee et al. 1995). In addition, the extreme and severe classifications occur with greater frequency in some regions than in others (Willeke et al. 1994), which can make planning response actions based on drought intensity impractical (Hayes 2005). The National Oceanic and Atmospheric Administration (NOAA) keeps weekly maps of PDSI as part of their national drought monitoring program (www.cpc.ncep.noaa.gov/products/analysis_monitoring/regionalmonitoring/palmer.gif).

Due to the shortcomings of the PDSI in accounting for topographic and climatic variability in Colorado, Shafer and Dezman (1982) developed a new index called the Surface Water Supply Index (SWSI). In addition to the meteorological considerations of the PDSI, the SWSI also accounts for snowpack, streamflow, precipitation, and reservoir storage. It is calculated by river basin and standardized for facilitating comparison. Like the PDSI, a 0 value represents normal conditions and has a range from +4 to -4. Perhaps its major disadvantage is that any change in water management (e.g. new diversions or reservoirs) or new streamflow data would require new algorithms to be calculated for that particular basin (Hayes 2005). SWSI has been used in Colorado as complement to the PDSI to trigger drought responses.

In 1993, McKey et al. developed the Standardized Precipitation Index (SPI) which represents the effects of droughts in water availability of different sources. The SPI determines precipitation deficits for 3, 6, 12, 24, and 48 months based on long-term precipitation records and transforms them into a normal distribution. Positive SPI values correspond to wetter than median conditions and negative values to less than median precipitation (e.g. -1 to -1.5 moderately dry, -1.5 to -1.9 severely dry, -2 or less extremely dry). A drought is defined as an event where the SPI is continuously negative reaching values less than -1 and ends when SPI become positive. SPI has been used operationally to monitor droughts in Colorado since 1994 (Hayes 2005) but it's yet to be widely applied and tested anywhere else (Oklahoma Drought Management Team 1997).

In 1988, Congress passed the Reclamation States Drought Assistance Act which allowed states to request the assistance from the Bureau of Reclamation for drought mitigation projects. As part of those projects, the Bureau developed the Reclamation Drought Index (RDI) as a tool for defining duration and severity of droughts. The RDI is flexible so it can accommodate the meteorological and hydrological conditions particularly of the western states. RDI is calculated at the basin level and is unique to each basin. This could be advantageous since the RDI can be tailored to the specific characteristics and needs of a particular state although it can make interbasin comparisons difficult. The RDI main strength is that it has the ability to account for climatic as well as water supply factors. It incorporates water supply components (precipitation, snowpack, reservoir levels, etc.), demands (consumption as a function of temperature), and duration with months weighted according to their significance in water consumption (Hayes 2005). The RDI values for severity are similar to those for PDSI (-1.5 mild, -1.5 to -4 moderate, -4 or less extreme). The state of Oklahoma uses the RDI as part of their water supply drought monitoring system (Oklahoma Drought Management Team 1997). There are many other drought indexes used in US and abroad for monitoring drought conditions. Some of them are specialized for assessing impacts on specific sectors such as the Keetch-Byram Drought Index for assessing wildfire potential hazard and the Satellite Vegetation Health Index which uses satellite gathered data to assess the health of crops.

7.10.2 Drought Management at the International Level

Traditionally, drought has been a misunderstood phenomenon against which cultures have felt powerless. In impoverished countries, governments concerns with droughts are centered mostly on issues of food security and meeting the nutritional needs of the population, environmental degradation, and a retardation of the development process (Wilhite and Svodoba 2000). In more developed countries, even though droughts do not necessarily translate into starvation, they have caused substantial environmental, economic, and social impacts. Due to the magnitude of the situation, some drought planning efforts have been undertaken at the international level, especially in the last decades.

Droughts in international treaties and interstate compacts are not comprehensively address. Most transboundary water agreements do not have specific provisions for times of severe scarcity. Some, however, have several provisions for dry years (i.e. below normal precipitation or streamflow). For instance, the Rio Grande Compact has provided a system of water credits and debits in which water debt accrued over dry years can be repaid during wet years. This, however, is far from being comprehensive since it assumes low flow periods to be short and that there is enough storage capacity in the river to withstand them.

The Rio Grande Treaties of 1906 and 1944 between US and Mexico specifically addresses the potential of drought. The 1906 Treaty established that in the case of "extraordinary drought" water deliveries to Mexico are to be reduced in the same proportion as deliveries to the US. Similarly, the 1944 Treaty established that during "extraordinary drought" conditions Mexico can accrue water debts that shall be made up in the next five year cycle (Chapter VI). However, the term "extraordinary drought" was not defined in the treaties and no mechanism of conflict resolution was provided. Therefore, this provision rather than providing a mechanism to deal with droughts, has allowed Mexico to curtail water deliveries on the Rio Grande, which has produced serious differences on whether Mexico is compliance or non-compliance with the treaty and fuel hostilities between the two countries (Combs 2004).

More recently, there has been some interest in organizing international efforts to address droughts in a proactive way rather than emergency relief. As a result, there have been some consorted efforts between riparian and/or neighboring countries to develop regional anti-drought programs. For example, the Southwest Asia Drought Assessment and Mitigation Project has the objective of developing a conjunctive drought mitigation program in Afghanistan, Pakistan and India. This project, like other international drought management efforts, is still in its initial phase and studies are been conducted on regional analysis of drought indices, satellite data and their potential use in drought monitoring and management, and development of drought-related policies and institutions (IWMI 2005).

7.10.3 Drought Management at the Interstate and Intrastate Level

In the US, efforts have also been made for establishing regional drought preparedness programs. For example, in 1997, the Western Drought Coordination Council (WDCC) was created with the purpose of developing model drought policies and management/mitigation measures to reduce impacts associated with droughts. However, the WDCC has been in hiatus since 1999 and its functions have been delegated to the National Drought Policy Commission.

Other regional entities follow the basin planning approach. For example, the Delaware River Basin Commission (DRBC) has an active drought management program that provides initiatives to help states in the basin prepare for droughts. The DRBC also conditions the granting and renewal of permits to the implementation of water conservation practices. The Susquehanna River Basin Commission has gone a step further and developed a coordinated plan of drought management activities among the basin's riparian states. The coordination plan establishes precipitation deficit, ground-water level, streamflow, reservoir levels and PDSI as the triggers for initiating mitigation actions. After the assessment of these triggers, if a drought emergency is declared, non-essential water uses in the basin are to be limited to 75 to 85% of their normal withdrawal rate (Susquehanna River Basin Commission 2000).

Historically in the US, droughts have been addressed at the state or local level. However, as a result of several episodes of severe droughts in the last century and billions of dollars in losses, the Congress passed in 1998 the National Drought Policy Act that created the National Drought Policy Commission (NDPC) to advice Congress in drought response and preparedness issues. In 2000, the NPDC reported to Congress its recommendations on how to achieve a coordinated approach in order to mitigate the impacts of and respond to droughts. The report concluded that national drought policy was needed to "support but not supplant nor interfere with state, tribal, regional, local, and individual efforts to reduce drought impacts" (NPDC 2000). The reality is that even though these national initiatives have developed recently, at the state level there has been significant progress in proactive drought management for the last twenty years. Nonetheless, the report marks a shift from the emphasis on drought relief to drought preparedness and mitigation and the need for institutional coordination among all levels of government.

Drought mitigation usually follows one or several of three response alternatives: strategic long-term responses, tactical short-term responses, and/or emergency responses (Werick and Whipple 1994). A long-term approach refers to long-term economical and institutional measures such as infrastructure and legislation. A tactical approach involves response measures, planned for in advanced, to cope with expected short term water deficits. Emergency responses are measures taken when circumstances exceed the expectations or level of preparedness of the system due to inefficiency or the occurrence of more intense and/or prolonged droughts than those in record. Long-term strategic planning and emergency response are concerned with institutional capacity and appropriate organizational structure that can facilitate governmental response to droughts.

Tactical short-term measures are more concerned with decision-making and responsive actions that can be implemented at the time of the drought to reduce the residual drought vulnerability, especially in terms of water availability. It is in this branch of drought preparedness that most mechanisms of drought mitigation related to water supply systems are developed. Tactical responses for risk-reduction require climate and water supply monitoring as well as pre-developed plans for mitigation called drought contingency plans

(US Army Corps of Engineers 1981). The development of such plans and strategies requires modeling capabilities for developing water supply alternatives.

The most important mechanism in tactical responses is the use of triggers. Different sectors of the water management system use different triggers to launch mitigation measures. For instance, an agency in charge of overseeing agricultural production might use one or several agriculture indexes such as the CMI or more general indexes like the PDSI to launch mitigation measures as specified in their drought contingency plans.

Since most drought indexes describe climatological conditions, WAS most commonly use other type of triggers to launch mitigation. Lakes and reservoir level conditions and streamflows are the most common operational triggers. The state of Texas Drought Preparedness Plan establishes five drought stages: abnormally dry (advisory level), first-stage drought (watch), severe drought (warning), extreme drought (disaster) exceptional drought (emergency). One of the criteria for defining a drought and its severity is water availability. Both reservoir conditions and streamflows are used as triggers or thresholds for initiating different levels of responsive actions.

Each drought stage has an associated range of values describing reservoir and streamflows conditions. In Texas, reservoir conditions are described as percent of reservoir conservation storage capacity and it is calculated by dividing the actual water volume storage by the total conservation storage capacity (municipal water supply, hydropower and irrigation). Streamflows conditions are represented by percent exceedance probabilities computed from 30-day historical mean flows from 29 stations all over the state (Drought Preparedness Council 2005). Percent exceedance probability is the probability or percent of time that flows of a given magnitude are exceeded. For example, if a streamflow magnitude is said to have a 70% exceedance probability, it can be also said that the stream is expected to have flows greater than that particular value 70% of the time. Table 7.5 presents the percent of reservoir conservation storage capacity and streamflow percent of exceedance values associated with the different drought stages.

The Texas Water Development Board (TWBD) is responsible for compiling information, determining the aforementioned trigger values, and developing an overall level of concern in terms of water availability from 1 to 5 accordingly to the drought stages already explained. This is done for each of Texas ten climatic regions as defined by NOAA

Table 7.5. Water Availability Assessment Values for Texas Drought Preparedness Plan

Drought Severity Classification		Ranges	
Drought Stage	**Description**	**Percent of Reservoir Storage Conservation Capacity**	**Streamflow Percent Exceedance**
Advisory	Abnormally Dry	<70	70-79
Watch	First-Stage Drought	<60	80-89
Warning	Severe Drought	<40	90-94
Emergency	Extreme Drought	<20	95-98
Disaster	Exceptional Drought	<10	99-100

Source: Drought Preparedness Council (2005)

(Drought Preparedness Council 2005). The levels of concern are then analyzed by the State Drought Manager who decides if any state specific mitigating measures are necessary. Otherwise, it is left to the local water management organizations to adopt specific mitigation actions in accordance with their drought contingency plans, the drought stages, and level of concern established by the TWDB. The Texas Water Availability Modeling System supports the formulation of drought mitigation strategies. Most drought contingency actions in Texas involve rationing, water marketing, inter-basin transfers, and voluntary restrictions.

An alternative strategy for defining drought and activating drought mitigation based on current storage conditions was presented by Salazar and Wurbs (2004). The authors developed a conditional reliability model (CRM) (see Section 7.2.5) that determines the likelihood of meeting water use requirements as a function of storage. In contrast to reliability indices based on long-term simulations, the CRM can create short-term reliability estimates that reflect the current storage conditions. The model can be used to find a trigger level based on an assumed acceptable level of reliability. For instance, a trigger level can be defined as the minimum storage required to guarantee 100% reliability of meeting water demands over a 12-month period. If storage levels fall below this minimum, contingency measures are adopted.

The state of California has a well-developed process for drought mitigation. In addition to the drought contingency actions found in Texas, California also has specific requirements to cut some water uses up to 50% during severe droughts (National Drought Policy Commission 2000). Also, in 1991-92, after several years of severe drought, California established a temporary Drought Emergency Water Bank (DEWB). In this strategy, the Department of Water Resources served as a broker for water transfers and set a fixed price for both purchases and sales of water by the Bank. Most of the water used in transfers came from farmers who fallowed their land and sold the water their crops would have consumed to the bank and from inter-basin transfers. Also, the DEWB established a dual-contract system in which buyers and sellers who committed to the Bank early, made a deposit on the water they thought would need or supply, which allowed the Bank to anticipate water surplus or deficit (Howitt 1994). Overall, the experience of the DEWB is considered a success because it facilitated the transfer of water from low-valued uses to high-valued uses during a period of intense scarcity by minimizing transaction costs and risks.

Werick and Whipple (1994) have listed several mechanisms for drought mitigation that can be triggered by state drought plans. Among them are: conjunctive management of groundwater and surface water resources, water markets, water banking, conditional reservoir operation for protection of instream flows, voluntary and mandatory water use restrictions, and water pricing. There are more than 30 drought plans from various states and many of them provide triggering mechanisms or thresholds that are intended to initiate specific actions by various agencies, but when these thresholds are reached or exceeded, the prescribed responses are rarely implemented in a timely or effective manner (Drought Preparedness Council 2005).

CHAPTER VIII

MODELING THE WATER ALLOCATION FRAMEWORK

One of the main arguments that permeate throughout this dissertation is the complexity of water allocation systems (WAS). WAS encompass many levels of physical, administrative, legal, and regulatory aspects. Computer simulation models can assist water managers in dealing with complex water allocation issues. Computer simulation models can be used to evaluate water management strategies, plan development projects, simulate allocation under alternative water availability scenarios, support the negotiation of agreements, administer water rights systems, and the like. During the planning and design stage, computer models can allow decision makers to evaluate the physical and economic impacts of alternative allocation policies, demand levels, and institutional restrictions. Once a WAS is established, computer models may be used to simulate the management and regulation of the water resources of a river basin within its hydrological and administrative setting.

The state of Texas has successfully developed and implemented a Water Availability Modeling (WAM) system to support the water planning process and the administration of its water rights permit system (Chapter VI). The WAM system was authorized by the 1997 Senate Bill 1, the Brown-Lewis Water Management Plan. A key component of the WAM system is the Water Rights Analysis Package (WRAP). This computer model has been used to simulate water allocation and management scenarios in all Texas river basins, including the international Rio Grande.

The scope of this Chapter is to demonstrate how the principles presented in the conceptual framework (Chapter VII) can be used to assess water allocation issues. In order to do that, the Rio Grande basin in Texas will be used as a case study. Three major current water allocation issues of the Texas Rio Grande are evaluated in this Chapter: reallocation among uses, instream flow considerations, and drought assessment.

8.1 WRAP PROGRAM OVERVIEW

WRAP is the computer program used for modeling all Texas basins as part of the WAM system. WRAP is a generalized model, developed at Texas A&M University, designed to simulate a river basin under a priority-based WAS (Wurbs 2005). WRAP is a suite of programs that include *WinWRAP, SIM, HYD,* and *TABLES*. *WinWRAP* is a user interface to apply the model under the Windows operating system environment. *SIM* is the main river/reservoir system water allocation simulation model. *HYD* is a pre-simulation program designed for developing sequences of monthly naturalized streamflows and reservoir net evaporation-precipitation rates. These sequences are then read by *SIM* as input files. *TABLES* is the post-simulation program that organizes, summarizes, analyzes, and displays *SIM* results. Recent additions that expand the model capabilities include the *SIMD, DAY,* and *SALT* programs. *SIMD* is similar to *SIM* but with additional features that allow sub-monthly time steps, flood forecasting, routing, and flood control operations. *DAY* provides the input data for *SIMD* by transforming monthly hydrologic data into daily time steps and determining routing parameters. *SALT* uses the *SIM/SIMD* output file along with a salinity input file to determine salinity levels throughout the river/reservoir system.

WRAP evaluates the ability of the river/reservoir system to meet demands during a hypothetical repetition of historical natural hydrology. Demands are met as long as water is available from streamflow and/or reservoir storage. Shortages are declared if insufficient water is available in the system to satisfy the water rights demand targets. The program performs the water allocation computations by tracking inflow sequences and accounting for reservoir storage, system losses (evaporation, channel losses, etc.), diversions, instream flows, and other variables.

Water allocations are also subject to prescribed water rights conditions and reservoir operational rules. The spatial connectivity of the system is modeled as a set of control points. The computational algorithms are based on the location of each control point related to the others as defined in the input data. The modeling process starts by computing naturalized inflows at gauging stations that are used as primary control points and distributing flows from those control points to others located in ungauged areas. Naturalized flows represent the natural flows that would have occurred in the absence of the water users and water management facilities and practices. Then water is allocated to each water right in priority order subject to water availability and other management constraints. Simulation results include regulated flows (i.e. physical flows at control points), reservoir storage contents, diversions, water right shortages, unappropriated flows (i.e. flows still available for appropriation), reliability indices, frequency statistics, and other pertinent variables. Detailed program information can be found in the program manuals for its latest version of April 2005 (Wurbs 2005). Full documentation and downloadable versions of the program can be obtained at: http://ceprofs.tamu.edu/rwurbs/wrap.htm.

8.2 RIO GRANDE WAM MODEL

The Rio Grande WAM model was developed by R. J. Brandes Company (2004). The Rio Grande WAM was modeled using the February 2003 version of WRAP but can be run with the 2005 version with no complications. Since water allocation in the Rio Grande is governed by two international treaties, an interstate compact, and two intrastate water right systems, a series of special considerations were incorporated in the WRAP input files to properly simulate this complex system. These special considerations are summarized below.

8.2.1 Modeling Considerations for International Allocation

The allocation of water between the United States (US) and Mexico (MX) was accomplished in WRAP by using two interconnected parallel water systems, one models US water and the other MX water. The naturalized flows determined for each of the tributaries to the Rio Grande included in the model are assigned to its country of origin. In this manner, it is ensured that the naturalized flows originating in each country are only available for use in that country. Naturalized flows computed in *WRAP-HYD* were determined for the mainstream, regardless of the ownership of the flows as established by both the 1944 Treaty and the 1906 Convention. Since the *SIM* model is structured as two parallel systems, the naturalized inflows needed to be divided between the two river systems prior to the water allocation simulation. This was accomplished with a spreadsheet program that performs a mass balance of the flows for each side of the Rio Grande. The inflows to MX include the allocation assigned by the 1906 Convention (60,000 ac-ft/yr).

According to the 1944 Treaty, MX must deliver to Texas one-third of the flows reaching the mainstream of the Rio Grande from MX tributaries. This is accomplished in the WAM model by first simulating the MX demands and then transferring one-third of the simulated inflows that reach the control points representing the mouth of six MX tributaries to the Texas system as return flows. The priority of the MX water rights is established in the model using priority codes that are based on type of use (municipal and industrial first and then irrigation) and river order (from upstream to downstream). Another consideration is the equal split of the water in the mainstream of the Rio Grande at Fort Quitman in accordance with the International Boundary and Water Commission (IBWC) accounting procedures. After accounting for all water rights above Fort Quitman, one-half of the regulated flows in the Texas system are transferred to the MX system and vice versa. Water allocation above Fort Quitman within Texas is explained in section 8.2.3. Evaporation losses from the Amistad and Falcon Reservoirs are proportionally allocated to each country based on the beginning-of-month storage in each country's pool.

The WAM model also incorporates the treaty provisions with regard to excess inflows. For instance, if the MX pool in Amistad is full, excess inflows are delivered to the MX Falcon pool. However, if the MX Falcon pool is full, then excess water is transferred to the Texas pool in Amistad. Similarly, if the MX pool in Falcon is full and Texas has storage capacity available in Falcon, then the water is transfer to that pool. If Texas does not have storage capacity available, releases made are available for the MX portion of the Rio Grande. The same logic applies for Texas excess inflows with corresponding transfers being made to MX.

8.2.2 Modeling Considerations for Interstate Allocation

From the US allocation of the waters of the Rio Grande, the Texas share is defined by the Rio Grande Compact. This water is subject to the operation of the Rio Grande Project (RGP), which delivers waters to New Mexico, Texas, and to Mexico according with the 1906 Convention. The project is operated by the U.S. Bureau of Reclamation and water is allocated based on the quantity of water in storage in Elephant Butte Reservoir (EBR) on December 1 of each year. Therefore, the amount of water Texas receives varies according with the storage at EBR. Inflows to EBR are dependent on water usage and storage at Colorado and New Mexico. Historically, there have been years when deliveries to EBR by one of both states (i.e. Colorado and New Mexico) have been more or less than those required by the Rio Grande Compact. Also, there have been occasions when the water already allocated in storage at EBR at the end of a year has not been released and carried over as storage for next year.

To account for these issues two adjustments were made to the historical inflows used in WRAP. Inflows were adjusted to reflect the effects of any Rio Grande Compact over/under deliveries by New Mexico and of any unreleased Project water on the allocation of RGP water to Texas. In order to do this, first a series of relationships between total RGP releases, total diversions and charges by Texas were used to develop a complete record of historical monthly diversions. These quantities were then added to the historical monthly flows to establish historical annual amounts available to Texas and MX. The historical annual amounts diverted by MX into the Acequia Madre Canal were then subtracted to establish the total historical annual quantities of Rio Grande water available for diversion by Texas.

8.2.3 Modeling Considerations for Intrastate Allocation

The allocation of the Texas share of the Rio Grande water is governed by two distinct water rights systems: one for water rights above Fort Quitman and one for water rights below Fort Quitman. Water rights above Fort Quitman are honored in accordance with the doctrine of prior appropriation, like the rest of Texas. These water rights are not associated with the Amistad-Falcon Reservoir system. As explained in section 8.2.1, one-half of the regulated flows reaching Fort Quitman from the Texas system are transferred to the MX system and vice versa. Therefore, the allocation of water rights above Fort Quitman needs to be performed first in the simulation. In the WAM model, the number representing the priority date, which is related to the actual date stipulated in the permits, is reduced by 100. This adjustment makes these water rights senior to all other Texas water rights.

Water rights below Fort Quitman are subject to an allocation sequence that is governed by water use type instead of priority date. Since the WRAP model requires the use of priority dates to perform the computations, a special numbering scheme was developed for the Rio Grande WAM. The number assigned to each right is an eight digit code in which the first four numbers represent a specific group of rights with the same general priority and the last four digits specify a river order number (from upstream to downstream) which determines the order of the individual rights. For example, the first four digits of all Texas water rights classified as Domestic, Municipal, and Industrial (DMI) are between 4000 and 4999. The last for digits begin with 0100 and continue increasing in intervals of 100 up to 9900. The Class A water rights code starts with 5000, and for Class B with 6000. Therefore, DMI uses are satisfied first, followed by Class A and Class B rights. For rights within the same general priority group, the river order number establishes their relative priority.

The Texas water rights below Fort Quitman are dependent on the Amistad-Falcon Reservoir system. Water rights with diversion points between Amistad and Falcon are satisfied first using available streamflow with backup from Amistad. For water rights below Falcon, streamflow is used first with backup from Falcon and then from Amistad. In the model, Amistad is given a higher priority for refilling storage than Falcon in accordance with IBWC operational rules. The amount of storage available to backup the water rights and for operational purposes is determined by Texas Commission on Environmental Quality (TCEQ) rules. The next month storage allocations are accomplished within the WAM model by means of three dummy reservoirs. The first dummy reservoir (FDR) represents the combined storage in the Texas Amistad and Falcon Reservoirs. The other two computational reservoirs represent the amount of storage available to Class A and Class B irrigation rights and are sized to have a capacity of 1.41 times the combined annual diversion amounts for each category. Storage allocations are performed in the following fashion:

(1) The FDR is set equal to the end-of-month combined storage from the Texas Amistad and Falcon pools. The FDR has zero water in storage at the beginning of a simulation and the beginning of each time step.
(2) DMI reserve (225,000 ac-ft) and dead storage (4,600 ac-ft) is deducted from the FDR.
(3) The end-of-month account balance for Class A and Class B rights is deducted from the FDR.
(4) The operating reserve (75,000 ac-ft) is removed from the FDR.
(5) Deductions are made from the second and third dummy reservoirs (negative allocations) when the accounting process determines that water is required to re-establish the system operating reserve.

(6) If excess water is available in the FDR, this water is transferred to the second and third dummy reservoirs. The second dummy reservoir (Class A) receives 63% of the remaining water and 37% goes to the third dummy reservoir (Class B).

At the beginning of each month, a check is performed for Class A and Class B rights using the Drought Index (DI) option in WRAP. The DI option is used to modify the Class A and Class B diversion targets as a function of storage content in the second and third dummy reservoirs. If there is enough storage to satisfy all demands in the coming month the DI evaluates to 1 and no adjustments are made. If there is not enough storage, the DI evaluates to a factor equal to the amount of water in the dummy reservoir divided by the monthly demand for that particular month. The diversion amounts associated with that Class of water right are then reduced in accordance with the DI factor.

Although all water rights in the Rio Grande WAM are simulated individually, the Amistad-Falcon storage accounting process is performed with all water rights of a single class grouped and accounted for as a single account. Therefore, all Class A and Class B water rights generally have the same diversion reliability within the WAM.

8.3 MODELING OF WATER ALLOCATION ISSUES ON THE RIO GRANDE

The Rio Grande is a basin in stress. In the Middle Rio Grande, arid climate, dwindling water supplies, increased demand for services both in Texas and New Mexico, and contamination discharges of heavy industries and military-related facilities which are exempt from regulation have created a scenario of water crisis waiting to occur. In the Lower Rio Grande, overappropriation, alarming increase in demands for municipal uses, decreased reliabilities of irrigation water, drought susceptibility, and international treaty issues are impacting the long-term water availability of the region. The river's role as a border, and its crossing of states, means that regional and binational political considerations are essential to managing the basin's water supply. Also, population is expected to more than double over the next fifty years (RWPG 2001). This growth only adds to the urgency to improve water efficiency and increase long-term planning efforts.

About 10% of the population of Texas lives in the 32 counties around the Rio Grande (Silvy *et al.* 2003) and virtually all water needs in the Lower Rio Grande Basin are met by only one source, the river (Berger 1995). However, the amount of water supplied by the river is limited and often erratic given the basin semi-arid climate. Groundwater supplies are of such poor quality that they do not provide a valid alternative solution to the problem (McCoy 1990). Water rights for using the river have evolved over a long period of disputes between users. These disputes were intended to be resolved by the court decree of 1969 that established the current use-type based water rights system. However, despite the creation of this complicated system of water rights, the system remains over-allocated and no new rights are granted. However, existing rights can be transferred by several market means.

During the last two decades there has been an "active market" for water rights, mostly from agricultural uses to municipal uses (Chang and Griffin 1992). Purchased agriculture water is not fully converted into municipal water. Instead, the quantity available for municipal uses is a fraction of the irrigation right depending on the class of irrigation water right (Chapter VI). This approach is a conservation measure to ensure the system is not further stressed by the higher reliability required for municipal uses.

Droughts in the region further aggravate this situation. Drought occurs, on average, once every seven to ten years (Berger 1995). While droughts cannot be avoided in the region, steps can be taken to reduce their deleterious effects. The rapidly growing demands in the region make drought preparedness a main concern for ensuring that demands are met during dry years. Moreover, this area hosts an environment of rare and spectacular wildlife and plant species fueling an important local eco-tourism industry (Berger 1995). Many acres of wetlands have disappeared since the 1960's, since water use has been on a steep incline. Wetlands and surrounding upland areas are important to the survival of a number of endemic mammals, fish, birds, insects and plants. Any alternations to the hydrologic regime of the region could have devastating effects on the basin’s ecosystems.

In the following sections some of these issues will be addressed within the context of reallocation of water between uses, drought management, and instream flow requirements. The conceptual framework developed in Chapter VII is used as the basis for assessing the effectiveness of several alternative water management strategies in addressing these issues.

8.3.1 Reallocation Simulation

The scope of this simulation is twofold: (1) to assess water availability in the current system for future demands, and (2) explore the effects of reallocation mechanisms to supply such demands. Several of the water issues identified in the conceptual framework will be used in this assessment: water rights (section 7.2.1), reservoir storage considerations (section 7.2.4), system reliability (section 7.2.5), and multiple uses (section 7.2.6).

8.3.1.1 DMI Reserve Size Assessment

As mentioned previously, the terms of water rights in the Lower Rio Grande have been established by court decree and priorities are based on type of use. The allocation of storage between the use types in the system's reservoirs (Amistad and Falcon) is also predetermined by this decree (Chapter VI). One of the provisions is the establishment of the DMI reserve. Every month, 225,000 ac-ft are reserved in storage to provide an added measure of security for DMI uses in case of future scarcity. This is a form of hedging based on legal stipulations (section 7.2.4). In addition, an operational reserve (OR) is kept in storage for several purposes including delivery of water during low flow periods. Thus, the OR serves as another backup storage for DMI uses. The size of the OR varies monthly according with the water available after allocations.

The water right system in the Lower Rio Grande allocates all the risks of shortages to irrigators as it intends to protect DMI uses. The mechanism for storage allocation is imbedded in the water code (Chapter VI). These rules of allocation were developed in the late 1960s and 1970s when methodologies for assessing the necessary storage for ensuring complete protection of DMI uses were limited. A conservative approach was taken in which the DMI reserve size was set equal to the annual DMI diversions. In other words, it was guaranteed that the storage would be enough to cover all DMI demands for an entire year even if there were no inflows. However, an entire year without inflows is an extremely unlikely, if not impossible, hydrologic scenario. The purpose of this simulation exercise is to address if the current size of the DMI pool is necessary for ensuring complete satisfaction of DMI demands. This assurance will be assessed in terms of volume and period reliabilities.

In this exercise, the September 2005 full appropriation scenario (TCEQ Run 3) for the Rio Grande was used as the base model for comparison purposes. A preliminary simulation run using the base model was performed to establish the initial storage conditions of the reservoirs. TCEQ applications of WRAP assume that the reservoirs are full at the beginning of the simulation. The rationale behind this is that the results for a long period of analysis are not significantly affected by the initial conditions. However, having full reservoirs at the beginning of the simulation may not be a realistic assumption for arid areas like the Rio Grande basin. The initial storage content less the storage content at the end of the simulation represents extra water that could result in estimated reliabilities being higher than they should (Wurbs 2005). Thus, the Beginning-Ending Storage (BES) feature in WRAP was used to determine the initial storage conditions. The BES feature is based on setting beginning and ending storages equal, which reflects the concept of a cycling hydrologic simulation period. The initial storage condition for Amistad Reservoir was determined to be 259,929 ac-ft (15.5% of capacity) and for Falcon 61,140 ac-ft (3.9% of capacity). The storage traces for Amistad and Falcon Reservoirs shown in Figure 8.1 illustrate the results of this preliminary exercise.

Once the initial storage conditions were determined, several simulation runs were performed representing different scenarios of DMI and OR reserves sizes. The current water demands for the Lower Rio Grande (below Amistad) are shown in Table 8.1. The period of analysis extends from 1940 to 2000. The WAM model input data was modified as necessary to represent the different scenarios. The first set of runs consisted of the following scenarios:

- Preliminary run (Pre-run): base scenario with full initial storage conditions at reservoirs.
- Base scenario: DMI = 225,000 ac-ft/month; OR storage included.
- Scenario 1: DMI = 50% of total (112,500 ac-ft/month); OR storage included.
- Scenario 2: DMI = 25% of total (56,250 ac-ft/month); OR storage included.
- Scenario 3: DMI = 0% of total (0 ac-ft/month); OR storage included.

The average period (R_p) and volume (R_v) reliabilities for water right groups that are dependent on the Amistad-Falcon Reservoirs system are presented in Table 8.2. Notice that as expected reliabilities for the Pre-run scenario are higher than for the Base scenario. Therefore, determining a beginning-of-period storage as described above, rather than assuming full storage capacity, provides a more realistic analysis of the base conditions in the basin.

Table 8.1 Summary of Water Demands by Use in the Lower Rio Grande

DMI Water Demands	Class A Irrigation and Mining Demands	Class B Irrigation and Mining Demands
297, 067	1,616,363	183,894

Note: Values given in ac-ft/year

Table 8.2. Reliabilities Based on Various DMI Reserve Sizes

Scenario	% of Total DMI Reserve	Municipal Water Rights		Class A Irrigation Water Rights		Class B Irrigation Water Rights	
		R_v	R_p	R_v	R_p	R_v	R_p
Pre-run	100	100	100	62.3	45.2	39.8	23.2
Base	100	100	100	61.3	44.6	38.3	21.6
1	50	100	100	62.0	45.0	38.8	21.6
2	25	100	100	62.3	45.0	38.9	21.5
3	0	100	100	62.6	45.3	39.2	21.4

Notes: Reliabilities are given in percentages.

R_v = Volume Reliability; R_p = Period Reliability

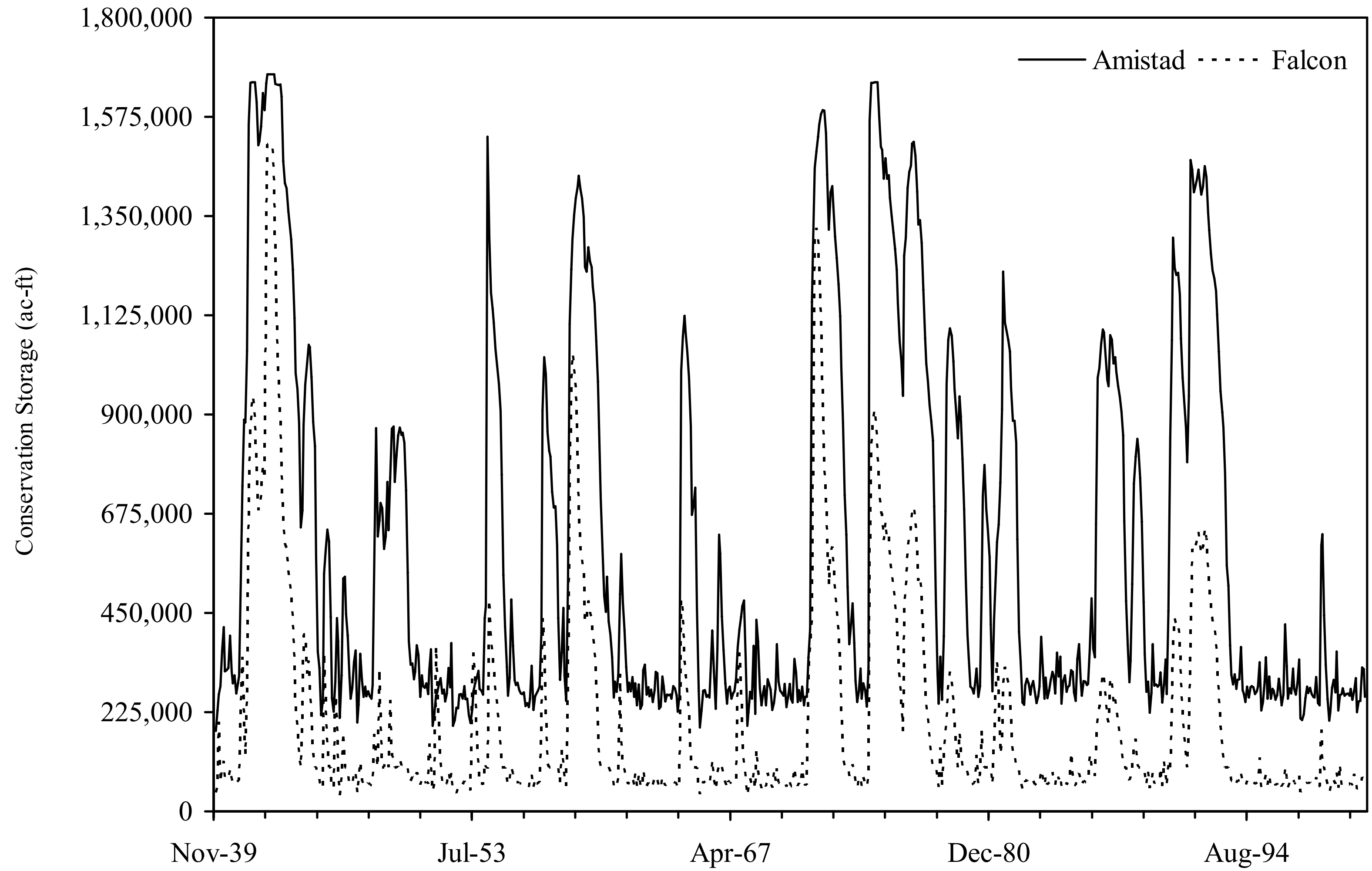


FIGURE 8.1. US Storage Trace for Amistad and Falcon Reservoirs. Preliminary Run

The R_p and R_v for municipal water rights in all scenarios is 100%. This demonstrates that municipal water rights are not affected by reductions in DMI reserve storage. Based on the model premises and assumptions, municipal demands would be fully met even if the DMI reserve is eliminated. This suggests that reserving 225,000 ac-ft/month of DMI storage is an extremely conservative hedging measure. The water liberated from the DMI reserve was available for other purposes in the simulation. With respect to Class A and Class B water rights, the liberated water helped to improve the reliabilities for irrigators. The largest increase was observed for Class A reliabilities, with increases of 1.3% and 0.7% for R_v and R_p, respectively. The significance of these increases in terms of additional volume is expounded in section 8.3.1.2. The OR also absorbed some of the freed water. The average OR storage in the Base scenario is 68,988 ac-ft/month, while for Scenario 3 the average is 69,678 ac-ft/month, an increase of 690 ac-ft/month.

The significance of the OR in terms of its effects on reliabilities was also evaluated. The second set of runs consists of the following scenarios:

- Base scenario: DMI = 225,000 ac-ft/month; OR storage included.
- Scenario 4: DMI = 225,000 ac-ft/month; OR = 0 ac-ft.
- Scenario 5: DMI = 0% of total (0 ac-ft/month); OR storage included.
- Scenario 6: DMI = 0% of total (0 ac-ft/month); OR = 0 ac-ft.

The average R_p and R_v for water right groups that are dependent on the Amistad-Falcon Reservoirs system are presented in Table 8.3. It is observed that if both the OR and DMI reserves are eliminated (Scenario 6), the municipal use reliabilities would fall slightly below 100%. In other words, there are some periods, although not many, when backup storage was needed for meeting municipal demands. Scenario 5 suggests that the water stored in the OR might be enough to ensure 100% reliabilities for the current municipal demands. In other words, when backup storage was needed for municipal rights, the OR had enough storage to satisfy demands. However, the storage allocated to the OR is not constant and it could even reach 0 ac-ft. Therefore, the simulation results cannot be seen as a guarantee that the OR will always have enough water for municipal demands when needed. This situation can be

Table 8.3. Reliabilities for Water Rights Dependent on Amistad and Falcon Reservoirs Based on Inclusion or Elimination of DMI and/or OR Reserves

		Volume Reliability			Period Reliability		
Scenario	**Simulation Conditions**	**Municipal**	**Class A Irrigation**	**Class B Irrigation**	**Municipal**	**Class A Irrigation**	**Class B Irrigation**
Base	DMI 100% OR 100%	100.0	61.3	38.3	100.0	44.6	21.6
4	DMI 100% OR 0%	100.0	62.1	38.4	100.0	45.9	21.9
5	DMI 0% OR 100%	100.0	62.6	39.2	100.0	45.3	21.4
6	DMI 0% OR 0%	99.98	63.3	39.2	99.99	46.3	21.7

Note: Reliabilities are given in percentages.

avoided if provisions are made for not allowing the OR to fall to zero; perhaps not allowing it to fall below the 48,000 ac-ft/month minimum established in the operational rules (Chapter VI, section 6.2.1).

8.3.1.2 Improving Reliabilities for Irrigation Uses

From the previous section it was observed that reliabilities for irrigation uses did not increased significantly from the reduction or elimination of the DMI reserve. However, as discussed in section 7.2.5, large amounts of water can be liberated by small changes in reliabilities. A trial-and-error exercise was performed using Scenario 3, in which irrigation diversions (Class A and Class B) were systematically increased in the WRAP input file using adjustment factors (UP records) until irrigation volume reliabilities matched those of the Base scenario.

The purpose of this exercise is to determine the amount of water that could be added to irrigators' diversions under Scenario 3 by maintaining the current reliabilities (R_v for Base scenario). This exercise assumes that it is preferable for irrigators to have a larger interruptible supply of water than a more consistent but smaller amount. It was determined that under the Scenario 3 conditions an increase of 20% on irrigation demands can be attained with the same reliability as the base scenario. Therefore, eliminating the DMI reserve could potentially provide to Class A and Class B irrigators an extra 323,273 ac-ft/year and 36,779 ac-ft/year, respectively, without affecting the current municipal and irrigation reliabilities. However, this conclusion is valid only if the storage capacity for irrigation uses does not change. The Lower Rio Grande water rights system establishes that the maximum storage capacity for irrigation rights changes as a function of the permitted diversion (maximum of 1.41 ac-ft of storage for each ac-ft of authorized diversion). In addition, Class A rights accrue storage at a rate 1.7 greater than Class B rights (Chapter VI). An additional simulation exercise was performed in which these varying storage capacities were considered. The objective of these simulations is to investigate the effects of eliminating the DMI reserve (Scenario 3) on irrigators' reliabilities subject to the storage allocation policy explained above. The exercise consisted of determining the reliabilities associated with diversion increases of 20, 30, and 40%.

- Base: DMI = 225,000 ac-ft/month; Current irrigation diversions.
- Scenario 3: DMI = 0 ac-ft/month; Current irrigation diversions.
- Scenario 7: DMI = 0 ac-ft/month; Irrigation diversions increased by 20%.
- Scenario 8: DMI = 0 ac-ft/month; Irrigation diversions increased by 30%.
- Scenario 9: DMI = 0 ac-ft/month; Irrigation diversions increased by 40%.

Results are presented in Table 8.4. It would be expected that the increase in demands would result in a decrease in reliability. Period reliabilities followed this pattern, especially for Class B irrigators. However, notice how Class A volume reliability increases when demands are increased by 20%. This increase in volume reliability shows the effect of increasing the maximum allowable storage for Class A rights. Yet, Class B volume reliability in this scenario is smaller than the Base scenario reliability. This disparity could be attributed to the different storage accruement rates for Class A and Class B. No clear relationship can be observed between irrigation volume reliability and increases in diversions, which could be attributed to the complex storage allocation formula of the system. More insight was obtained by increasing irrigation storage capacities rather than demands. The next simulation exercise explores this alternative in more detail.

Several simulation runs were performed to investigate the effects of using water made available from the elimination of the DMI reserve for increasing the storage capacity of irrigation rights. Permitted irrigation diversions are not increased in this simulation. The current maximum storage allocation formula (X * permitted diversions, X = 1.41) was modified by multiplying the permitted demands by different adjustment factors (X).

Table 8.4. Evaluation of Increases in Irrigation Diversions. No DMI

		Scenarios				
		Base (No increase)	**3** (No increase)	**7** (20% increase)	**8** (30% increase)	**9** (40% increase)
R_v	**Class A**	61.3	62.6	62.7	61.6	61.6
	Class B	38.3	39.2	37.7	38.3	35.4
R_p	**Class A**	44.6	45.3	44.0	42.8	46.6
	Class B	21.5	21.4	19.0	17.2	16.6

Note: Reliabilities are given in percentages.

This exercise runs consist of the following scenarios:

- Base: DMI = 225,000 ac-ft/month; Irrigation pools capacity set at 1.41 times their annual permitted diversion.
- Scenario 10: DMI = 0 ac-ft/month; Irrigation pools capacity set at 1.55 times their annual permitted diversion.
- Scenario 11: DMI = 0 ac-ft/month; Irrigation pools capacity set at 1.78 times their annual permitted diversion.

- Scenario 12: DMI = 0 ac-ft/month; Irrigation pools capacity set at 2.16 times their annual permitted diversion.

The adjustment factor of 1.55 used in Scenario 10 corresponds to a 10% increase in the irrigation pool size. In Scenarios 11 and 12 the adjustment factors correspond to the reallocation of 25 and 50% of the DMI reserve to irrigation storage pools. Table 8.5 shows irrigators' reliabilities as a function of the adjustment factors (or Class A and Class B storage capacity). In general, reliabilities for Class A water rights increase with increases in their storage capacities. For Class B, volume reliabilities increase in Scenario 10 but then decrease in Scenarios 11 and 12. Also, changes in Class B period reliabilities do not appear to correspond

Table 8.5. Evaluation of Increases in Irrigation Storage Capacity. No DMI

Scenario	Adjustment Factor	Storage Capacity (ac-ft/yr)		Volume Reliability		Period Reliability	
		Class A	Class B	Class A	Class B	Class A	Class B
Base	1.41	2,279,072	259,291	61.3	38.3	44.6	21.6
3	1.41	2,279,072	259,291	62.6	39.2	45.3	21.4
10	1.55	2,505,363	285,036	63.6	39.5	47.0	22.6
11	1.78	2,877,126	327,331	63.6	39.0	46.9	22.3
12	2.16	3,491,344	397,211	63.7	37.7	47.0	21.2

Note: Reliabilities are given in percentages.

with increases in storage capacity. This can be explained by understanding the Rio Grande model assumptions regarding the allocation of shortages to Class A and Class B water rights. Since there is no priority among irrigation rights within the same class group, the model assumes that shortages within a class group are distributed uniformly. This is accomplished by lowering diversion targets by a fraction that is determined based on the available storage for that class group at the beginning of the month (section 8.2.3). Therefore, the potentially higher storages at Class A pool (perhaps from excess flows that could not be stored with the original capacity) could avoid diversion reductions. This may translate into greater Class A depletions at diversion points, leaving less inflow available for Class B water rights which have a lower priority than Class A rights. Nonetheless, overall reliabilities improve as a result of the reallocation of portions of the DMI storage reserve to the irrigation pools. This suggests that increasing storage capacities rather than increasing diversion amounts could be a more effective strategy for improving irrigators' reliabilities. In other words, it is more efficient to have water in storage for use when needed, than being allowed to divert an additional amount of water that may or may not be available in the stream.

8.3.1.3 Assessment of Future Municipal Demands

Municipal demands for the year 2050 were calculated based on the projection developed by the Rio Grande Regional Water Planning Group M (RWPG 2001). According to the plan, the three counties that will experience the greatest population growth and therefore greatest demand for municipal uses are: Cameron, Hidalgo, and Webb. These three counties account for 72% of all municipal demands in the region. On average, by the year 2050 municipal demands are expected to increase in these three counties by 106% (from 178,483 to 367,675 ac-ft/yr). In order to simulate this future water use scenario, all municipal water rights in these counties were increased by 106%. The adjusted water rights diversion targets are presented in Table 8.6. The following set of simulation runs was developed to assess the capability of the system to supply the increased demands:

- Scenario 13: DMI = 225,000 ac-ft/month; OR storage included; 2050 municipal demands.
- Scenario 14: DMI = 0% of total (0 ac-ft/month); OR storage included; 2050 municipal demands.
- Scenario 15: DMI = 0% of total (0 ac-ft/month); OR = 0 ac-ft; 2050 municipal demands.

The average R_p and R_v for water right groups that are dependent on the Amistad-Falcon Reservoirs system are presented in Table 8.7. The results demonstrate the inability of the system under the current water allocation scheme to fully provide for future municipal demands

Table 8.6. Municipal Water Rights Data for Hidalgo, Cameron, and Webb Counties

Owner	Water Right ID	Use ID	Priority	Current Diversion (ac-ft/yr)	Diversion Year 2050 (ac-ft/yr)
US Dept Agri-Animal&Plant	1230312700100M	MUNMID	40005000	600.0	1236.0
Central Power & Light Co	6230002700100I	MUNLWR	40005400	600.0	1236.0
Central Power & Light Co	6230002700100I	MUNLWR	40005100	375.0	772.5
Falcon Rural WSC	6230007200101M	MUNLWR	40011200	85.0	175.1
La Joya WSC	6230008100100M	MUNLWR	40005200	250.0	515.0
La Joya WSC	6230008100100M	MUNLWR	40005300	750.1	1545.1
North Alamo WSC	6230024000100M	MUNLWR	40007200	1198.0	2467.9
North Alamo WSC	6230024000100M	MUNLWR	40008800	6251.2	12877.4
Central Power & Light	6230029400101M	MUNLWR	40005100	375.0	772.5
Hidalgo, County of	6230031300100M	MUNLWR	40006705	15.3	31.4
Rio WSC	6230033900101M	MUNLWR	40003500	131.5	270.9
Rio WSC	6230033900101M	MUNLWR	40004700	200.0	412.0
Mcallen, City of	6230035300101M	MUNLWR	40006700	678.8	1398.4
Hidalgo County Mud No. 1	6230054300101M	MUNLWR	40005900	84.0	173.1
City of Edinburg	6230080100100M	MUNLWR	40007100	2591.3	5338.1
City of Pharr	6230080800101M	MUNLWR	40003700	1083.9	2232.8
City of Pharr	6230080800101M	MUNLWR	40006800	1764.0	3633.8
Sharyland WSC	6230080900101M	MUNLWR	40006500	5583.5	11502.0
Palm Valley Est Utility Dist	6230080900201M	MUNLWR	40009500	312.5	643.8
Mercedes, City of	6230082300100M	MUNLWR	40007800	1015.0	2090.9
City of Weslaco	6230082400100M	MUNLWR	40007900	736.3	1516.7
Military Highway WSC	6230083100101M	MUNLWR	40009600	632.0	1302.0
Calpine Constr Finance Co	6230083500201M	MUNLWR	40005700	250.0	515.0
Cameron Co Irr Dist No 2	6230084100102M	MUNLWR	40010200	15057.5	31018.5
Town of La Blanca	6230085200100M	MUNLWR	40007400	12.5	25.8
Town of Hidalgo	6230085700100M	MUNLWR	40007000	12.5	25.8
Town of Los Ebanos	6230085800100M	MUNLWR	40004400	12.5	25.8
Town of Sullivan City	6230085900100M	MUNLWR	40004300	12.5	25.8
Town of Penitas	6230086000100M	MUNLWR	40006000	12.5	25.8
Village of La Joya	6230086400100M	MUNLWR	40004600	12.5	25.8
Texas Plastics Inc	6230087000100M	MUNLWR	40008000	100.0	206.0
Arroyo WSC	6230062500101M	MUNLWR	40010600	60.0	123.6

Note: Year 2050 diversions are based on future estimated demands (Rio Grande RWPG 2001)

Table 8.6. Continued

Owner	Water Right ID	Use ID	Priority	Current Diversion (ac-ft/yr)	Diversion Year 2050 (ac-ft/yr)
Boca Chica Water Supply Inc	6230015100201M	MUNLWR	40012000	20.0	41.2
Brownsville Public UtilBoard	6230086500201M	MUNLWR	40011800	29285.1	60327.3
Brownsville Public UtilBoard	12301838001	MUNLWR	40000000	40000.0	82400.0
City of Harlingen	6230022300100M	MUNLWR	40009800	162.0	333.7
City of Harlingen	6230022300100M	MUNLWR	40009300	131.2	270.2
City of Harlingen WS	6230083100102M	MUNLWR	40009400	1875.0	3862.5
City of Los Fresnos	6230085300100M	MUNLWR	40011500	911.7	1878.0
City of Lyford	6230082100100M	MUNLWR	40008200	370.3	762.9
East Rio Hondo WSC	6230006600201M	MUNLWR	40010500	17.6	36.2
East Rio Hondo WSC	6230006600201M	MUNLWR	40010100	40.0	82.4
East Rio Hondo WSC	6230006600201M	MUNLWR	40011100	70.0	144.2
East Rio Hondo WSC	6230006600201M	MUNLWR	40010300	75.0	154.5
East Rio Hondo WSC	6230006600201M	MUNLWR	40010700	21.3	43.9
East Rio Hondo WSC	6230083800101M	MUNLWR	40010900	2602.3	5360.7
Falcon Rural WSC	6230007200101M	MUNLWR	40011200	85.0	175.1
Laguna Madre Water Dist	6230085000100M	MUNLWR	40011000	7300.4	15038.7
Olmito Water Supply Corp	6230085400100M	MUNLWR	40011400	995.7	2051.2
Town of Primera	6230085500100M	MUNLWR	40009700	400.0	824.0
Valley Mud 2	6230020200100M	MUNLWR	40011300	898.0	1849.9
A C Durivage Et UX	6230242800100M	MUNLWR	40000900	0.5	1.1
Clarence Holt Et UX	6230243500301M	MUNMID	40002100	0.5	1.1
AEP Texas Central Company	6230002700100I	MUNLWR	40005400	4326.0	8911.6
Sacred Heart Childrens Home	6230274600100M	MUNMID	40000300	28.5	58.7
County of Webb	6230272000100M	MUNMID	40000400	2339.6	4819.6
City of Laredo	6230399700100M	MUNMID	40000200	45672.2	94084.7

Note: Year 2050 diversions are based on future estimated demands (Rio Grande RWPG 2001)

Table 8.7. Reliabilities for Water Rights Dependent on Amistad and Falcon Reservoirs for 2050 Projected Municipal Demands

		Volume Reliability			Period Reliability		
Scenario	**Simulation Conditions**	**Municipal**	**Class A Irrigation**	**Class B Irrigation**	**Municipal**	**Class A Irrigation**	**Class B Irrigation**
Base	DMI 100% OR 100%	100.0	61.3	38.3	100.0	44.6	21.6
13	DMI 100% OR 100%	100.0	52.6	32.3	100.0	37.9	18.5
14	DMI 0% OR 100%	100.0	53.9	33.2	100.0	38.4	18.9
15	DMI 0% OR 0%	99.8	55.1	33.2	99.8	38.8	18.9

Note: Reliabilities are given in percentages.

demands without decreasing current agricultural reliabilities (Scenario 13). A significant decrease in irrigators' reliabilities is observed when comparing Scenario 13 with the Base scenario (between 6 and 8.7%). Increased municipal demands cannot be fully satisfied from streamflow alone and some storage reserve is needed (Scenario 15). However, notice that the DMI reserve is not required to assure 100% reliabilities for municipal uses (Scenario 14). Once again, the simulation results suggest that the OR is sufficient to backup the municipal demands, but at the expense of irrigators. Scenario 14 shows that reallocation of the DMI reserve for future municipal appropriation is not an adequate mechanism for satisfying increased municipal demands while maintaining irrigation reliabilities. For that reason, a different reallocation mechanism was investigated.

Market transactions for transferring rights from irrigation to municipal have become the favored source of "new" water for meeting municipal demands in the basin. In the next simulation exercise, water market transfers from irrigation to municipal water rights are simulated to evaluate the effectiveness of this reallocation mechanism. In order to do this, Class A irrigation rights with permitted diversions larger than 500 ac-ft/yr were reduced to simulate a transfer of 189,192 ac-ft/year of water to municipal water rights (106% increase from current demands) (Table 8.8). The selected water rights account for 98.9% of all Class A irrigation water rights in the three named counties. According to TCEQ rules, when changing water use from Class A irrigation to municipal, only 50% of the total transferred water can be converted to municipal (Chapter VI). Consequently, in order to obtain the necessary water, 378,383 ac-ft from Class A rights need to be purchased. To accomplish this, the selected Class A water rights were reduced by 23.67% (Table 8.8). Reliabilities for water right groups that are dependent on the Amistad-Falcon Reservoirs system are presented in Table 8.9.

The only difference between Scenario 16 and the base run is the adjustment in Class A and municipal rights. Under the current allocation rules for the Lower Rio Grande, the market mechanism is the only strategy of the ones in this simulation exercise that, by providing water for increased municipal demands, does not decreases the reliabilities of irrigators. In fact, under the market strategy, irrigation reliabilities improve between 3.4 and 7.1%. In other words, these market transactions not only benefit the municipal users that purchase the water and the irrigators that sell it, but also the irrigators remaining in the system. It functions both as a "new" source of water and a conservation measure, liberating more water for irrigators. Notice that in order to increase irrigation reliabilities and provide 100% to municipal uses, no water from the DMI reserve had to be liberated. However, this does not change the fact that the backup storage in the DMI reserve is not required for ensuring 100% reliability for current or future municipal uses, raising again the question if this water could be available for other uses; perhaps for maintaining environmental flows.

Table 8.8. Adjusted Class A Water Rights for Water Market Transfer to Municipal Use

Owner	Water Right ID	Use ID	Priority	Current Diversion (ac-ft/yr)	Adjusted Diversion (ac-ft/yr)
United States Dept. of Interior	1230312900100A	AM-IRR	50015900	2935	2240
US Fish & Wildlife Service	6230012600101A	AL-IRR	50011700	1848.365	1410.829
Sam R Sparks Inc	6230021300100A	AL-IRR	50021600	3199.825	2442.378
Diana Inez Santiso Del Rio	6230024300100A	AL-IRR	50024400	920.9875	702.9759
Dulaney Farms Ltd	6230026800100A	AL-IRR	50020900	1000	763
Martha M & James D Russell	6230028800101A	AL-IRR	50024100	9145.875	6980.908
Madeira Properties, Ltd	6230028800102A	AL-IRR	50024200	2654.125	2025.854
Carl L Bauer et al	6230029600201A	AL-IRR	50022100	959.215	732.154
Coronado Company Llc	6230029700100A	AL-IRR	50023600	1492.25	1139.01
River Farms Partnership	6230031700100A	AL-IRR	50016700	1325	1011
Moore & Sons Farms Inc et al	6230031800100A	AL-IRR	50022400	500.175	381.776
Sharyland Corporation	6230033200100A	AL-IRR	50013200	2592.125	1978.530
W G Bell Jr	6230034900200A	AL-IRR	50016600	1875	1431
Club Mark Corporation	6230039900101A	AL-IRR	50013000	1990.235	1519.116
Annette Katz Cottingham et al	6230060100201A	AL-IRR	50011400	1287	982
Starr Produce Company	6230071100101A	AL-IRR	50011100	822.175	627.554
Salvador Garcia Jr	6230076700101A	AL-IRR	50011200	1146.22	874.89
Hidalgo County Irr Dist 16	6230080200101A	AL-IRR	50011600	30948.85	23622.79
La Feria Id Cameron Co 3	6230080300101A	AL-IRR	50018800	75625.93	57724.13
City of Roma	6230080300102A	AL-IRR	50018700	551.4	420.9
Santa Cruz Irr Dist 15	6230080400101A	AL-IRR	50012000	77180	58910
Donna Id Hidalgo Co 1	6230080500101A	AL-IRR	50016400	94063.6	71797.3
Hidalgo Co Wcid 19	6230080600100A	AL-IRR	50013100	9437.57	7203.55
Valley Acres Irrig Dist	6230080700100A	AL-IRR	50017800	16324.25	12460.05
Hidalgo Co Irr Dist 2	6230080800101A	AL-IRR	50015300	137775	105162
Engleman Irrig District	6230080900401A	AL-IRR	50016300	18994.35	14498.10
Hidalgo County Irr District #13	6230081000101A	AL-IRR	50016900	4856.85	3707.16
Delta Lake Irr Dist	6230081100101A	AL-IRR	50018400	174776.4	133404.2
Hidalgo & Cameron Wcid #9	6230081200101A	AL-IRR	50017400	177151.6	135217.1
Hidalgo Co Irr Dist 5	6230081300100A	AL-IRR	50016900	14234.63	10865.08
Hidalgo Co Irr Dist 1	6230081600101A	AL-IRR	50011900	85615	65349
Santa Maria Id Cameron Co 4	6230081700101A	AL-IRR	50018600	10182.5	7772.1
City of Elsa	6230082600100A	AL-IRR	50017900	697.6	532.5
Hidalgo Co Irr Dist No 6	6230082800101A	AL-IRR	50011800	34913	26649
Cameron Co Irr Dist No 6	6230082900100A	AL-IRR	50026100	52141.93	39799.15

Table 8.8. Continued

Owner	Water Right ID	Use ID	Priority	Current Diversion (ac-ft/yr)	Adjusted Diversion (ac-ft/yr)
Harlingen Irr Dist	6230083100101A	AL-IRR	50019300	98232.5	74979.4
City of Harlingen Waterworks	6230083400101A	AL-IRR	50019200	1625	1240
Cameron Co Wid 10	6230083400201A	AL-IRR	50024900	8587.5	6554.7
Bayview Irr Dist 11	6230083500101A	AL-IRR	50026000	17478.03	13340.72
Cameron Co Wid #16	6230083800101A	AL-IRR	50022500	3712.5	2833.7
Cameron County Wid 17	6230083900100A	AL-IRR	50022700	625	477
Adams Gardens Irr Dist 19	6230084000101A	AL-IRR	50019100	18737.66	14302.17
City of Harlingen	6230084100101A	AL-IRR	50021300	147823.7	112831.6
Brownsville Irrig District	6230084300101A	AL-IRR	50026500	33949.45	25913.10
United Irrig District	6230084700101A	AL-IRR	50012500	57374.31	43792.94
Hidalgo Co Wid 3	6230084800101A	AL-IRR	50013300	9852.6	7520.3
Brownsville Public Util Board	6230086500101A	AL-IRR	50026400	1782.5	1360.6
Brask-Dumont Ranch	6230242100401A	AM-IRR	50000800	3071	2344
Maverick Co Wcid 1	6230267100100A	AM-IRR	50000100	135000	103043
Maverick Co Wcid 1	6230267100100M	AM-MUN	50000100	2145	1637
5D, Inc	6230269600100A	AM-IRR	50001200	990	756
Mandel Properties Ltd	6230269800100A	AM-IRR	50001300	680	519
Central Power & Light Co	6230272700100A	AM-IRR	50003400	2194.5	1675.0
Laredo National Bank Trustee	6230276300100A	AM-IRR	50005400	1500	1145
Rancho Blanco Corporation	6230277200201A	AM-IRR	50005500	899	686
Lannie Mecom	6230278000100A	AM-MIN	50005800	1050	801

Table 8.9. Comparison of Reliabilities for Market Tranfers Simulation

Scenario	Municipal Water Rights		Class A Irrigation Water Rights		Class B Irrigation Water Rights	
	R_v	R_p	R_v	R_p	R_v	R_p
Base	100	100	61.3	44.6	38.3	21.6
16	100	100	65.4	51.6	41.8	28.0
Difference	0	0	4.1	7.1	3.4	6.4

Notes: Reliabilities are given in percentages.
R_v = Volume Reliability; R_p = Period Reliability

8.3.2 Instream Flow Requirements Simulation

Mechanisms for developing and incorporating instream flow requirements are covered in Chapter VII, section 7.2.8. The scope of this simulation exercise is to demonstrate some mechanisms for incorporating instream flow requirements in the Lower Rio Grande system and to assess their relative effectiveness using reliability indices.

8.3.2.1 Evaluation of Methodologies for Establishing Instream Flow Requirements

There is only one water right in the Lower Rio Grande basin with a diversion restriction for instream flows. The City of Brownsville Public Utilities Board (BPUB) owns a water right for diverting 40,000 ac-ft/year from excess flows with priority date of 1956. The BPUB water right is subject to water being available in excess of 25 cfs at its diversion point and has no access to storage in Amistad-Falcon Reservoirs. In the Rio Grande WAM this instream flow requirement is set senior to all other municipal rights that are dependent on the Amistad-Falcon Reservoirs. In this manner, these excess flow rights have access to whatever US flows may occur in the river downstream of Falcon before the reservoir-dependent water rights. Otherwise, all of the US flows in the Lower Rio Grande would be diverted first by the reservoir-dependent water rights, and these water rights would never have water available for impoundment or diversion (R.J. Brandes Company 2004).

The two methods that are commonly used in Texas for defining instream flow benchmarks (minimum instream flows) are: the Lyons method (Bounds and Lyons 1979) and the Consensus Criteria for Environmental Flow Needs (CCEFN). The Lyons method was developed by the Texas Parks and Wildlife Department (TPWD) and has been applied by the TCEQ for water permitting purposes. The CCEFN method is part of the Texas Guidelines for Regional Water Plan Development, produced by the Texas Water Development Board (TWDB 2002) and it is intended to be the official methodology for evaluating instream flows as part of the agency's water planning duties by 2007.

The Lyons method uses percentages by month of daily-averaged flows as the parameter that determines instream flows. For permitting, instream flows minimums are defined as 40% of the median monthly flows from October to February; and 60% of the monthly median flows from March to September. The 60% values were chosen to provide more protection during the critical spring and summer months (NRC 2005). The CCEFN method defines three zones for pass-through flows in reservoirs and for direct diversions from free-flowing streams and rivers (TWDB 2002). The first zone minimum benchmark value is the monthly median flow. If the flow at the measured location is equal or greater than the monthly median, the pass-through flow is set equal to the monthly median flow. Zone 2, is defined between the monthly median flow (upper limit) and the monthly 25th percentile flow. The pass-through flow is set equal to the 25th percentile. In zone 3, which is the lowest flow category zone, minimum flows will be the larger of the flow necessary to maintain acceptable water quality standards or some site-specific minimum flow determined by TCEQ's planning staff. For the purpose of this simulation, the criterion for establishing the zone 3 benchmark is assumed to be the 7-day 2-year low flow (7Q2) water quality standard (49.58 ac-ft/day). The 7Q2 is a statistical estimate of the lowest average flow that would be experienced during a consecutive 7-day period with an average recurrence interval of two years. For zones 1 and 2, if the target flows (median and 25th percentile) are smaller than the 7Q2 water quality standard, the 7Q2 is used as target flow instead. Whereas the Lyons method is routinely developed from gage flow data, CCEFN uses percentile values of naturalized flows to determine direct diversion and pass-through flows.

Both methodologies determine the flow benchmarks using daily flow data. Therefore, the first step is to extract from the WAM model the naturalized flows at the control point of interest. Monthly naturalized flows for the BPUB diversion point were then disaggregated into daily flows based on the historical streamflow distribution of the same gaging station used to determine compliance with the BPUB water permit (IBWC Station at Rio Grande Near Brownsville, Texas and Matamoros, Tamaulipas). Since the Rio Grande basin has been extensively altered by human activities, a period of record was selected where flow alteration was minimal. The available daily flow values from the period before the construction of Amistad-Falcon Reservoirs were selected for the analysis (1939 – 1950). Daily and monthly gage flow values were used for disaggregating monthly naturalized flows and obtaining daily naturalized flows. These values were obtained using the following equation:

$$DNQ = MNQ\left(\frac{DGQ}{MGQ}\right) \qquad \text{Eq. 8.1}$$

where *DNQ* is daily naturalized flow, *MNQ* is monthly naturalized flows from WAM, *DGQ* is daily flow observed at the gage station, and *MGQ* is the monthly aggregated flow at the gage station (Trungale et al. 2003). A comparison between observed and the resulting naturalized daily flows is presented in Figure 8.2. As expected, the plot shows some differences between naturalized and observed values. On average, naturalized flows are higher than observed flows since observed values reflect the effect of flow depleting activities naturalized flows have accounted for.

From the daily naturalized flows the monthly benchmark instream flow values were computed. Table 8.10 summarizes benchmark values for the Lyons and CCEFN methods as well as the fixed regulatory minimum flow for the BPUB water permit. Several combinations of *IF, TS,* and *TO* records within WRAP were used to simulate the instream flow targets for each methodology.

Simulation results are summarized in Table 8.11. In general, the reliabilities of the diversion are high because it relies on storage from the Brownsville weir. It is observed that at the diversion's control point, results are similar for the BPUB permit flow and the CCENF. For the CCENF methodology diversion reliabilities were higher, but the instream flow requirement period reliability was lower.

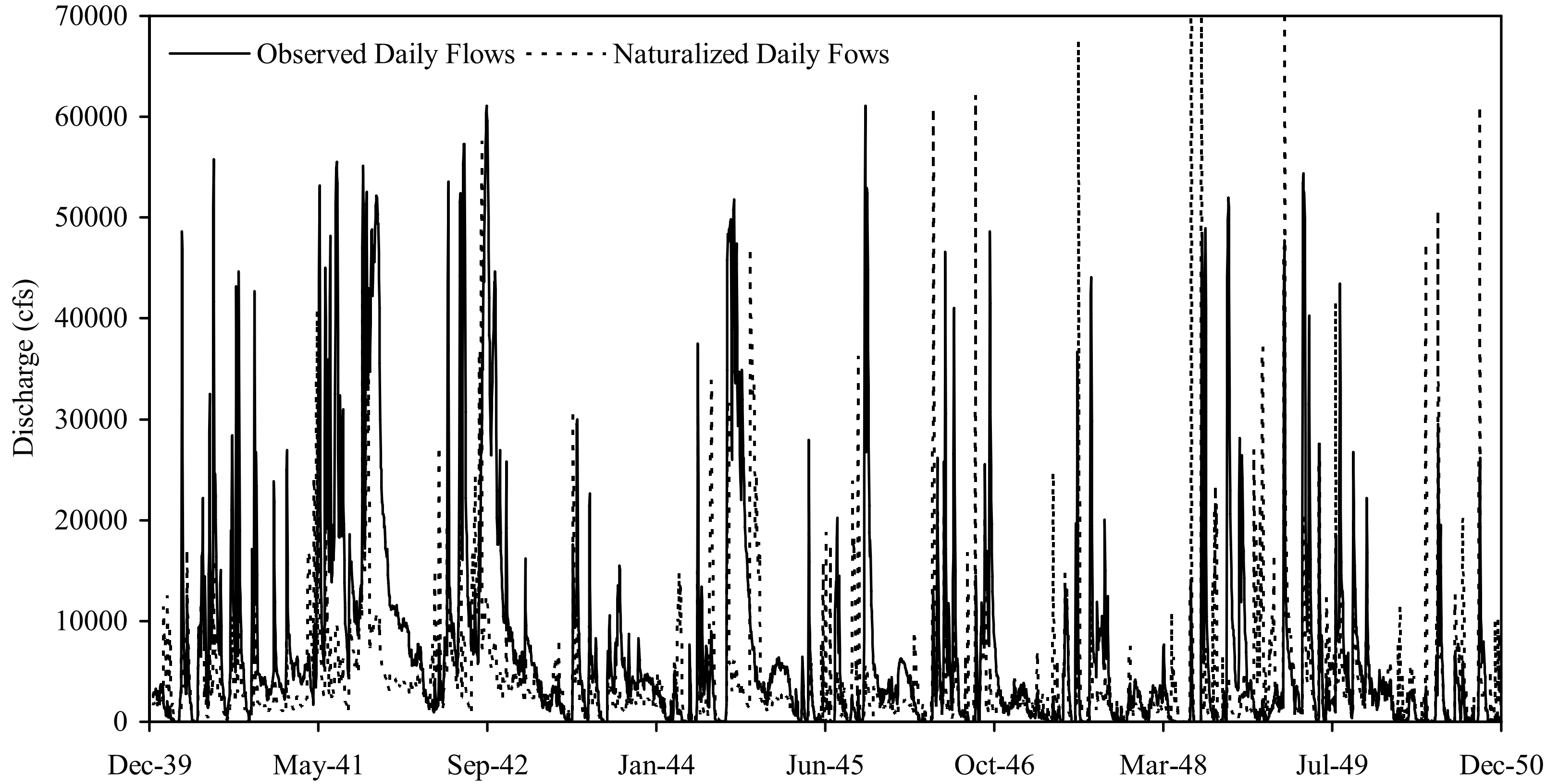


FIGURE 8.2. Observed and Naturalized Daily Flows at Brownsville

Table 8.10. Benchmark Flows for Establishing Instream Flow Requirements for the BPUB Water Right

Month	BPUB Minimun Flow	CCEFN			Lyons Minimun Flow
		Zone 1 Minimun Flows	Zone 2 Minimun Flows	Zone 3 Minimun Flows	
Jan	1,538	1,996	1,538	1,538	798
Feb	1,389	1,964	1,443	1,389	786
Mar	1,538	1,878	1,538	1,538	1,127
Apr	1,488	2,526	1,488	1,488	1,515
May	1,538	1,944	1,538	1,538	1,166
Jun	1,488	2,296	1,488	1,488	1,378
Jul	1,538	2,392	1,538	1,538	1,435
Aug	1,538	2,419	1,538	1,538	1,451
Sep	1,488	4,042	1,717	1,488	2,425
Oct	1,538	2,142	1,538	1,538	857
Nov	1,488	2,340	1,488	1,488	936
Dec	1,538	2,264	1,538	1,538	906

Table 8.11. Comparison of Instream Flow Requirement Methodologies for BPUB Water Right

	Control Point ET0104	Brownsville Diversion			Instream Flow Criteria
Instream Requirement Methodology	**Average Regulated Flow (ac-ft/month)**	**Mean Shortage (ac-ft/month)**	**R_v**	**R_p**	**R_p**
BPUB Minimun Flow	336.9	157.1	95.3	92.2	67.8
CCEFN	337.1	130.8	96.1	93.9	66.4
Lyons	266.2	139.2	95.8	93.2	77.1

Notes: Reliabilities are given in percentages.
R_v = Volume Reliability; R_p = Period Reliability

The Lyons method results in a better instream flow period reliability but that was expected given the fact that the monthly benchmark values were smaller than those of the other two methods. The National Research Council (NRC) (2005) reported that Texas WAM's assessments of instream flows using the Lyons method can greatly underestimate instream flows for certain months of the year.

The similarities between the CCENF and the BPUB permit minimum flow results are not surprising. The CCENF methodology uses the 7Q2 standard as the minimum flow allowed under zone 3 conditions. This value happens to be the same as the BPUB permit flow restriction. At that time the original permit was approved, there were no provisions for considering environmental flows into the permit process so the only consideration for determining pass-through flows was honoring downstream permits. It was determined that the flow required for downstream users was 25 cfs. In 2001, BPUB solicited a permit for the construction of a weir to impound an additional 6,000 ac-ft. It so happens that the TCEQ standard for minimum flows for maintaining water quality for the last stretch of the Rio Grande was also 25 cfs (Kathy Alexander, personal communication, September 30, 2005).

TCEQ approved the construction of the weir and the 25 cfs minimum flow was maintained. It is important to point out that the 7Q2 minimum flow standards are based on the last 30 years of flow records. Therefore, 7Q2 values probably reflect the effects of the BPUB diversion and not the minimum natural flow of the river.

The NRC (2005) report recommends assessing the possibility of operating the WAM models in a daily time-step since this could significantly improve the applications of the aforementioned methodologies and assessment of strategies for protecting instream flows. Monthly based methodologies are useful for giving general estimates of instream flow needs, but more detailed studies might be required in order to generate instream flow estimates that are consistent with flow protection goals. Currently, efforts are being undertaken to develop a daily time-step version of WRAP that could potentially address current limitations for better incorporating instream flow requirements into the planning process. Other methodologies such as base flow separation and site-specific habitat flow requirements that are based on daily flow variations could be potentially used in conjunction with WAM models to further improve instream flows protection efforts.

8.3.2.2 Instream Flow Requirements for the Lower Rio Grande

Two additional simulation scenarios were formulated in order to evaluate the effects of adding an instream flow requirement for all water rights in the Lower Rio Grande system near the mouth of the river at the Brownsville station. Currently, the instream flow requirement only applies to the Browsnville water right (i.e. BPUB). In the WAM model (Base scenario), the instream flow target is turned off after BPUB water is diverted. In this manner, the rest of the water rights are not affected by the instream flow requirement. This modeling structure is modified in Scenarios 17 and 18 in order to maintain the instream flow requirement after the BPUB diversion, thereby affecting all water rights. From the instream flow methodology evaluation it can be concluded that the 25 cfs instream flow requirement of the BPUB water right was the most conservative approach. This value was adopted in the next set of simulations. The scenarios can be summarized as follows:

- Base scenario: DMI = 225,000 ac-ft/month; OR storage included.
- Scenario 17: DMI =225,000 ac-ft/month; OR storage included; Instream flow requirement = 25 cfs at Brownsville gage.
- Scenario 18: DMI = 0 ac-ft/month; OR storage included; Instream flow requirement = 25 cfs at Brownsville gage.

Results from the simulation runs are summarized in Table 8.12.

Table 8.12. Evaluation of Instream Flow Requirement for all Water Rights

Scenario	% of Total DMI Reserve	Municipal Water Rights		Class A Irrigation Water Rights		Class B Irrigation Water Rights		Instream Flow at Brownsville
		R_v	R_p	R_v	R_p	R_v	R_p	R_p
Base	100	100	100	61.3	44.6	38.3	21.6	67.8
17	100	100	100	61.2	44.5	38.2	21.5	78.0
18	0	100	100	62.5	45.3	39.1	21.4	82.1

Notes: Reliabilities are given in percentages.
R_v = Volume Reliability; R_p = Period Reliability

Under the current allocation scheme of the system, it is observed that when the instream flow requirement applies to all water rights in the system (Scenario 17), reliability values for irrigators drop approximately 0.1%. On the other hand, the period reliability for the instream flow increases 10.2%. Meanwhile, municipal diversion reliabilities are not affected. Also notice, that by making water available from the DMI reserve for appropriation (Scenario 18), instream flow period reliability increases 14.3%. This increase in R_p translated into an increase of 2,720 ac-ft/month in the monthly regulated flow average at the gaging station in Brownsville. Notice the significant increase in instream flow compliance due to the use of the water in the DMI reserve. As concern increase in Texas and the US regarding the protection of instream flows, more pressure has been placed on regulating agencies to provide water for environmental flows in this overappropriated system. The results from this simulation suggest that water for environmental flows could be obtained from the reallocation of some portion of the DMI reserve without affecting current uses reliabilities.

8.3.3 Drought Management Simulation

Drought management is an inherent component of the Lower Rio Grande WAS. Basically, the water right system acts as a drought contingency mechanism. Municipal uses receive the greatest protection against shortages by receiving their allotment first. The allocation sequence distributes the entirety of the risks among irrigators. Therefore, agricultural uses bear the entire burden by absorbing all the shortages. Furthermore, the current rules for operating Amistad-Falcon Reservoirs function as a drought response mechanism in the sense that as storage in the reservoirs fall, irrigation water rights will have their storage rights honored only when there is a water surplus after all other rights and operational needs of the system have been satisfied.

However, as shown in the previous simulations, the degree protection given to municipal against shortages is extremely conservative, unnecessarily harming irrigators. The purpose of this simulation is to investigate an alternative drought management strategy that can improve the overall efficiency of the system in supplying water to all users. The previous simulations showed that irrigation reliabilities can be improved by reducing the DMI reserve without affecting municipal reliabilities. Thus, a less conservative approach is evaluated here in which the DMI reserve size is adjusted as a function of relative drought conditions. In this application, the water availability state of the system, which is one of the principles presented in the WAS framework (section 7.2.8), is adopted for defining drought conditions.

The drought contingency provisions on the current water rights system are compared with two alternative mechanisms which use reservoir storage as a water availability drought trigger for implementing measures that can reduce drought vulnerability, not only for municipal uses, like the current system, but also for irrigation uses. The first alternative mechanism establishes storage triggers based on percent conservation storage capacity. This strategy reflects the recommendations presented in the Texas Drought Preparedness Plan (Drought Preparedness Council 2005) for defining drought stages based on water availability. Each drought stage has an associated range of values describing reservoir conditions. The lower value serves as a trigger to launch a particular mitigation measure. These storage triggers (i.e. % of storage capacity) were determined arbitrarily and may not properly reflect the hydrologic conditions of the system. The mitigation measures associated with each stage are determined as part of the local and regional planning process. For reference purposes, Table 8.13 presents a summary of the Amistad-Falcon Reservoirs conservation storage capacity data (Year 2000 sediment conditions).

Table 8.13. Amistad-Falcon Reservoir System Conservation Storage Capacity Data

Reservoir	Conservation Storage Capacity (ac-ft)	US % of Storage Capacity	MX % of Storage Capacity	US Storage Capacity (ac-ft)	MX Storage Capacity (ac-ft)
Amistad	3,151,306	56.2	43.8	1,771,034	1,380,272
Falcon	2,653,793	58.6	41.4	1,555,123	1,098,670
Combined	5,805,099	57.3	42.7	3,326,157	2,478,942

In the Rio Grande Regional Drought Preparedness Plan, it is suggested that no additional mitigation measures are needed besides the current water rights system (RWPG 2001). Here, the recommended trigger storage conditions were applied to the Amistad-Falcon Reservoir system and a set of mitigation measures (Plan 1) entailing resizing the DMI reserve were developed and tested (Table 8.14). The DMI reserve sizes associated with each drought stage were determined based on subjective judgment. An exceedance frequency analysis was performed in order assess how well the storage ranges represent the water availability state of the system. The exceedance frequency (i.e. percent of the time the storage value was equaled or exceeded) of the storage triggers was determined based on the historical combined end-of-period storages of Amistad and Falcon Reservoirs (Base conditions scenario). This analysis showed that according to the computed triggers, the system would be under some kind of drought condition 95% of the time. Therefore, these triggers may not properly represent the water availability conditions of this system.

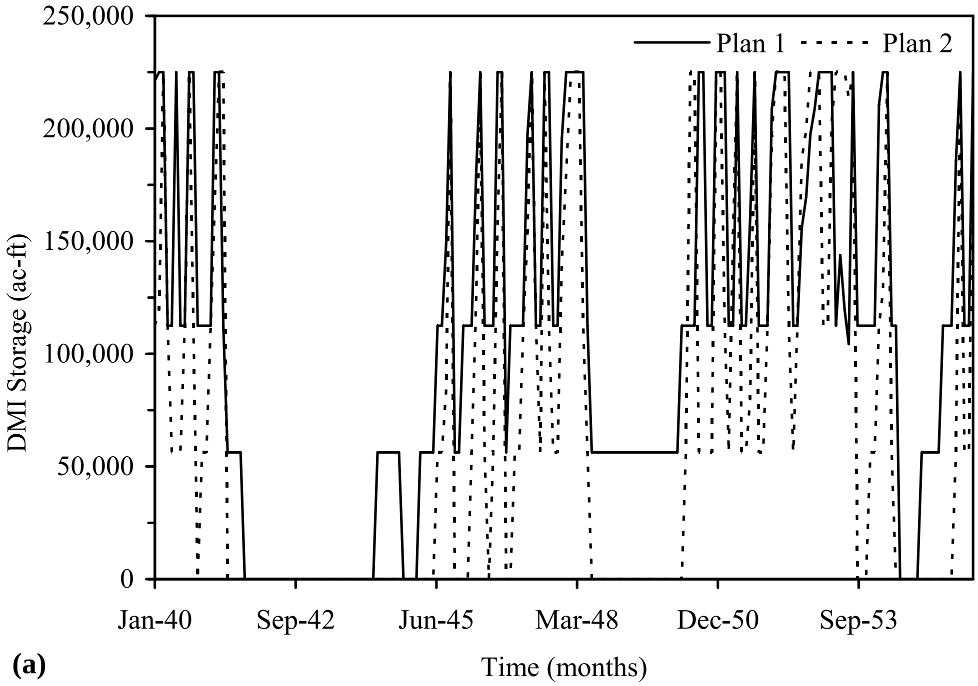
The second alternative (Plan 2) addresses this problem by developing a set of triggers based on the storage contents that are associated with certain exceedance frequency (Table 8.15). This proposed set of triggers may be better indicators of what can be considered normal (and conversely abnormal) storage conditions of the system. As with Plan 1, the mitigation measures (DMI reserve sizes) associated with Plan 2 triggers were determined based on subjective judgment. The proposed drought alternatives (Plans 1 and 2) were modeled with WRAP using the Drought Index option, which can adjust diversions as a function of reservoir storages. Figure 8.3 depicts a portion of the storage traces for the DMI reserve and the combined Amistad-Falcon storage resulting from the implementation of Plans 1 and 2. As expected, the size of the DMI reserve increases as storage on the reservoirs decreases and vice versa.

Table 8.14. Drought Management Plan 1. Based on Texas Water Availability Assessment Criteria

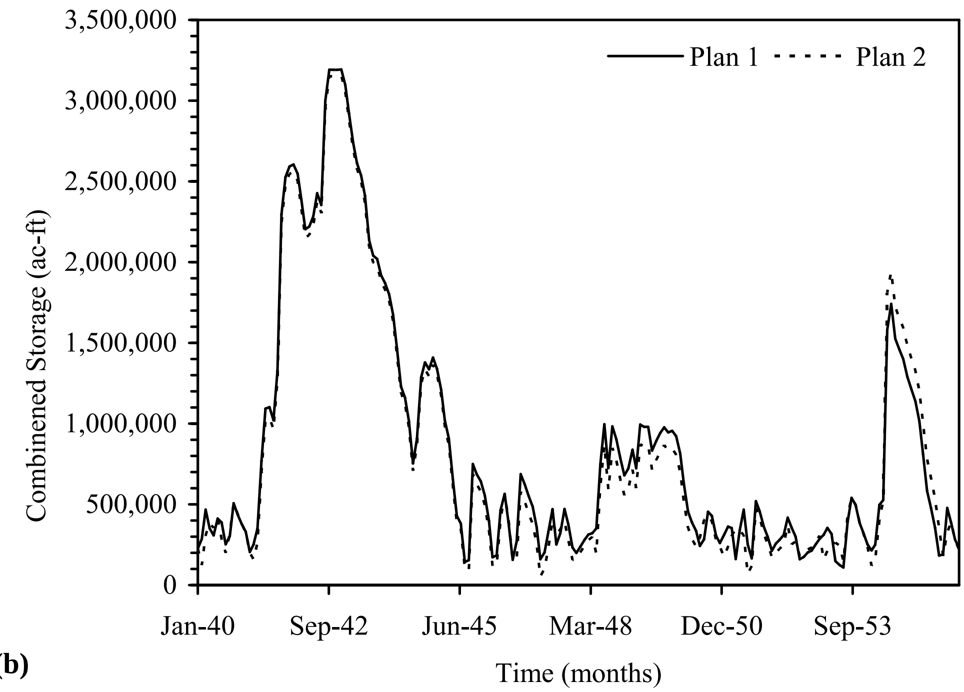
Drought Stage	Reservoir Storage Trigger (% of conservation capacity)	Combined Amistad-Falcon Storage (ac-ft)	% DMI Reserve	DMI Reserve (ac-ft)	Storage Exceedence Frequency (%)
Abnormally Dry	70	2,257,466	0	0	95
First-Stage Drought	60	1,934,971	0	0	90
Severe Drought	40	1,289,981	25	56,250	79
Extreme Drought	20	644,990	50	112,500	59
Exceptional Drought	10	322,495	100	225,000	15

Table 8.15. Drought Management Plan 2. Based on Storage Exceedence Frequency Analysis

Drought Stage	Reservoir Storage Trigger (% exceedence frequency)	Combined Amistad-Falcon Storage (ac-ft)	% DMI Reserve	DMI Reserve (ac-ft)
First-Stage Drought	35	825,850	0	0
Severe Drought	55	423,931	25	56,250
Extreme Drought	85	323,340	50	112,500
Exceptional Drought	99	249,983	100	225,000



(a)



(b)

FIGURE 8.3. Storage Traces Sample under Drought Management Plans. (a) DMI Traces; and (b) Combined Amistad-Falcon Traces

Also notice that in general Plan 1 results in a larger DMI reserve more frequently than Plan 2. The reason for this is that Plan 1 triggers declare drought conditions more often and more severe than Plan 2. Since Plan 2 triggers consider the actual distribution of storages, they can be more flexible than both the Base scenario and Plan 1 which adopt more conservative approaches for compensating for system uncertainties.

Reliability values for the municipal and irrigation water rights for the base scenario, Plan 1, and Plan 2 are presented in Table 8.16. As with previous simulations, the results indicate that irrigation reliabilities can be improved when implementing measures that reduce the DMI reserve without affecting the period and volume reliability for municipal uses. In these

Table 8.16. Comparison of Reliabilities for Drought Management Alternatives

Scenario	Municipal Water Rights		Class A Irrigation Water Rights		Class B Irrigation Water Rights	
	R_v	R_p	R_v	R_p	R_v	R_p
Base	100	100	61.3	44.6	38.3	21.6
Plan 1	100	100	61.4	48.9	39.7	24.9
Plan 2	100	100	61.7	51.3	39.7	25.6

Notes: Reliabilities are given in percentages.
R_v = Volume Reliability; R_p = Period Reliability

simulations, all irrigation reliabilities improve, especially with the less conservative Plan 2. The effect of the drought measures are observed more clearly for Class B irrigation rights. Since Class B rights experience more shortages than Class A, they also benefit the most from the studied drought mitigation plans. Another interesting finding is that some reliabilities, especially period reliabilities, are higher than those obtained by eliminating completely the DMI reserve (Scenario 3). Only Class A volume reliability was higher for Scenario 3 than Plan 2. These changes in reliability values are difficult to interpret, but in the simulation of storage allocation to irrigation uses (section 8.3.1.2) it was shown that increases in water availability to irrigation uses, being inflows or storage, benefit Class A and Class B differently due to the system's complex water allocation scheme.

8.3.4 Concluding Remarks Regarding Simulation Study

The strategies presented in this Chapter's simulations indicate that there is potential for improving the efficiency of the system by the reallocation of portions of the DMI reserve. In addition, it was observed that the primary safeguard of municipal uses is its priority in the water allocation sequence. In addition to this, municipal uses have two additional protection mechanisms: the DMI and OR reserves. The results in this Chapter show that having one of these reserves is sufficient for providing extra protection against shortages.

Even in a scenario of increase municipal demands, the OR reserve could provide enough protection for municipal uses, provided that operational rules are modified to avoid the reserve from been emptied. Making DMI reserve water available for future municipal diversions was not found to be an effective reallocation strategy for satisfying the fast-growing municipal demands without penalizing irrigators. Market mechanisms were shown to be a better alternative for this purpose. Under the current allocation rules, it was demonstrated that market mechanisms can provide water for increased municipal demands without decreasing the reliabilities of irrigators. In fact, under the market strategy, irrigation reliabilities improved. In other words, these market transactions not only benefit the municipal users that purchase the water and the irrigators that sell it, but also the irrigators remaining in the system. It functions both as a "new" source of water and a conservation measure, liberating more water for the irrigators that remain in the system.

Even though the reallocation of DMI reserve to increased municipal demands was not sufficient, other benefits can be obtained from a multiuse reallocation approach of portions the DMI reserve. For instance, irrigators could benefit from the elimination or reduction of the DMI reserve, especially if the reallocation involves increasing irrigation storage. Also, if water for environmental flows is needed, water from the DMI reserve can significantly increase instream flows. The results show that an instream flow requirement could potentially be incorporated into the system without significantly affecting existing uses reliabilities.

Due to the administrative and legal constraints of the Lower Rio Grande WAS, it is unlikely that the DMI reserve would be eliminated based on simulation models that are not without shortcomings and do not represent the entire range of possible inflow sequences. The drought management plans tested in this study offer another alternative for improving the system reliabilities without completely giving up the security of the DMI reserve while lessening drought related damages to irrigators. A myriad of methodologies may be developed and strategies tested to determine optimal water availability drought triggers. The DMI reserve sizes associated with each drought stage, although determined arbitrarily, were used here to demonstrate the potential and benefits of using a system of increasing levels of protection for municipal uses as drought conditions worsen. On the other hand, as water availability conditions improve, water liberated from the DMI reserve can be made available to irrigators in order to offset drought impacts.

CHAPTER IX

SUMMARY AND CONCLUSIONS

9.1 RESEARCH SUMMARY

The allocation of water resources is typically accomplished within the framework of water allocation systems (WAS). In general, a WAS sets priorities, applies rules, and organizes responses to a range of water allocation scenarios. This dissertation presents a comprehensive study of water allocation strategies and provides a conceptual framework of principles and guidelines for designing, assessing, implementing and supporting WAS.

Water allocation strategies vary at the international, interstate, and intrastate water management levels. The voluminous compilation of international treaties and conventions, interstate compacts, intrastate administrative documentation, and scientific/engineering literature was reviewed and researched in order to identify different water allocation strategies and mechanisms. The dissertation provides an enhanced understanding of the specific mechanisms for allocating water by systematically addressing how water allocation is achieved among nations, states, water management entities, and individual users. The dissertation also addresses how computer simulation models can be used to support and facilitate water allocation efforts.

From the aforementioned analysis, eight fundamental areas of WAS were identified: water rights, determination of water allotment, administrative systems, reservoir storage considerations, system reliability, multiple uses, instream flow requirements, and drought management. The systematic scrutiny of these eight areas at all three management levels defined the conceptual framework for assessing WAS.

The dissertation also provides an in depth review of the Texas WAS. The two Texas water rights system, five interstate compacts, and two international treaties are described in detail. The Texas experience with regard to its Water Availability Modeling (WAM) system is also reviewed with particular emphasis on the application of the Water Rights Analysis Package (WRAP) model. The Lower Rio Grande WAS is used as a case study to demonstrate how the principles presented in the conceptual framework can be used to assess water allocation issues. Three WRAP simulation studies utilizing several components of the conceptual framework were performed in order to assess the Lower Rio Grande basin WAS. The simulations focused on three of the major water allocation issues of the Texas Rio Grande: reallocation among uses, instream flow requirements, and drought management. The simulations showed several deficiencies in the Lower Rio Grande WAS and proposed several strategies that can potentially improve the overall efficiency of the system.

9.2 MAJOR RESEARCH FINDINGS AND CONCLUSIONS

9.2.1 General Strategies and Mechanisms to Allocate Water

9.2.1.1 International Level

The legal mechanisms within modern international water law pertinent to water allocation are defined in the 1997 UN Convention on the Law of the Non-Navigational Uses of International Watercourses. They are the doctrines of equitable utilization and prevention of significant harm. The major controversy revolves around which concept, equitable utilization or obligation not to cause significant harm, should have prevalence over the other. International conventions on water law have not been able to establish guidelines on how to apply these principles in the design of methodologies for water allocation. Instead, it is left to the ability and desire of states to use the Convention principles as a framework to design and implement more specific allocation agreements and practices.

In the absence of detailed and clear water law and adequate enforcing institutions, the allocation mechanism that has been used by riparian nations more often and with greater success has been bilateral and multi-lateral water treaties. For the most part, these water treaties establish general goals of cooperation and equitable apportionment to maintain amicable relationships between riparian countries. Yet, specific guidelines for allocation, enforcement, and conflict resolution are usually lacking.

Some of the allocation mechanisms utilized in the treaties are: equal portions, fixed annual or daily amounts or flows, storage allocations, minimum flows, allocative schedules or formulas dependent on current flows, “needs-based” allocation, and exchange of goods for water. More recently, treaties have established joint commissions with a range of responsibilities to manage transboundary basins and determine the allocations and/or approving water rights and projects in the transboundary basin. However, the big picture is still that the legal management of transboundary waters remains conceptually deficient.

9.2.1.2 Interstate Level

In the US there are three venues for the allocation of water among states: congressional apportionment, judicial adjudication, and interstate compacts. In Congressional apportionment, members of the Congress vote on which allocation mechanism should be implemented. However, it is highly unlikely that Congress members will have the specialized knowledge necessary to deal with water disputes, and decisions are mostly based on political interests. Judicial adjudication by the Supreme Court also exhibits significant inefficiencies as an allocation mechanism. The vagueness of allocating standards, the Court's lack of expertise on the subject, and the staggering expenses of litigation and of paying a special master, are some of the shortcomings of this allocation approach.

A more beneficial venue is for the states to reach a voluntary agreement by signing an interstate compact. The advantage of compact water allocation lies in its legal and political characteristics that allow it to adapt to the unique needs of a particular basin and the regional philosophy of water appropriation. They can also be used to create permanent administrative entities for the management of the compact and the region's water resources as a whole.

Water allocation compacts vary in their terms, from allocating storage to dividing the actual flow in the stream. Flow can be apportioned by determining a percentage of the streamflow for each state, requiring the delivery of a fixed quantity of water at a specific point on the stream, or some proportion determined from a hydrologic model. The allocation mechanisms adopted in these compacts determine the distribution of risks and losses in periods of low flows. Under a percentage allocation rule, states both on the upper and lower portions of the basin share the losses and gains during periods of low and high flows. Fixed flow allocation mechanisms are easier to implement. However, under this mechanism, the downstream state absorbs the entire loss during droughts.

Compacts that follow the proportion rate approach use hydrologic models as the basis of their allocation. The end result is similar to the percentage allocation but the division of water obeys a schedule that varies with the streamflow instead of being a fixed percentage. The main drawback that has been observed in the application of this approach is the model itself. Even if the model is found to be inadequate, once the compact is in effect, it is unlikely that the allocation scheme will be modified.

9.2.1.3 Intrastate Level

Water rights systems (WRS) are the legal and institutional arrangements that define the terms and conditions that must be met in order to claim the legal right to use water. In the US, there are three legal systems that define water allocation between individual users within a state: prior appropriation, riparianism, and regulated riparianism.

The riparian doctrine recognizes the right to use water only to the owners of lands abutting a watercourse in accordance with the principle of reasonable use. Rights are attached to the ownership of land and cannot be forfeited by non-use. Reasonable use gives flexibility in the face of changing conditions of water use and supply by considering the social and economic value of the use. Once a right is recognized, there is a certain degree of protection from unreasonable uses of water. However, some complexities arise due to a lack of specificity and its dependency on the outcome of torts. The fact that the system restricts the use of the water to riparian owners ignores the possibility that better use may be made at other places by riparian and non-riparian owners.

Prior appropriation relies on the doctrine of beneficial use to determine who has the right to use water. In contrast to riparianism, the property where the water is applied to beneficial use does not need to be adjacent to the natural source. Prior appropriation enforces the conditions of the established rights based on the priority order of the appropriators. If water is insufficient to meet all needs, earlier users will obtain all their allotted water while those who appropriated later may see their allotment diminished or cutoff completely. Water rights under this doctrine cannot be forfeited save for non-use, which penalizes water conservation. Another shortcoming of this doctrine is that traditionally only consumptive uses of water were deemed beneficial and efforts to incorporate non-traditional uses, such as environmental flows, are too recent to have a significant impact in instream flow conditions.

Regulated riparianism relies on a well structure administrative system to determine validity of water rights. Even though it relies on the principle of reasonable use, its application is completely different from pure riparianism. Reasonableness of use is determined in accordance with the state's general water policy and other permitted uses and users in non-riparian lands are not considered unreasonable. One major advantage over pure riparianism is the use of permits, which provides security in the case of investments. In addition, since administrative agencies determine the terms of the permits, there is no need to depend on court rulings to determine validity of right. In contrast to the prior appropriation permit system, these permits are not perpetual, which allows for the reallocation of water to a potentially more reasonable use once the permit expires.

9.2.2 Systematic Framework for Assessing WAS

9.2.2.1 Water Rights

The framework of policies and rules that administer water rights are usually developed at the state level. Two important concepts were used to analyze the different mechanisms that define who has the right to use water: certainty and flexibility. Certainty is the most important criteria for water development. It can be defined as the level of security water right holders can have that water will be available to supply their demands. The degree of certainty WRS give to their water rights holders vary with the system and doctrine of appropriation. Some mechanisms for providing certainty to water rights are: priority among users or uses, permit systems, and courts rulings. The permit system is the most efficient mechanism for establishing certainty as opposed to systems that are dependent on court rulings to determine the validity and terms of a water right.

Flexibility refers to the provisions of a WRS that enables it to supply the water needs of water right holders under changing water availability and demand circumstances. For the most part, there is a trade-off between providing a high degree of certainty to promote progress and enough flexibility to adapt to changing conditions of demand and supply. Two mechanisms used to add flexibility to WAS are market mechanisms and duration of permit systems. Voluntary reallocation or transferability of water rights through water markets is driven by economic efficiency, where water is transferred from low valued uses to the highest valued use. However, the value society puts on its water resources cannot always be expressed in monetary terms and overseeing institutions are crucial for ensuring the protection of non-quantifiable values of water.

Water rights permit systems that have a prescribed duration period give a high degree of flexibility to the system since they allow accommodating newcomers and reallocating water to more desirable uses once a permit has expired. Nonetheless, care must be taken in establishing the duration period since short duration periods may not allow the users sufficient time to payoff capital equipment or recover from losses during dry years, thus adding uncertainties that may promote economically inefficient decisions.

WRS in interstate rivers can present an administrative challenge in terms of establishing priorities and honoring rights that follow different doctrines of appropriation or in the case of prior appropriation states, have different appropriation dates. To avoid this situation provision must be made within the interstate agreement to establish clear allocative terms that could preserve pre-compact rights. Another approach is to establish watershed management and planning agencies with water rights granting capabilities that allow them to determine the validity of rights and resolve disputes.

International water rights are an evolving concept modeled after the doctrine of equitable utilization. International water rights are defined by vague concepts that in practice have little meaning. The weakness of the definition of water rights is probably the major reason for international water law shortcomings in becoming a major factor for stabilizing and securing international relations over shared water resources. Several propositions to address this situation have surfaced recently. The "community property" model evaluates water rights regardless of international borders, but has not been implemented in any international water project. Another proposition is the use of needs rather than rights to determine water allocation based equitable utilization. However, allocations based on relative needs present a dilemma in regions with great economical and political mismatches where a history of unwillingness for cooperation and compromise exist. Also the lack of strong and impartial enforcement institutions makes the application of equitable utilization as impractical as the other international doctrines of allocation.

9.2.2.2 Determination of Water Allotment

At the international level, a nation's water allotment is governed by the principles of equitable utilization and avoidance of significant harm. However, these principles are often contradictory. To determine an equitable allotment, the 1997 UN Convention identifies seven factors that should be considered. Yet, methodologies are needed to establish guidelines for estimating these factors and establishing their relative importance.

Allotment mechanisms are not explicitly incorporated in interstate compacts. However, two criteria can be inferred: (1) protection of pre-compact levels of beneficial use, and (2) equitability of use. Typically, water originating in a state belongs to that state, and water from shared sections of a stream is divided. Whatever the underlying principle, the allocation mechanism is defined as fixed amounts or percentages of streamflow and/or storage. With regard to allocating storage, special considerations to limit storage on upstream states must be explicitly addressed in the compact in order to avoid future conflict.

Three water allotment mechanisms were identified at the intrastate level. In riparian states, courts determine the size of the allotment based on an interpretation of the doctrines of reasonable use and equitable utilization. In regulated riparian states, the methodology used usually involves some measure of the use needs, such as operational size or length of the riparian front. In prior appropriation, the size of the allotment is established based on beneficial use. The methodologies that determine allotment based on needs should make provisions to avoid over-exploitation by considering additional criteria such as: harm to other users, local economic interests, preferred water used, use of conservation technology, and environmental concerns.

9.2.2.3 Administrative Systems

Four key aspects in the administration of water resources were identified from the evaluation of administrative water agencies at all management levels. Administrative agencies must have the power and capability to conduct and lead efforts in the areas of: (1) data collection, (2) planning, (3) resource management and regulation, and (4) conflict resolution. Data collection involves conducting and supporting water resources monitoring and research and promoting information sharing and dialogue. Long-term planning involves formulation of alternatives for responding to potential scenarios of water supply and demand. Adopting watershed scale management strategies, in which watershed boundaries rather than political boundaries are the basic unit of analysis, may be beneficial as they provide a more hydrologically correct view of the water resources of a region. The agencies also need the authority to manage and operate water resources systems and regulate water allocations. The extent of this authority should be in accordance with their position within the hierarchy of management levels. Water accounting methodologies are a critical aspect of resource management as it provides a mechanism for assessing compliance of agreements and the enforcement of regulations. Finally, these agencies must provide the necessary framework and mechanisms for conflict resolution and define courses of action in the case of non-compliance.

9.2.2.4 Reservoir Considerations

Once water has been allocated, managing and enforcing international treaties or interstate compacts must incorporate proper water accounting procedures that allow to evaluate if the parties are in compliance with the established agreements and to provide a better basis for evaluating and solving conflicts. Coordination between actual reservoir operations and the administration of the treaties or compacts is recommended in order to manage the reservoir storage in a manner that reflects the established agreements and meet demands more efficiently.

A critical storage consideration is how to manage the tradeoffs between how much water to withhold from immediate use and retaining that water in storage for future use (i.e. hedging). The most common methods for incorporating hedging into a WAS are based on: (1) legal specifications (laws, treaties, and compacts) and (2) operational rules. Operational rules provide greater flexibility in managing storage and releases since, in contrast to legal specifications; it is relatively easy to modify them over time based on experience and changing conditions. When hedging rules are incorporated as part of treaties and compacts, the allocation process becomes calcified and is unable to readily adapt to changing conditions. Instead, it may be more beneficial that the legal agreements establish management agencies (or enable existing ones) with the power to adopt these considerations within their operational policies.

9.2.2.5 System Reliability

Reliability is a measure of dependability and can be used to assess the capabilities of a river/reservoir system to satisfy specified water use requirements. Reliability concepts can be used to aid in the planning and design of reservoirs, to assess the water supply capabilities of a system, to evaluate the effects of new water right permits on other users, to provide a measure of the risks of shortages, and to establish priorities between competing uses, among others. Proper understanding of the relationship between reliability and water availability also improves water management strategies as significant quantities of water may be "liberated" for beneficial use by tolerating relatively small risks of shortages. However, care must be taken when interpreting reliability indices as they are subject to modeling assumptions and are based on hydrologic data that may not necessarily reflect the entire range of possible future inflows.

Incorporating reliability considerations also require certain flexibility in the administration of WAS. At the international and interstate levels this could be a challenge due to the lack of management agencies with enough enforcement and administrative power to incorporate these concepts. Typically, no provisions are made within treaties and compacts for improving allocation schemes in response to newer and more precise hydrological studies or unforeseen changes in water availability. Moreover, in the case where treaties or compacts protect certain uses or users against shortages, any modification to the water allocation scheme based on a redistribution of risk of shortages would be illegal.

Therefore, legal and institutional amendments may be required to incorporate reliability considerations at those levels. Greater applicability can be achieved at the intrastate level since water management is more flexible and decisions are typically based on operational policies that can be modified in response to experience, new management practices, improved hydrologic information, and changes in water demand and availability.

9.2.2.6 Multiple Uses

Water uses that are considered legitimate vary according to the appropriation doctrine and even among states following the same doctrine. Typically, they are defined based on the doctrines of beneficial use and reasonable use. States following the former must recognize as beneficial all uses valued by society and thus they need to include provisions that allow adapting to changes in those values. States following the reasonable use doctrine, all uses are considered beneficial and thus no use has precedence over others. However, under water scarcity conditions there is a need to pre-establish which uses are considered more reasonable in order to protect the most fundamental water needs.

In general, water institutions can use several criteria for solving conflicts among the different sectors of water usage: pre-established priorities among users and uses, economic criteria, equity, and sustainability. When using the economic criteria, water uses with higher economic value can be favored by institutions or market mechanisms can be used to reallocate water from low to high valued uses. Yet, care must be taken when assigning the appropriate value to the use as low values can result in inefficient use of the resource, water hoarding, wastefulness and damage to water ecosystems. Under the equity criterion, all water users stand on the same level in right, even if the intended use has a low economic value. In order to ensure equity in the allocation process, government intervention may be necessary. Ecological sustainability recognizes the value of ecological components in advancing important public interests. Usually, protecting these uses also requires government involvement. On the other hand, economic sustainability relates to supplying current needs while conserving enough resources for future benefit. This requires comprehensive planning and proactive measures such as basin development plans and integrated water resources management.

9.2.2.7 Instream Flow Requirements

At the international level, the concept of instream flows is explored only in the more recent doctrines of integrated water resources management and community of riparian states. However, these concepts are ambiguous and give ample margin for interpretation. More practical applications are found in the study of treaties. Although very few treaties specifically address instream non-consumptive uses of water, the few that do have used one of two approaches. Treaties either set very specific allocative provisions and limitations or establish an administrative body which, among other duties, will determine how these uses are going to be addressed. Specific mechanisms usually involve the establishment of fixed, seasonal, or drought emergency minimum flows.

Typically, interstate compacts do not make specific provisions for instream requirements. Instead, individual states must provide for them in accordance with their own water administration policy. A more efficient approach has been taken in some Eastern states where transboundary commissions have been created with management responsibilities that include instream flow regulations.

Several mechanisms can be adopted in prior appropriation systems to incorporate instream flows. The first one is regulation amendments to recognize such uses as beneficial, which entails granting permits. Another mechanism is limiting new permits based on their effects on environmental flows. The effectiveness of such practices, however, is dependent on the level of development of the river system. In overappropriated rivers this practice has come too late to make any significant impact on ensuring healthy aquatic ecosystems.

For these reasons, water markets have become the most effective mechanism for accommodating instream needs since organizations interested in ensuring instream flows for environmental protection and other non-consumptive uses can purchase rights from more senior users. However, reliance on markets shifts the responsibility of environmental protection from the government to the private sector which creates uncertainty. When designing strategies to use this mechanism, provisions must be made for assuring a high level of long-term protection and security at least comparable to those obtained by more traditional mechanisms such as legislation.

9.2.2.8 Drought Management

Drought periods are the ultimate test of WAS. The severity of droughts is dependent not only on physical factors but also on administrative efficiency. The manner in which WAS define droughts is critical because they determine drought policies and response actions. Due to the many intricacies and interconnections between the physical and socio-economical aspects of droughts, the more traditional definitions of drought are impractical to integrate into water management systems.

Public declarations of droughts are often triggered by specific and well-defined conditions. These triggers then become the practical definition of drought for a particular region or for specific sectors such as agriculture or municipal water supply. The use of drought indexes has become the preferred mechanisms for defining droughts. Some indexes are only applicable for specific regions and those that are more generalized may not be appropriate for use in certain regions. Consequently, care must be taken in selecting both the type of drought index and its trigger values.

International treaties and compacts do not address droughts explicitly. Some do have provisions for allocating water during dry years. These provisions include definitions, albeit ambiguous, of drought and some mechanisms for the repayment water debts. When incorporating definitions of droughts on legal agreements, specific provisions must be made regarding the parameters that will define the occurrence and severity of droughts. Otherwise, conflict can arise on whether drought conditions are applicable. In addition, mechanisms of credits and debits systems need to be more comprehensive by providing alternative solutions under long-term droughts.

Regional approaches at both the international and intrastate levels are being undertaken in order to address droughts in a proactive manner rather than emergency relief. These efforts must involve regional analysis of drought indices, use of consistent technology and data, and the development of drought-related regional policies and institutions.

In the US, most drought preparedness and mitigation efforts occur at the state or local level and include: long-term planning, tactical short-term mitigation, and emergency response. The most important mechanism in tactical responses is the use of triggers. In terms of water availability triggers can be defined as a function of reservoir storage and streamflows. Multiple criteria can be used to assign trigger values but in general the selected triggers must be defined to represent the water availability state of the system. Selected triggers must be paired with corresponding mitigation measures and specified in a drought response plan. Several mechanisms for drought mitigation can include: institutional reallocation, rationing, emergency water banking, inter-basin transfers, conjunctive management of groundwater and surface water resources, water markets, conditional reservoir operation for protection of instream flows, and water pricing.

9.2.3 Conclusions from the Lower Rio Grande WAS Simulation Study

In the Lower Rio Grande, overappropriation, alarming increase in demands for municipal uses, decreased reliabilities of irrigation water, drought susceptibility, and international treaty issues are impacting the long-term water availability of the region. The assessment of the Lower Rio Grande WAS, utilizing the conceptual framework developed in Chapter VII, helped to highlight some of the system's shortcomings. The strategies tested in Chapter VIII indicate that there is potential for improving the efficiency of the system in supplying water more equitably to all users.

It was observed that the primary safeguard of municipal uses is its priority in the water allocation sequence. In addition to this, municipal uses have two additional protection mechanisms: the domestic-municipal-industrial (DMI) and operational (OR) reserves. The results showed that having one of these reserves is sufficient for providing extra protection against shortages. Even in a scenario of increased municipal demands, the OR reserve could provide enough protection for municipal uses, provided that operational rules are modified to avoid the reserve from been emptied. Making DMI reserve water available for future municipal diversions was not found to be an effective reallocation strategy for satisfying the fast-growing municipal demands without penalizing irrigators. Market mechanisms were shown to be a better alternative for this purpose. Under the current allocation rules, it was demonstrated that market mechanisms can provide water for increased municipal demands without decreasing the reliabilities of irrigators. In fact, under the market strategy, irrigation reliabilities improved. In other words, these market transactions not only benefit the municipal users that purchase the water and the irrigators that sell it, but also the irrigators remaining in the system. It functions both as a “new” source of water and a conservation measure, liberating more water for the irrigators that remain in the system.

Even though the reallocation of DMI reserve to increased municipal demands was not sufficient, other benefits can be obtained from a multiuse reallocation approach of portions the DMI reserve. For instance, irrigators could benefit from the elimination or reduction of the DMI reserve, especially if the reallocation involves increasing irrigation storage. Also, if water for environmental flows is needed, water from the DMI reserve can significantly increase instream flows. The results show that an instream flow requirement could potentially be incorporated into the system without significantly affecting existing uses reliabilities.

Due to the administrative and legal constraints of the Lower Rio Grande WAS, it is unlikely that the DMI reserve would be eliminated based on simulation models that are not without shortcomings and do not represent the entire range of possible inflow sequences. The drought management plans tested in this study offer another alternative for improving the system reliabilities without completely giving up the security of the DMI reserve while lessening drought related damages to irrigators. A myriad of methodologies may be developed and strategies tested to determine optimal water availability drought triggers. The DMI reserve sizes associated with each drought stage, although determined arbitrarily, were used here to demonstrate the potential and benefits of using a system of increasing levels of protection for municipal uses as drought conditions worsen. On the other hand, as water availability conditions improve, water liberated from the DMI reserve can be made available to irrigators in order to offset drought impacts.

The Lower Rio Grande water allocation scheme is governed by pre-established legal criteria that are intended to provide a high degree of certainty in this arid region. However, the Lower Rio Grande WAS was found to be inflexible, outdated, and very conservative. Even though the recent use of market mechanisms (economic criteria) has added some flexibility to the allocation process, questions can be raised regarding equity and ecological sustainability considerations. The simulations performed in Chapter VIII demonstrated that the water allocation sequence (priority) provides enough protection to municipal uses even during the worst drought periods in the historical record. Therefore, the current water allocation scheme places what can be considered as an unjustified and unfair burden on agricultural users. Also, since the system has been declared over-appropriated no water is being made available for environmental flows and the ecosystems of the region continue to deteriorate. All this, while water in the DMI reserve remains unused.

This dissertation sheds light on several areas of the Lower Rio Grande WAS where improvements can be made and presented alternative strategies to address them. Nonetheless, implementing new strategies and water allocation policies in the Lower Rio Grande WAS would require considerable changes in regulation policies.

9.3 FINAL REMARKS

The conceptual framework developed in this dissertation can assist in the design, development, and implementation of WAS. The conceptual framework provides a format that can be used as a guide on how to systematically approach new water allocation issues and for future evaluations of existing WAS. Also, this systematic approach can help identify areas where policy and institutional reform may be needed.

The conceptual framework may also be used to guide in the design of new water allocation agreements and in the revision of old ones. The review of existing computer modeling capabilities provides water management agencies helpful information for comparing and selecting an appropriate model to support their WAS. Managers can also use the Lower Rio Grande case study as a model for improving water allocating practices and integrating computer models to assist in the various phases of water allocation.

REFERENCES

Anderson, O. L., Simmons, P., and Beck, R. E. (1991). "Reallocations, transfers and changes." *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 14-1 – 14-91.

Applied Research Institute-Jerusalem (ARIJ) (2000). "Final report on water and environmental risk modeling for developing sustainable water management in the Jordan Valley." *Final report of activity WP-4.2*, Bethlehem, Palestine. <http://systemforschung.arcs.ac.at/jowapubl/results/download/Water%20Allocation%20 Model%20-%20ARIJ%20Report%20Dec%202000.pdf> (Sep. 28, 2005).

Arizona v. California (1963). 373 U.S. 546, 565. <http://laws.findlaw.com/us/373/546.html> (Jan. 27, 2005).

Ausness, R. (1983). "Water rights legislation in the east: A program for reform." *William and Mary Law Review*, 24, 547-950.

Australian Government (2005). "Living with drought." Bureau of Meteorology, Commonwealth of Australia. <http://www.bom.gov.au/climate/drought /livedrought.shtml> (Jul. 3, 2005).

Azevedo, L. G. T., Gates, T. K., Fontane, D. G., Labadie, J. W., and Porto, R. L. (2000). "Integration of water quantity and quality in strategic river basin planning." *Journal Water Resources Planning and Management*, 126(2), 85-97.

Bayazit, M., and Ünal, N. E. (1990). "Effects of hedging on reservoir performance." *Water Resources Research*, 26(4), 713-719.

Beach, H. L., Hamner, J., Hewitt, J. J., Kaufman, E., Kurki, A., Oppenheimer, J. A., and Wolf, A. T. (2000). *Transboundary Freshwater Dispute Resolution: Theory, Practice and Annotated References*, United Nations University Press, Tokyo.

Beck, R. E., Anderson, O. L., Kuntz, E., and Simmons, P. (1991a). "Elements of prior appropriation." *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 12-1 – 12-68.

Beck, R. E., Anderson, O. L., Kuntz, E., and Simmons, P. (1991b). "Storage, reuse, and preservation." *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 13-1 – 13-33.

Berger, D. (1995). “Precious resource: Water issues in the Lower Rio Grande Basin.” *Population-Environmental Report of the Lower Rio Grande Basin*, National Audubon Society, Sabal Palm Chapter, Brownsville, Texas. <http://www.planeta.com/ecotravel /border/sabal.html> (Sep. 11, 2005).

Biswas, A. K. (1993). “Management of international waters: Problems and perspective.” *Water Resources Development*, 9(2), 167-188.

Biswas, A. K. (1999). “Management of international waters: Opportunities and constraints.” *Water Resources Development*, 15(4), 429-441.

Bounds, R., and Lyons, B. (1979). “Existing reservoir and stream management: Statewide minimum streamflow recommendations.” *Federal Aid Project F-30-R-4*, Texas Parks and Wildlife Department, Austin, Texas.

Brown & Root Services (2001). “Water availability modeling for the Sabine River basin.” *Final Report*, Austin, Texas.

Brown, T. C., Diaz, G. E. & Sveinsson, O. G. B. (2002). “Planning water allocation in river basins, AQUARIUS: A system’s approach.” *Proceedings of the 2nd Federal Interagency Hydrologic Modeling Conference*, Las Vegas, Nevada. <http://72.14.203.104/search?q=cache:uDbQZLTZDC8J:www.fs.usda.gov/rm/value/docs/planning_water_allocation_river_basins.pdf+Planning+water+allocation+in+river+basins,+AQUARIUS:+A+system%E2%80%99s+approach&hl=en > (Nov. 7, 2005)

Burchi, S., and Speij, M. (2003). “Institutions for international freshwater management.” *UNESCO IHP-IV Technical Documents in Hydrology, PC-CP Series, Number 3.* United Nations Educational Scientific and Cultural Organization, Paris, France. <http://webworld.unesco.org/water/wwap/pccp/cd/institutions.html> (Jul. 27, 2004).

Canadian River Compact Commission (CRCC) (2004). “Agency strategic plan for the 2005-2009 period.” Canadian River Compact Commission, Amarillo, Texas. <http://www.tnrcc.state.tx.us/permitting/waterperm/wrpa/splan.canadian.pdf> (Jun. 22, 2005).

Cano, G. (1989). “The development of the law in international water resources and the work of the International Law Commission.” *Water International*, 14, 167-171.

Caponera, D. (1985). “Patterns of cooperation in international water law: Principles and institutions.” *Natural Resources Journal*, 25(3), 563-587.

Caroom, D. G. (1997). “The law of water development and water rights.” *Water law in a nutshell*, <http://www.bickerstaff.com/articles/waternut.htm> (Feb. 8, 2005).

Carriker, R. R. (1985). “Water law and water rights in the south: A synthesis and annotated bibliography.” *Southern Rural Development Center Synthesis-Bibliography Series No. 16*, Mississippi State, Mississippi.

Carter, H. O., Vaux, H. J., and Scheuring, A. F. (1994). “Understanding water marketing: An introduction.” *Sharing scarcity gainers & losers in water marketing*, H. O. Carter, H. J. Vaux, and A. F. Scheuring, eds., University of California, Agricultural Issues Center, Davis, California, 1-9.

Chang, C. and Griffin, R. (1992). “Water marketing as a reallocative institution in Texas.” *Water Resource Research,* 28, 879-890.

Colorado v. New Mexico (1982). 459 U.S. 176, 103 S.Ct. 539, 74 L.Ed.2d 348. <http://caselaw.lp.findlaw.com/scripts/getcase.pl?court=us&vol=459&invol=176>(Jan. 27, 2005)

Combs, S. (2004). “The Mexico water debt.” *Texas Bar Journal*, 67(3), 198-201.

Connecticut v. Massachusetts (1931). 282 U.S. 660, 669. <http://caselaw.lp.findlaw.com/scripts/getcase.pl?court=us&vol=282&invol=660> (Nov. 7, 2005).

Copas, D. N. (1997). “The southeastern water compact: Panacea or Pandora’s box? A law and economics analysis of the viability of interstate water compacts.” *William and Mary Environmental Law and Policy Review*, 21(3), 697-734.

Correia, F. N., and Silva, J. E. (1999). “International framework for the management of transboundary water resources.” *Water International*, 24(2), 86-94.

Cortner, H. J., and Auburg, J. (1988). “Water resources policy: Old models and new realities.” *Water Resources Bulletin*, 24(5), 1049–1096.

Cox, W. E. (1994) “Reallocation impacts of eastern water-law changes.” *Journal of Water Resources Planning and Management*, 120(4), 476-484.

Dai, T. and Labadie, J. W. (2001). “River basin network model for integrated water quantity/quality management.” *Journal of Water Resources Planning and Management*, 127(5), 295-305.

Danish Hydraulic Institute (DHI) (2001). “MIKEBASIN 2001: A versatile decision support tool for integrated water resources management planning.”

<http://www.dhisoftware.com/general/BD_material/Brochures/MIKE_BASIN.pdf> (May 12, 2005)

Davis, P. (1982). "Eastern water diversion permit statutes: Precedents for Missouri." 47 *Missouri Law Review*, 429, 436-437.

Dellapenna, J. W. (1985). "Owning water in the eastern United States." *Proceedings, 6th Ann. Inst. Eastern Mineral L. Found*, Boulder, Colorado, 1-1.

Dellapenna, J. W. (1991a). "Dual systems". *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 8-1 – 8-76.

Dellapenna, J. W. (1991b). "Regulated riparianism". *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 9-1 – 9-213.

Dellapenna, J. W. (1991c). "The right to consume water under pure riparian rights." *Waters and water rights,* R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 7-1 – 7-172.

Dellapenna, J. W. (1994a) "The regulated riparian version of the ASCE Model Water Code: The third way to allocate water." *Water Resources Bulletin*, 30,197-204.

Dellapenna, J. W. (1994b). "Treaties as instruments for managing internationally-shared water resources: restricted sovereignty vs. community of property." 26 *Case Western Reserve Journal of International Law Review*, 27-48.

Dellapenna, J. W., ed. (1997). *The regulated riparian model water code*, American Society of Civil Engineers, New York, New York.

Diaz, G. E., Brown, T. C., and Sveinsson, O. (2000). *AQUARIUS: A modeling system for river basin water allocation*, General Technical Report RM-GTR-299, U.S. Department of Agriculture, Fort Collins, Colorado.

Dolan, L. S. and DeLuca, D. K (1993). "Use of hydrologic model in a basin-wide water allocation proceeding." *Water Resources Bulletin* 29(1), 107-117.

Draper, A. J., and Lund, J. R. (2004). "Optimal hedging and carryover storage value." *Journal of Water Resources Planning and Management*, 130(1), 1-5.

Drought Preparedness Council (2005). "State of Texas drought preparedness plan." Texas Department of Public Safety. <http://www.txwin.net/DPC/State_Drought_Preparedness_Plan.pdf> (Aug. 28, 2005).

Duranyildiz, I., Bayazit, M., Önöz, B, and Oğuz, B. (2000). "Optimum operation management of the Istanbul water supply system." *Turkish Journal of Engineering and Environmental Science*, 24, 247-254.

Dzurik, A. A. (1996). *Water resources planning*, Rowman and Littlefield Publishers, Lanham, Maryland.

Eckstein, G. E. (1995). "Application of international water law to transboundary groundwater resources, and the Slovak-Hungarian dispute over Gabcikovo-Nagymaros." *Suffolk Transnational Law Review*, 19(1), 67-116.

Eckstein, G. E. (2000). "Ground water, international water law and the Middle East peace process." *Ground Water: A Transboundary, Strategic and Geopolitical Resource, Association of Ground Water Scientists and Engineers Annual Meeting and Conference*, Las Vegas, Nevada.

Eckstein, G. E. (2002). "Development of international water law and the UN watercourse convention." *Hydropolitics in the developing world: A Southern African perspective,* A. R. Turton and R. Henwood, eds., African Water Issues Research Unit, Pretoria, South Africa, 81-96.

Eheart, J. W., ed. (2002). *Riparian water regulations: Guidelines for withdrawal limitations and permit trading*, American Society of Civil Engineers, Reston, Virginia.

El-Beshri, M. and Labadie, J. (1994). "Optimal conjunctive use of surface and groundwater resources in Egypt." *Proceedings of the 8th IWRA World Congress on Water Resources*, Ministry of Public Works and Water Resources, Cairo, Egypt. (CD-ROM)

Elmusa, S. S. (1998). "Harmonizing equitable utilization and significant harm: Comments on the 1997 ILC Convention". *Conference on Water, Dispute Prevention and Development: South Perspectives*. Center for the Global South, American University, Washington, DC, October 12-13.

Espey Consultants Inc. (2002). *Water availability models for the Red and Canadian River basins*, Volume II, Austin, Texas.

Frederiksen, H. D. (1992). "Water resources institutions: Some principles and practices." *Technical Paper No. 191*, World Bank, Washington, D.C.

Freyfogle, E. T. (1996). "Water rights and the common wealth." *Environmental Law*, 26(1), 27-51.

Getches D. H. (1997). *Water law in a nutshell*, West Publishing Company, St. Paul, Minnesota.

Getches, D. H. (1985). “Competing demands for the Colorado River.” *University of Colorado Law Review*, 56, 413-479.

Girardot J. W. (1989). “Toward a rational scheme of interstate compact adjudication.” *Journal of Law Reform*, 23, 151-178.

Gleick, P. (1988). “The effects of future climatic changes on international water resources: the Colorado River, the United States, and Mexico.” *Policy Sciences*, 21, 23-39.

Gleick, P. (1993). “Water and conflict: Fresh water resources and international security.” *International Security*, 18(1), 79-112.

Gloperud, C. P. III (1991a). “The permit process and Colorado’s exception.” *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 15-1 – 15-52.

Gloperud, C. P. III (1991b). “Administration, protection, and termination of water right.” *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 17-1 – 17-31.

Graham, L. P., Labadie, J. W., Hutchison, I. P. G., and Ferguson, K. A. (1986). “Allocation of augmented water supply under a priority water rights system.” *Water Resources Research*, 22(7), 1083-1094.

Grant, D. L. (1991). “Water apportionment compacts between States.” *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 46-1 – 46-32.

Griffin, R. C. and Characklis, G. W. (2002). “Issues and trends in Texas water marketing.” *Water Resources Update*, 121, 29-33.

Hayes, M. (2005). “Drought indices.” *National Drought Mitigation Center,* <http://drought.unl.edu/whatis/Indices.pdf> (Aug. 28, 2005).

Hayter, D. J. (2005). “Pecos River.” *Handbook of Texas Online*, <http://www.tsha.utexas.edu/handbook/online/articles/PP/rnp2.html> (Aug. 27, 2005).

Hobbs, G. J. (2004). “Citizens guide to Colorado water law.” *Colorado foundation for water education*. <http://cfwe.org/EducationalProducts/ss/ListCatalog.asp> (Aug 2, 2005).

Housen-Couriel, D. (1994). *Some examples of cooperation in the management and use of international water resources*, The Harry S. Truman Research Institute for the Advancement of Peace, Tel Aviv University, Tel Aviv.

Howitt, R. E. (1994). “Empirical analysis of water market institutions: The 1991 California Water Market.” *Resource and Energy Economics*, 16(4), 357-371.

International Boundary and Water Commission (IBWC) (2005). “Payment of Mexico’s Rio Grande water debt, Lower Rio Grande conservation easements, Brownsville-Matamoros weir on agenda for April 4 public meeting.” <http://www.ibwc.state.gov/PAO/CURPRESS/2005/LRGCFApril.pdf> (Aug. 13, 2005).

International Water Management Institute (2005). “Defining drought—and dealing with it.” *International Water Management Institute Research Update*, <http://www.iwmi.cgiar.org/pubs/Newsletters/Index.htm> (August 2005)

Iowa Natural Resources Council (1978). “Iowa water plan ’78: Framework study.” *Main report 189*, Iowa Natural Resources Council, Des Moines, Iowa.

Jha, M. K. and Das Gupta, A. (2003). “Application of Mike Basin for water management strategies in a watershed.” *Water International*, 28(1), 27 - 35.

Kaiser, R. (2004). “A problem in search of a solution.” *Texas Bar Journal*, 67(3), 188-192.

Kaiser, R. A. (1996). “Texas water marketing in the next millennium: A conceptual and legal analysis.” *Texas Tech Law Review*, 27(1), 181-261.

Kansas v. Colorado (1907). 206 U.S. 46, 27 S.Ct. 655, 51 L.Ed. 956.

Kenney, D. S. (2003). “Water allocation and management in the western United States: An overview.” *International Working Conference on Water Rights: Institutional Options for Improving Water Allocation*. Hanoi, Vietnam.

Kibaroglu, A. (2002). *Building a regime for the waters of the Euphrates-Tigris River basin*, Kluwer Law International, The Hague, Netherlands.

Labadie, J. (2004). “Optimal operation of multi-reservoir systems: State of the art review,” *Journal of Water Resources Planning and Management,* ASCE, 130(2), 93-111.

Landry, C. (1998). “Market transfers of water for environmental protection in the western United States.” *Water Policy*, 1, 457-469.

Letcher, R. A., Jakeman, A. J., and Croke, B. F. W. (2004). “Model development for integrated assessment of water allocation options.” *Water Resources Research*, 40, W05502, 1-15.

Lévite, H., Sally, H., and Cour, J. (2003). “Testing water demand management scenarios in a water-stressed basin in South Africa: application of the WEAP model.” *Physics and Chemistry of the Earth*, 28, 779-786.

Lien, R. A. (1998). “Still thirsting: Prospects for a multilateral treaty on the Euphrates and the Tigris rivers following the adoption of the United Nations Convention on international watercourses.” *Boston University International Law Journal*, 16(1), 273-307.

Lipper, J. (1967). “Equitable utilization.” *The law of international drainage basins*, A. H. Garretson, R. D. Hayton, C. J Olmstead, R. Baxter, L. A. Teclaff, and E. Teclaff, eds., Oceana Publications, Institute of International Law, New York University School of Law, Dobbs Ferry, New York.

Livingston, M. L. (1995). “Designing water institutions: Market failure and institutional response.” *Water Resources Management,* 9, 203-220.

Loucks, D. P., Stedinger, J. R. and Haith, D. A. (1981). *Water resource systems planning and analysis*. Prentice Hall, Englewood Cliffs, New Jersey.

Maloney, F. E., Ausness, R. C., and Morris, J. S. (1972). *A model water code,* Water Resource Center, University of Florida, Gainesville, Florida.

Masloff, A. (2002). “The water planning database: From excel spreadsheets to active server pages and data collection via the internet.” *Texas Water Development Board*, <http://www.txwmc.org/2002_Congress/TWMC_2002_Content/Paper%20-%20Masloff.pdf> (Sep. 12, 2005).

McCaffrey, S. C. (2001). “International water law for the 21st century: The contribution of the U.N. convention.” *Water Resources Update*, 118, 11-19.

McCormick Z. L. (1994). “Interstate water allocation compacts in the western United States – some suggestions.” *Water Resources Bulletin*, 30(3), 385-395.

McCoy, T. W. (1990). “Evaluation of ground-water resources in the Lower Rio Grande Valley, Texas.” *Report 316*, Texas Water Development Board, Austin, Texas.

<http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R316/R316.pdf>(Nov. 7, 2005)

McKee, T. B., Doesken, N. J., and Kleist, J. (1993). "The relationship of drought frequency and duration to time scales." *Eighth Conference on Applied Climatology*, American Meteorological Society, Boston, Massachusetts.

McKee, T. B., Doesken, N. J., and Kleist, J. (1995). "Drought monitoring with multiple time scales." *Ninth Conference on Applied Climatology*, American Meteorological Society, Boston, Massachusetts.

McKinney, D. C., Karimov, A. Kh. and Cai, X. (1997). "Report on model development: Aral Sea regional allocation model for the Amudarya River." *Technical Report*, US Agency for International Development, Environmental Policy and Technology Project, Central Asia Regional EPT Office, Almaty, Kazakstan.

Miller, K. A., Rhodes, S. L., and MacDonnell, L. J. (1997). "Water allocation in a changing climate: Institutions and adaptations." *Climate Change*, 35, 157-177.

Musick, J. D. (1989). "Reweave the Gordian knot: Water futures, water marketing, and western water mythology." 35 *Case Rocky Mountain Mineral Law Institute,* 22-1-22-6.

Muys J. C. (2003). "Interstate water management in the Colorado River Basin in the United States." *World Bank Conference on Water Development*, Washington, D.C.

Nakayama, M. (1997). "Successes and failures of international organizations in dealing with international waters." *Water Resources Development*, 13(3), 367-382.

Nancarrow, B. E., and Symeb, G. (2004). "Fairness principles in allocating water: Integrating views of different agents." *iEMSs 2004 International Congress: Complexity and Integrated Resources Management.* C. Pahl, S. Schmidt, and T. Jakeman, eds., International Environmental Modelling and Software Society, Osnabrück, Germany.

National Audubon Society v. Superior Court (1983). 189 Cal.Rptr. 346, 658, P.2d 709.

National Drought Policy Commission (NPDC) (2000). *Report of the national drought policy commission: Preparing for drought in the 21th century.* U.S. Department of Agriculture, Washington, D.C.

National Research Council (NRC) (1992). *Water transfers in the west: efficiency, equity and the environment*. National Academy Press, Washington, D.C.

National Research Council (NRC) (2005). *The science of instream flows: A review of the Texas instream flow program.* National Academy Press, Washington, D.C.

National Water Commission (NWC) (1973). *Water policies for the future.* U.S. Government Printing Office, Washington, D.C.

Nebraska v. Wyoming (1945). 325 U.S. 589, 54 S.Ct. 1332, 89 L.Ed.1815. <http://caselaw.lp.findlaw.com/scripts/getcase.pl?navby=case&court=us&vol=325&invol=589> (Jan. 27, 2005)

Oggins, C. R. and Ingram, H. (1990). "Does anybody win? The community consequences of rural-to-urban water transfers: an Arizona perspective." *Issue Paper No. 2*, Udall Center for Studies in Public Policy, University of Arizona, Tucson, Arizona.

Oklahoma Drought Management Team (1997). *Oklahoma drought management plan*. Oklahoma Department of Emergency, Management & Oklahoma Water Resources Board, Oklahoma City, Oklahoma.

Oliveira, R., and Loucks, D. P. (1997). "Operating rules for multireservoir systems." *Water Resources Research*, 33(4), 839-852.

Palmer, W. C. (1965). "Meteorological drought." *Research Paper No.45*, U.S. Department of Commerce Weather Bureau, Washington, D.C.

Peck, J., and Weatherby, K. (1994). "Condemnation of water and water rights in Kansas." *Kansas Law Review*, 42, 827-836.

Pecos River Compact Commission (PRCC) (2004). "Agency strategic plan for the 2005-2009 period." <http://www.tnrcc.state.tx.us/permitting/waterperm/wrpa/splan.pecos.pdf> (Jun. 22, 2005).

Pherry, C. (2000). "Towards equitable sharing of international water resources – The Zambezi River case." *1st WARFSA/WaterNet Symposium: Sustainable Use of Water Resources*; Maputo, Mozambique.

R.J. Brandes Company (2004). "Water availability modeling for the Rio Grande basin. Water availability assessment" *Final Report*, R.J. Brandes Company, Austin, Texas.

Recknagel, C. (2005). "Middle East: Water dispute, Part 1: Turkey, Iraq, Syria disagree on rivers' use." *Radio Free Europe*, <http://www.b-info.com/tools/miva/newsview.mv?url=news/2000-09/text/sep14f.rfe> (Sep. 25, 2005).

Restatement (Second) of Torts (1979). §850A, <http://www.tomwbell.com/NetLaw/Ch05/R2ndTorts.html > (Jan. 27, 2005)

Ringler, C. and Huy, N. V. (2004). "Water allocation policies for the Dong Nai River basin in Vietnam: an integrated perspective." *EPTD Discussion Paper No. 127*, Environment and Production Technology Division, International Food Policy Research Institute, Washington, D.C.

Rio Grande Regional Planning Group M (RWPG) (2001). "Adopted regional plan, Rio Grande." *The Regional Water Plans,* <http://www.twdb.state.tx.us/rwpg/main-docs/regional-plans-index.htm> (Sep. 10, 2005).

Rochelle, M. C. (2004). "Environmental flows: Competing for limited resources." *Texas Bar Journal*, 67(3), 202-205.

Roe, C. B. and Brooks, W. J. (1989). "Loss of water rights – old ways and new." 35 *Case Rocky Mountain Mineral Law Institute,* 23-1-23-9.

Salazar, A. A., and Wurbs, R. A. (2004). "Conditional reliability modeling of short-term river basin management." *Journal of Water Resources Planning and Management*, 130(6), 450-459.

Sansom, A. (1995). *Texas lost: vanishing heritage*. Parks and Wildlife Foundation of Texas, Inc., Dallas, Texas.

Sax, J. L. (1994). "A legal view: community rights and the privatization of water". *Sharing scarcity: Gainers & losers in water marketing.* Carter, H. O., Vaux, H. J., and Scheuring, A. F. eds., University of California, Agricultural Issues Center, Davis, California, 11-20.

Schlager, E. and Ostrom, E. (1992). "Property-rights regimes and natural resources: A conceptual analysis." *Land Economics*, 68(3), 249-262.

Shafer, B.A. and Dezman, L.E. (1982). "Development of a Surface Water Supply Index (SWSI) to access the severity of drought conditions in snowpack runoff areas." *Proceedings of the Western Snow Conference*, Reno, Nevada, 164-175.

Sherk, G. W. (1994). "Resolving interstate water conflicts in the eastern United States: The re-emergence of the federal-interstate compact." *Water Resources Bulletin*, 30(3), 397-408.

Silvy, V., Kaiser, R., Lesikar, B., and Runyan, C. (2003). "Urban water conservation along the Rio Grande: An inventory of water conservation programs." *Technical Report 269*, The Texas A&M University System, <http://texaswater.tamu.edu/Resources/water_conservation_along_the_rio_grande.pdf> (Sep. 10, 2005).

Smith, D. I., Hutchinson, M. F., and McArthur, R. J. (1993). "Australian climatic and agricultural drought: payments and policy." *Drought Network News*, 5(3), 11-12.

Smits, S., Moriarty, P., Butterworth, J., Restrepo, I., van Koppen, B., and Cousins, T. (2004). "Towards multiple use water services." *Background paper IRC*. <http://www.irc.nl/page/9405> (Jun. 22, 2005).

Solanes, M., and Getches, D, (1998). "Prácticas recomendables para la elaboración de leyes y regulaciones relacionadas con el recurso hídrico." *Informe de Buenas Prácticas No. ENV-127*, Banco Interamericano de Desarrollo, Departamento de Desarrollo Sostenible, Washington, D.C.

Sporhase v. Nebraska (1982). 458 U.S. 941, 102 S.Ct. 3456, 73 L.Ed.2d 1254. <http://caselaw.lp.findlaw.com/scripts/getcase.pl?court=US&vol=458&invol=941>(Jan. 27, 2005)

Stavins, R. N. (1989). "Harnessing market forces to protect the environment" *Environment*. 31(1), 5-7.

Susquehanna River Basin Commission (2000). "Susquehanna River Basin drought coordination plan." *Publication No. 212*, Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

Tang, S. Y. (1992). *Institutions and collective action: Self-governance in irrigation*, Institute for Contemporary Studies, San Francisco, California.

Tarlock, A. D. (1987). "The changing meaning of water conservation in the West." *Nebraska Law Review*, 66, 101-110.

Tarlock, A. D. (2000). "How well can international water allocation regimes adapt to global climate change?" *Journal of Land Use & Environmental Law*, 15(3), 423-449.

Tarlock, A. D., Corbridge, J. N., and Getches D. H. (2002). *Water resource management: A casebook in law and public policy*. Foundation Press, New York, New York.

Teclaff, L. A. (1967). *The river basin in history and law.* Martinus Nijhoff Publishers, The Hague, Netherlands.

Templer, O. W. (2001). "Water law." *Handbook of Texas Online*, <http://www.tsha.utexas.edu/handbook/online/articles/WW/gyw1.html> (Sep. 15, 2005).

Texas Administrative Code (TAC) (1977). Title 30 – Chapter 303, <http://info.sos.state.tx.us /pls/pub/readtac$ext.viewtac> (Sep. 1, 2005).

Texas Commission on Environmental Quality (TCEQ) (2005a). "Surface water rights in Texas: How they work and what to do when they don't." <http://www.tceq.state.tx.us/assets/public/comm_exec/pubs/archive/gi228/index.html> (Sep. 15, 2005).

Texas Commission on Environmental Quality (TCEQ) (2005b). "Water rights permitting and availability." <http://www.tnrcc.state.tx.us/permitting/waterperm/wrpa/permits.html #databases> (Sep. 15, 2005).

Texas Commission on Environmental Quality (TCEQ) (2005c). "Rights to surface water in Texas." < http://www.tceq.state.tx.us/...ubs/pubs/gi/gi-228_167960.pdf.> (Sep. 15, 2005).

Texas Commission on Environmental Quality (TCEQ) (2005d). "Watermaster programs." <http://www.tnrcc.state.tx.us/enforcement/fod/wmaster/wmaster1.html.> (Sep. 15, 2005).

Texas Commission on Environmental Quality (TCEQ) (2005e). "WAM resolved technical issues." <http://www.tnrcc.state.tx.us/permitting/waterperm/wrpa/resolve.html#simulated> (Sep. 16, 2005).

Texas Parks and Wildlife Department (TPWD), Texas Commission on Environmental Quality (TCEQ), and Texas Water Development Board (TWDB) (2002). "Texas instream flow studies: Programmatic work plan." <http://www.twdb.state.tx.us /InstreamFlows/pdfs/Programmatic_Work_Plan.pdf> (Aug. 28, 2005).

Texas Parks and Wildlife Department (TPWD), Texas Commission on Environmental Quality (TCEQ), and Texas Water Development Board (TWDB) (2003). "Texas instream flow studies: Technical overview, draft." <http://www.twdb.state.tx.us /InstreamFlows/pdfs/TechnicalOverview-Draft080803.pdf> (Aug. 28, 2005).

Texas Water Code (1963). Chapter 11. *Water Rights*. < http://www.capitol.state.tx.us /statutes/wa.toc.htm> (Aug. 10, 2005).

Texas Water Development Board (TWDB) (2002). "Exhibit B: Guidelines for regional water plan development." <http://www.twdb.state.tx.us/rwpg/twdbdocs/Data%20Guidance%20072302-modified.pdf> (Sep. 28, 2005).

Texas Water Development Board (TWDB) (2005). "A Texan's guide to water and water rights marketing." *TWDB,* <http://www.twdb.state.tx.us/publications/reports/WaterRightsMarketingBrochure.pdf> (Aug. 10, 2005).

Trungale, J. F., Mayes, B. K., Moss, R. E., and Kleinsasser, L. J. (2003). "Using water availability models to assess alterations in instream flows." Resource Protection Division, Texas Parks and Wildlife Department, Austin, Texas.

United Nations (UN) (1997). "Convention on the law of the nonnavigational uses of international watercourses", *Official Document System of the United Nations*, <http://ods-dds-ny.un.org/doc/UNDOC /GEN/N97/772/93/PDF/N9777293.pdf> (Nov. 15, 2004).

U.S. Army Corps of Engineers (USACE) (1981). "Engineering and design - Drought contingency plans.", *ER 1110-2-1941*, U.S. Army Corps of Engineers, Washington, D.C.

U.S. Army Corps of Engineers (USACE) (1997). "Engineering and design - Hydrologic engineering requirements for reservoirs." *EM 1110-2-1420*, U.S. Army Corps of Engineers, Washington, D.C.

U.S. Bureau of Reclamation (USBR) (2000). "M&I Shortage Policy - Central Valley Project." <http://www.usbr.gov/mp/cvpia/proposals/mi_shortissue6allocationjar.html> (Aug. 21, 2005).

U.S. Congress (1988). "Project 88 - Harnessing market forces to protect the environment: Initiatives for the new president." Public policy study sponsored by Senators Timothy E. Wirth and John Heinz of Pennsylvania, Washington D.C. <http://www.heinz.org/files/Project88.PDF>(Nov. 8, 2005)

U.S. Department of Agriculture Economic Research Service (ERC) (2004). "Irrigation and water use." <http://www.ers.usda.gov/Briefing/WaterUse/> (Nov. 22, 2004).

Utton, A. E. (1988). "The battle over the allocation of interstate waters: Two contending doctrines." *Evaluation and Program Planning*, 11, 357-363.

Utton, A. E. (1991). "International streams and lakes generally." *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 3-47.

Utton, A. E. (1991b). “Canadian international waters.” *Waters and water rights*, R. E. Beck, ed., Lexis Law Publishing, Charlottesville, Virginia, 51-92.

Werick, W. J., and Whipple, W. (1994). “Managing water for drought: National study of water management during drought.” *Report 94-NDS-8*, U.S. Army Corps of Engineers. Water Resources Support Center, Institute for Water Resources, Alexandria, Virginia.

Wheeler K., Magee, T. M., Fulp, T. and Zagona, E. A. (2002). “Alternative policies in the Colorado River.” *Proceedings of the Natural Resources Law Center Allocating and Managing Water for a Sustainable Future: Lessons from Around the World*, Boulder, Colorado. <http://cadswes.colorado.edu/PDF/RiverWare/WheelerNRLC2002.pdf> (Nov 8, 2005)

Wilhite, D. A. and Glantz, M.H. (1985). “Understanding the drought phenomenon: The role of definitions.” *Water International*, 10, 111-120.

Wilhite, D. A.; Sivakumar, M. V. K., and Wood, D. A. (2000). “Early warning systems for drought preparedness and management”, *Proceedings of an Experts Group Meeting*, World Meteorological Organization, Geneva, Switzerland.

Wilhite D.A. and Svoboda, M.D. (2000). “Drought early warning systems in the context of drought preparedness and mitigation.” *Proceedings of an Experts Group Meeting*, D. A. Wilhite, M. V. K. Sivakumar; and D. A. Wood, eds., World Meteorological Organization, Geneva, Switzerland. <http://drought.unl.edu/monitor/EWS/ch1_Wilhite.pdf>(Nov. 8, 2005)

Willeke, G., Hosking, J. R. M., Wallis, J. R., and Guttman, N. B. (1994). “The national drought atlas.” *Report 94-NDS-4*, US Army Corps of Engineers, Institute for Water Resources, Alexandria, Virginia.

Wolf, A. T. (1997). “International water conflict resolution: Lessons from comparative analysis.” *Water Resources Development*, 13(3), 333-365.

Wolf, A. T. (1998). “Conflict and cooperation along international waterways.” *Water Policy*, 1(2), 251-265.

Wolf, A. T. (1999). “Criteria for equitable allocations: The heart of international water conflict.” *Natural Resources Forum*, 23(1), 3-30.

Wolf, A. T. (2001). “Water and human security.” *Journal of Contemporary Water Research and Education*, 118, 29-37.

Wolf, A. T., Natharius, J. A., Danielson, J. J., Ward, B. S., and Pender, J. K. (1999). "International river basins of the world." *Water Resources Development*, 15(4), 387-427.

Wollmuth, J. J. C. and Eheart, J. W. (2000). "Surface water withdrawal allocation and trading systems for traditionally riparian areas." *Journal of the American Water Resources Association*, 36(2), 293-303.

Wong, B. D. C. and Eheart, J. W. (1983). "Market simulations for irrigation water rights." *Water Resources Research*, 19(5), 1127-1138.

World Bank (1992). *World development report*, Oxford University Press, New York.

World Bank (1993). "Water resources sector strategy: strategic directions for World Bank engagement." International Bank for Reconstruction and Development, The World Bank Washington, D.C.

Wurbs, R. A. (1993) "Reservoir-System simulation and optimization models." *Journal of Water Resources Planning and Management*, 119(4), 455-472.

Wurbs, R. A. (1996). *Modeling and analysis of reservoir system operations*, Prentice Hall PTR, Upper Saddle River, New Jersey.

Wurbs, R. A. (1997). "Water rights considerations in reservoir system management." *Water Resources Update*, 106, 57-68.

Wurbs, R. A. (2003). "Modelling river basin management: An institutional perspective." *Water Resources Development*, 19(4), 523-534.

Wurbs, R. A. (2004) "Water allocation systems in Texas." *Water Resources Development*, 20 (2), 229-242.

Wurbs, R. A. (2005a). "Texas water availability modeling system." *Journal of Water Resources Planning and Management*, 131 (4), 270-279.

Wurbs, R. A. (2005b). *Water Rights Analysis Package (WRAP) Modeling System Reference Manual*. Technical Report 255, Texas Water Resources Institute, College Station, Texas.

Yeh, W. W. (1985). "Reservoir management and operations models: A state-of-the-art review." *Water Resources Research*, 21(12), 1797–1818.

Zagona, E. T., Fulp, J. T., Shane, R., Magee, T., and Goranflo, H. M. (2001). "RiverWare: A generalized tool for complex reservoir system modeling." *Journal of the American Water Resources Association*, 37(4), 913-929.

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