WATER ALLOCATION IN A CHANGING CLIMATE: INSTITUTIONS AND ADAPTATION

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Abstract. Global warming may profoundly affect temporal and spatial distributions of surface water availability. While climate modelers cannot yet predict regional hydrologic changes with confidence, it is appropriate to begin examining the likely effects of water allocation institutions on society's adaptability to prospective climate change. Such institutions include basic systems of water law, specific statutes, systems of administration and enforcement, and social norms regarding acceptable water-use practices. Both climate and the changing nature of demands on the resource have affected the development and evolution of water allocation institutions in the United States. Water laws and administrative arrangements, for example, have adapted to changing circumstances, but the process of adaptation can be costly and subject to conflict. Analysis of past and ongoing institutional change is used to identify factors that may have a bearing on the costliness of adaptation to the uncertain impacts of global warming on water availability and water demands. Several elements are identified that should be incorporated in the design of future water policies to reduce the potential for disputes and resource degradation that might otherwise result if climate change alters regional hydrology.

1. Introduction

Global climate modeling experiments suggest that anthropogenic emissions of carbon dioxide and other trace gases are likely to result in global warming over the course of the next century (Houghton et al., 1990). While climate modeling efforts cannot yet provide consistent and reliable forecasts of the timing and nature of regional climatic and hydrologic changes, the available evidence suggests that global warming may have profound impacts on water resource availability. Hydrologic analyses of plausible climate change scenarios indicate possible substantial reductions in streamflows in some areas, increased flood frequencies in other areas, and changes in the seasonal pattern of flows, with reduced summer flows likely in many mountainous and northern river basins (Schaake, 1990; Waggoner, 1990; Duell, 1992).

Researchers have given considerable attention to the possible physical effects of climate change on hydrologic regimes as well as to the assessment of strategies to manage those impacts (NRC, 1977; Beran, 1986; WMO, 1989; Rango and Van Katwijk, 1990; Tegart et al., 1990; Waggoner, 1990; Chang et al., 1992). They have given less attention to the role of institutional factors in determining the efficacy of alternative response strategies. These factors include the existing configuration of

Climatic Change **35:** 157–177, 1997.

rights, responsibilities and expectations regarding water resources as well as factors determining the relative ease or difficulty of altering the distribution of rights among competing users of the resource. Rogers (1994) argues that political and economic uncertainties are often far more important than hydrologic uncertainties for public water supply decisions, and that the hydrologic impacts of climate change may present fewer difficulties for water planning than the growing interdependence among water users. He further notes that the environmental aspects of hydrologic change may be considerably more problematic than traditional water supply concerns. He urges continued "research on the nexus of climate change, water resources, and socioeconomic adaptation; not solely on the hydrology but also upon other parts of the socioeconomic system and the aquatic ecosystem" (Rogers, 1994, p. 204). This paper takes up that challenge by examining the interactions between institutional factors and socioeconomic adaptations to the possible hydrologic impacts of climate change.

Water is a multifaceted resource, and competing claimants to the resource value its various dimensions differently. Valuations of the quantity, reliability, quality, location and timing dimensions of the resource differ across competing user groups, and these relative values change over time. In addition, the degree to which there is direct competition among water users varies with the type of use and across the various dimensions of the resource. Thus, decisions about water use can involve a host of competing claimants whose desires may increasingly come into conflict if climate change alters the location and timing of water availability. The increased potential for conflict warrants closer examination of the ways in which institutions may channel such competition to either facilitate or hinder adjustment to the effects of climate change.

Demographic change, increased environmental awareness and changing patterns of water demand have already created pressures for changes in the allocation of water among competing uses. The resulting adjustment process has entailed conflicts as well as cooperative solutions. The institutions governing water allocation sometimes appear to impede effective responses to changing circumstances (OTA, 1993), but those institutions have also evolved in response to pressures exerted by competing resource users. In some cases, climate-related uncertainties have contributed to costly disputes over water resources, as occurred in the recent battle over proposed groundwater exports from Colorado's San Luis Valley. That dispute was fueled by irrigators' fears that the difficulty of proving impacts in the presence of climatic variability would impair their ability to secure compensation for damages. In other instances, climatic events such as California's recent multi-year drought have catalyzed significant institutional change (Howitt et al., 1992). The record of such cases can provide a glimpse of issues that are likely to arise as water resources are increasingly subject to the effects of global environmental change.

If climate change leads to greater aridity in some regions, will that lead to increasing conflicts over water or will it inspire creative institutional approaches to resolve such disputes? Is any particular system of water law inherently better

suited to resolving conflicts in the presence of uncertainty regarding both relative valuations and the future state of the resource itself? Are there reasons to take actions now to allay the future costs of adapting to climate change? To address such questions, it is helpful to consider the nature of the relationship between institutions and individual decisions regarding the use of natural resources. Institutions can be defined as:

> the humanly devised constraints that structure human interaction. They are made up of formal constraints (e.g., rules, laws, constitutions), informal constraints (e.g., norms of behavior, conventions, self-imposed codes of conduct), and their enforcement characteristics. Together they define the incentive structure of societies and specifically economies (North, 1994, p. 360).

Recent work on the economics of property rights and related institutions suggests that institutions shape current decisions regarding the use of resources as well as the path of adjustment to changing circumstances (Ostrom, 1990; Bromley, 1991). These multiple effects arise because institutions influence the costs of engaging in transactions through markets and within organizations, as well as the costs of engaging in political action (Alchian, 1965; Bromley, 1982; Barzel, 1989; North, 1994). Transaction costs, defined as: "the costs of specifying what is being exchanged and of enforcing the consequent agreements" (North, 1994, p. 361), are thus molded by institutional choices. In turn, transaction costs influence the course of institutional change by affecting political exchanges and private contracts (Cheung, 1970; Eggertsson, 1990).

Use of the term 'institutions' in this literature differs from its use in common parlance. Institutions establish the ground rules within which individuals make decisions and organizations are created and operate (Bromley, 1982; North, 1994). Organizations, such as federal and state water agencies, water suppliers and water user associations, carry out their activities within the set of incentives and constraints provided by current institutions. In the context of this analysis, the relevant institutions include basic systems of water law, specific statutes, systems of administration and enforcement, and changing social norms regarding acceptable water-use practices.

To set the stage for our analysis, we begin with an overview of the evolution of water allocation institutions in the eastern and western portions of the United States. We highlight the importance of differences in climate and changing human demands. The two distinct traditions of water law in this country provide an opportunity to examine how differences in climate and historical patterns of water use continue to shape institutional responses to changing values and demands. We then discuss the potential hydrologic impacts of climate change and the uncertainties associated with those impacts. The evidence indicates that we must now accommodate competing water demands within the context of increasing hydrologic uncertainty. This additional source of uncertainty suggests factors that water managers and the public should consider in water policy decisions over the coming

decades. In the conclusion of this paper, we identify such factors and make recommendations regarding their incorporation in the design of future water policies.

2. Development and Evolution of U.S. Water Institutions

2.1. THE RIPARIAN AND PRIOR APPROPRIATION SYSTEMS OF WATER LAW

Courts and legislatures historically constructed American water law on two distinct doctrines, riparian rights and prior appropriation. Each system of law can be seen as a tool designed, within a particular climatic setting, to manage the dynamic competing efforts of individuals to control some part of the water resource. The riparian doctrine was the foundation of water laws in the water-abundant eastern states while prior appropriation developed in the more arid western section of the continental United States. While state water laws have changed significantly through the decades, the fundamental principles of the riparian doctrine and prior appropriation continue to shape the basic character of state water laws. Table I presents a brief synopsis of the nature of water rights under these two systems of law as well as under the newer riparian- based permit systems now widely used in the eastern states. The permit systems are described below.

Under the riparian doctrine, the owner of land adjacent to a water source has the right to make 'reasonable use' of the water on the riparian land. The riparian system was essentially court-made property law based on the common law of England. In both England and the eastern United States a humid environment and abundant surface water led to few conflicts over exclusive (e.g., consumptive) uses of water. In fact, the possibility of exclusive use was ignored in early statements of riparian principles that guaranteed riparians enjoyment of the full unaltered natural flow of a stream. Rather, riparian water law was designed to address conflicts that revolved around potentially competing instream uses of water, such as for the operation of mills (Rose, 1990).

Under the prior appropriation system, the party with the oldest right has first priority to the available water. Junior users may not exercise their rights until all older rights have been satisfied. This system makes it relatively clear who has the right to make use of each unit of water as flow levels fluctuate due to drought, seasonal variability, or sporadic storm flows (Chandler, 1913; Hutchins, 1971; Beck, 1990).

The prior appropriation system emphasized the private property nature of the right to use water that had been physically possessed and, in the process, succeeded in effectively privatizing much of the water in the western states. In contrast to the eastern states, where non-consumptive instream uses of water were historically important, early economic uses of western surface waters were predominantly out-of- stream and consumptive in nature. Because prior appropriation laws were designed to promote 'productive' water uses, most made no provision for establishment of water rights for instream uses other than for hydropower. Only very

Table I
Characteristics of U.S. Water Rights[1]

	Prior appropriation	Riparian	Riparian-based permit
Limits of right	Specific place of diversion, quantity/rate of diversion, place and type of use	Unquantified, 'reasonable use' relative to uses of other riparians	Specific quantity/rate of diversion; place and type of use
Basis of entitlement	Physical control, continued 'beneficial' use	Ownership of land adjacent to water source	Use, as defined by permit
Duration of right	Permanent, except for abandonment or forfeiture due to continued non-use	Permanent, but subject to change with the changing uses of other riparians	Temporary, duration of permit established at time of issuance
Allocation rule	First in time, first in right	Similarly situated riparians share co-equal rights	Priority established by code; within classes by state agency discretion
Enforcement of allocations	State engineer or equivalent; court	Civil court in response to suits	State water resources department; court
Transferability	Yes, subject to requirement of no damage to other vested water rights	No	Rules vary, in practice few or no transfers

[1] Tarlock (1989).

recently have western states revised their water laws to allow establishment of instream water rights for environmental, aesthetic and recreational purposes (MacDonnell and Rice, 1993). In most cases, only a public agency may hold such rights. In practice, with limited budgets to purchase senior rights, most instream rights have such junior status that they may be of little practical significance (Wilkinson, 1989). In some cases, however, states allow private groups to purchase senior agricultural water rights and donate them to instream use in perpetuity (Colby, 1993).

2.2. ADAPTATIONS TO CHANGING VALUES AND DEMANDS

In the western states, rapid population influx and urbanization have created new demands for water in areas where farmers and ranchers long ago appropriated the reliable supplies. Increasing environmental concerns and the elimination of

federal subsidies for new water projects have simultaneously reduced the options for developing new sources of supply. While certainty of supply remains a dominant concern to water users in the western states, flexibility to move water from one type of use to another has become increasingly valuable. The value of flexibility is reflected in increasing numbers of market transfers of water rights throughout the region and in efforts to devise new mechanisms to facilitate short-term transfers of water entitlements.

Under the prior appropriation system, transfers of water from one place or type of use to another may not result in damage to any other valid water right (MacDonnell, 1990a). Where there is no buffer of unappropriated water, any transfer could potentially impose such damages by altering the quantity, location, timing or quality of return flows. Transfer proposals thus often generate significant transaction costs (MacDonnell, 1990b) in the form of legal fees, costs of hydrologic analyses, and time and effort devoted by all parties whose rights could be affected as each seeks to ensure a favorable definition of the transferable limits of the right.

As transfer proposals have become more frequent, two opposing trends have become evident. On the one hand, parties interested in facilitating transfers have sought to clarify the legal definition of a transferable right (Anderson, 1983) and to improve documentation of existing rights through the adjudication process. Others have increasingly called for the protection of community values derived from the continuance of historical agricultural uses (Ingram and Oggins, 1990; NRC, 1992).

The value of recreational and environmental uses of water has also increased. To some extent, these values are also being expressed in water markets (Colby, 1993). However, since water laws in most states do not provide for private ownership of instream water rights and since environmental, aesthetic and recreational uses tend to be non-exclusive, the role of market transfers has been limited.

Instead, the expression of environmental and recreational water demands has often taken the form of efforts to change the rules of the game by which water is allocated, either through legislation or through court challenges of other proposed or ongoing water uses. With respect to legislation, environmental interests have actively supported improved transferability of water rights, because they see market transfers as an environmentally less damaging alternative to new dams. On the other hand, they have also sought to reallocate water to environmental purposes by favoring redefinition of water rights that are currently contributing to environmental damage, either through the courts (e.g., *National Audubon Society v. Superior Court of Alpine County,* 658 P.2d 709) or through legislation such as the 1992 Central Valley Project (CVP) Improvement Act (Title XXXIV of Public Law 102-575) which mandates the allocation of 800,000 acre-feet of Central Valley Project water supplies to implement fish and wildlife restoration.

As interest in the preservation and restoration of aquatic environments has grown, an increasing number of individuals have questioned the legitimacy of the prior appropriation system. Thus, the growth in demand for ‘common property’ aspects of western streams has led to growing pressure for more of a ‘public trust’

approach to western water law, entailing greater limits on the exercise of private rights and increased administrative control over water uses that pose a danger to instream values (Wilkinson, 1989; Butler, 1990).

In the eastern states, population growth and expanding municipal water withdrawals have made specific claims to a part of the water supply a more prominent concern than had been the case in the nineteenth century. As municipal and other out-of-stream water demands have increased, the weaknesses of the reasonable use rule in allocating water among rival consumptive uses has led to increasing pressures to clarify and quantify entitlements. In response to actual or anticipated difficulties in the delineation and enforcement of competing riparian rights, the majority of the traditional riparian states have modified their water laws. Several states have adopted permit systems while others have adopted only registration requirements or regulations governing particular types of uses (Sherk, 1990; Abrams, 1990). The permit systems typically establish threshold use amounts, thus exempting small diversions from all or part of the permit requirements. Where required, permits are generally fixed- duration, non-transferable licenses to divert a specified quantity of water. Permitting agencies maintain administrative oversight of permitted uses and do not convey permanent property rights to permit holders.

This attention to clarifying rights to withdraw water from eastern streams has not supplanted concern for preserving streamflows, but the players have changed. A growing cadré of conservationists and recreational users, seeking to protect and restore the quality of stream environments, have replaced mill owners as the primary champions of instream flows. Thus, it appears that in both the eastern and western states, inherently joint, instream uses are currently increasing in importance. If this trend continues, planning for the impacts of climate change and adaptation to those impacts as they actually unfold will likely occur in the context of ongoing efforts to clarify and redefine the rights of consumptive water users as against other parties who value the maintenance of instream flows primarily for ecological, aesthetic and recreational purposes. Since these latter values are likely to be sponsored by public agencies, ongoing struggles to redefine the boundaries between private and public discretion over water resources are likely to be part of the institutional setting within which the effects of climate change will be addressed.

2.3. OTHER INSTITUTIONAL CONSIDERATIONS

The prior appropriation and riparian/permit systems of water law constitute the institutional foundation for water use decisions in the United States. The full institutional infrastructure also includes many other laws, programs, contracts and administrative arrangements. In some western river basins, where federal water storage projects control a large portion of the annual streamflow, the contracts and operating rules pertaining to the projects are the dominant institutional arrangements. Congress authorized these projects to promote rapid development of the western states, always building subsidies to irrigated agriculture into the repay-

ment contracts (Wahl, 1989; Wilkinson, 1989). Projects were thus prizes, eagerly sought by western development interests.

In some instances, the promise of federal water projects served as the impetus for interstate agreements on the allocation of rivers crossing state boundaries. In the case of the Colorado River, California's desire to secure congressional authorization of the All American Canal and Boulder Canyon (Hoover) Dam propelled negotiations for the 1922 Colorado River Compact. The Compact divided the water between the Upper and Lower Basins, obligating the Upper Basin to deliver a moving ten-year average of 7.5 maf (million acre-feet) per year at Lee Ferry. Except for Upper Basin water rights that were perfected prior to the Compact, this gives the Lower Basin priority in the event of reduced flows (MacDonnell et al., 1995). In addition, the Lower Basin has the larger right because Compact allocations were based on an assumed average flow considerably larger than the long-run average of 13.5 maf suggested by tree-ring evidence (Stockton and Jacoby, 1976). Later, the Upper Colorado River Basin Compact clarified how the burden of meeting the obligation to the Lower Basin would be divided among the Upper Basin states, clearing the way for federal support for major storage projects in the Upper Basin. The system of reservoirs now in place in the Colorado Basin is capable of storing approximately four times the average annual flow of the River.

The Compact, subsequent statutes, an international treaty, court decisions and project operating rules together comprise the 'Law of the River'. A recent study of the potential impacts of a severe sustained drought found that this set of institutions would leave sensitive biological resources, hydropower generation and Upper Basin water users vulnerable to damages despite the extraordinary engineering attempts to drought-proof the River. The study team also found that certain proposed institutional changes could considerably alter the level and incidence of the damages (Booker, 1995; Kenney, 1995; Lord et al., 1995; Sangoyomi and Harding, 1995).

The past quarter century has witnessed tremendous change in federal involvement in the development of new water projects, operation of existing federal projects, management of water quality, and protection of aquatic environments. The so-called 'iron triangle' between local water development interests, the federal construction agencies, and congressional public works committees that fostered decades of pork-barrel water projects has given way to a newer pattern of greatly reduced federal funding for water projects, greater cost sharing by project beneficiaries and changes in the types of projects receiving federal support (Cortner and Auburg, 1988). Coalitions of environmentalists and congressional cost- cutters began to force changes in the established system of project authorization in the late 1960s and early 1970s (Ingram, 1972). The Reagan Administration further curtailed federal involvement in water resources planning by eliminating the Water Resources Council, the joint federal-state river basin commissions and federal grants for state planning, and by significantly cutting federal funding for water resources research. "By 1982, most of the institution framework for federal water resources policy had been dismantled" (Cortner and Auburg, 1988, p. 1052).

While federal financing of water projects has greatly diminished, federal regulation of water use and development has become an increasingly important part of the set of institutions governing the nation's water resources. Federal influences include federal jurisdiction over navigable waters, federal laws (e.g., Clean Water Act [P.L. 92-500, 1972]; Safe Drinking Water Act [P.L. 93-523, 1974]), and Supreme Court cases (e.g., *Sporhase v. Nebraska ex rel. Douglas*, 458 U.S. 941, 1 02 S.Ct. 3456, 1982; *City of El Paso v. Reynolds*, 365 F. Supp. 379 [D.N.M. 1983], 1983) (Wilhite and Rhodes, 1994). International treaties and interstate compacts may also constrain water allocation decisions at the state level, if the limits imposed by such agreements are binding and enforced (Bennett, 1994).

Two examples of federal control that may become increasingly important if water availability diminishes are the Endangered Species Act (P.L. 93-205) and reserved water rights for federal and Native American lands. The Endangered Species Act, which in recent years has become a forceful instrument for the protection of aquatic and other water-dependent biota, may restrict future use and development of water supplies (OTA, 1993). In addition, the Supreme Court has held that when the federal government established Native American reservations, National Parks and other permanent federal land reservations, it also implicitly reserved sufficient water to serve the purposes of the reservation (Tarlock, 1989). The date on which the reservation was established determines the seniority of these reserved water rights, giving them priority over most appropriative water rights. In many cases, Native American claims have not yet been quantified or exercised, and controversy has accompanied the exercise of federal reserved water rights for purposes of environmental protection (OTA, 1993). Both federal reserved rights and Native American rights have the potential for leading to future conflicts with other water users, particularly if streamflows diminish.

Despite the importance of federal influences, most of the ongoing authority over the use and management of water resources rests at the level of the state, the local supplier and the individual irrigator. Administrative arrangements differ significantly, and contracts, bylaws and authorizing legislation often constrain the pricing, allocation and water trading options available to irrigation districts, other local suppliers and their members.

In most states, a state engineer's office or its equivalent handles the issuance of new water rights or water use permits, approval of transfers and enforcement of existing rights. The powers granted to these offices, their budgets, established procedures, and the quality of the records available to them differ considerably from one state to the next. In eastern riparian states that have not yet adopted permit systems, the resolution of any disputes is handled by the courts. In the west, Colorado uses a unique system of specialized water courts for the establishment and transfer of water rights, coupled with active ongoing enforcement by state division engineers. Such differences have a significant impact on the transaction costs incurred in transferring water rights and therefore on the nature and amount of water transfer activity (MacDonnell, 1990b). The fact that water transfers are

more difficult in some jurisdictions than in others suggests that such state-level administrative arrangements will have an important bearing on the costs of adapting to the effects of climate change.

3. Challenges Arising From Prospective Climate Change

How might climate change affect the rights of competing users to the multiple facets of a water resource? What institutional factors will make it easy or difficult to adapt to climate change within the context of each system?

The physical effects of trace gas-induced climate change on streamflows will depend on changes in temperatures, evapotranspiration and precipitation. Smaller snowpacks may lead to reduced summer streamflows in some river basins. A study of the Sacramento Basin estimated, for example, that if temperatures increased by 2 °C and precipitation patterns remained unchanged, summer streamflows (June–Aug.) would decline by 22 percent while winter runoff (Dec.–Feb.) would increase by 8 percent (Gleick, 1987). Similar results were obtained in a study of the Animas River Basin in Colorado, which estimated that a 2 °C warming would reduce summer streamflows (July–Sept.) by roughly 40 percent (Schaake, 1990). In basins in which there are few acceptable options for additional artificial storage, such changes in the hydrologic regime imply a significant reduction in water availability to service competing demands. Those estimates are based only on changes in temperatures.

Analyses of climate change scenarios for river basins in the eastern states also suggest the possibility of reduced summer streamflows as well as increased winter runoff in those areas where there are currently winter snowpacks. A study of the Delaware River Basin (McCabe and Ayers, 1989) estimated that large percentage increases in precipitation would be required to maintain summer soil moisture, and that annual runoff would decline by 9–14 percent with a 2 °C warming and 20–25 percent with a 4 °C warming without offsetting increases in precipitation.

Surface runoff is sensitive to changes in temperatures and precipitation, and changes in interconnected aquifers will further affect streamflows (White, 1985). For example, if warmer temperatures cause soil moisture depletion, infiltration to aquifers will diminish. As the level of an aquifer declines, groundwater discharge to surface streams will decline and seepage losses from surface water bodies to the aquifer may increase. Changes in precipitation may offset or exacerbate the hydrologic changes that are predicted on the basis of temperature changes alone – and the climate models are a long way from being able to accurately forecast how regional precipitation regimes may change in a warmer world (Tegart et al., 1990; Waggoner, 1990).

The prospect of climate change thus creates considerable uncertainty regarding future water availability. What problems might arise from that uncertainty itself and how might the problems differ as a result of the initial legal framework and

existing patterns of use and availability? In the west, reliable hydrologic information is particularly valuable for assessment of the impacts of proposals to transfer or alter the use of a water right. Reliable estimates of the statistical distribution of streamflows, consumptive use and evaporative losses from natural channels and conveyance facilities are important to state engineers responsible for determining the availability of unappropriated water. They are equally important to parties seeking to establish new water rights and to those interested in ensuring the preservation of aquatic environments.

Climate change will affect not only initial surface runoff into a stream system, but also rates of evaporative loss, seepage to groundwater aquifers, recharge from those aquifers and rates of consumptive use from irrigation withdrawals along the entire stream system. Because the ultimate direction and magnitude of those changes may remain unpredictable until climate change is well under way, estimates of the reliability of new public or private rights and of the impacts of water right transfers will be both fraught with uncertainty and increasingly open to dispute. In the case of transfer proposals, water authorities often limit the quantity of water transferred from an existing user to another place or type of use to the seller's historic consumptive use to prevent impairment of other water rights. For example, half of the water diverted to an irrigated field might currently be lost to evapotranspiration while the remainder returns to a usable water body. If that right is transferred, the buyer's diversion right would be established to allow expected consumption equal to half of the original diversion right. In addition, the water court or state authority may impose terms and conditions on the transfer to further protect other water users against changes in the timing or location of return flows.

The prospect of climate change makes it more difficult to forecast both future consumptive uses and the future availability of water to keep existing uses intact. For example, warmer temperatures could cause return flows from a new use to be smaller than anticipated by increasing evaporative and seepage losses.

Even under the presumption of a stable climate, imprecise hydrologic information is now frequently at the heart of costly conflicts over proposed water transfers and new water developments. This suggests that uncertain changes in the climatic regime will likely enhance the basis for such disputes. Policymakers, hydrologists, administrators and the judiciary should therefore give careful attention to the question of how such climatic uncertainties might enter into decisions regarding the development or transfer of water rights and to the issue of who will bear the risk of mistaken assessments.

In the eastern states, voluntary transfers of established water rights have not yet become an issue, but the courts and water authorities are concerned with the potential impacts of new uses on other parties. Forecasting those impacts in the presence of potential climate change is likely to be difficult, particularly in states lacking reliable information on water uses. Unlike the western states where water rights, once granted, tend to be viewed as permanent property rights, rights held under permits in most of the eastern states are explicitly of limited duration. This

might suggest that decisions based on hydrologic assumptions that later prove inaccurate would be easier to 'fix' than under the prior appropriation system's presumption of relatively permanent rights. Eastern-state parties that have made substantial water-related investments, however, may be no more likely to quietly acquiesce to reduction of their permit rights than would be western appropriators faced with an administrator's demand, grounded on the public trust principle, that they line their ditches or reduce their withdrawals to mitigate streamflow reductions caused by climate change.

The uncertain hydrologic impacts of climate change may also complicate the enforcement of water rights even in the absence of proposed changes in water uses. The generally poor integration of groundwater and surface water rights in both western and eastern states may present increasing problems if climate change alters the entire hydrologic regime within interconnected groundwater and surface water systems. Here, measurability is important. Where hydrologic models are available, they may be unreliable under conditions departing significantly from those on which the models were based, and there are many watersheds and aquifers for which the hydrology is poorly understood even for the existing climate. In addition, records of actual withdrawals, consumption and instream uses are frequently lacking even in states that nominally follow the prior appropriation doctrine or that have adopted permit systems. Uncertainty about basic hydrologic relationships and inadequate water use records could make it difficult to determine responsibility for changes in water availability under climate change (i.e., is the lower water table the fault of nature or your neighbor?) Such measurement problems may lead to disputes as water authorities and users attempt to determine a fair and efficient allocation of altered supplies.

Now consider the case in which climate change is under way and water is becoming more scarce. Because interannual variability will continue as the climate system changes, it may take a very long time to clearly recognize any such trend (Rogers, 1994). Transitions to drier regimes are most likely to occur as a gradual increase in the frequency of dry years, interspersed with wet periods, and gradual shifts in the timing of runoff and in the recharge/discharge interactions of groundwater and surface water systems.

Under the prior appropriation system, the impacts of increasing water scarcity would fall most heavily on the most junior water users, as well as on environmental values that have not been protected by the dedication of reliable senior rights to instream flows. Junior users would have incentives to find ways to adapt, both to individual dry periods and to mounting evidence of a shift to a drier regime. For example, they could make arrangements to buy or periodically rent more senior water rights; they could invest in storage infrastructure, engage in water conservation, develop programs for conjunctive use of groundwater and surface water; or they could decide to cease their water-using activities. Another option, of course, would be to lobby for the mandatory reduction and reallocation of the rights of their senior neighbors. Well-functioning water markets would tend to

reduce such pressures and, in the absence of mandatory reallocation, the differential impacts of a climate change on junior and senior water users would create further opportunities for the development of water markets.

Water markets are likely to be most effective where the water uses are primarily exclusive or consumptive in nature, or if non-consumptive, involve a relatively small number of parties. Because most water uses are not fully consumptive, water markets will function efficiently only if the law protects third parties against changes in return flows. Trelease (1977) notes that providing that protection can be costly and time-consuming where rights are defined on the basis of diversion rather than on the basis of consumptive use. Consumptive use determines the availability of water to downstream parties, and it is typically difficult to measure. Recall that climate change may alter the relationship between diversions and consumptive use by changing conveyance losses and evapotranspiration from irrigated fields.

Privately arranged market transfers of water rights are unlikely to adequately protect environmental values accruing to a large and amorphous public against the impacts of a shift to warmer and drier conditions. This is due to the fact that voluntary collective action to provide such public goods is limited by the incentive of each individual to free-ride on the contributions of others. Government provision of environmental goods may be more efficient than private contracting in such cases (Barzel, 1989; Eggertsson, 1990). The experience of the western states suggests that some form of action by state authorities will be required to provide appropriate levels of protection for water quality and instream flows if drier conditions become more prevalent.

The Colorado River Severe Sustained Drought study provides analogical evidence that non-consumptive water uses would be more vulnerable to damage than traditional consumptive uses. That study concluded that damages to non-consumptive uses could not easily be mitigated without changes in statutes or judicial interpretations to give greater voice to those interests (Lord et al., 1995).

In the eastern states, the more fluid definitions of individual water rights might discourage advanced planning on the part of private parties. Users might attempt, instead, to convince water authorities or the courts that their own uses are more reasonable and beneficial than those of competing users and therefore warrant better protection. Whereas multilateral negotiations and exchanges appear likely in the west, the centralization of decision-making authority in the eastern permit-system states suggests that water users may concentrate on influencing the authorities. The flexibility inherent in the permit systems thus can give rise to transaction costs in the form of the efforts of competing users to plead their claims to a dwindling resource. On the other hand, that very flexibility may make it easier to protect water quality and instream uses than would be the case in the western states, where it may prove difficult to dislodge expectations that a water right entails protection of a particular rate of diversion and method of application regardless of the environmental consequences.

4. Recommendations

Both water allocation systems have potential strengths and weaknesses in the context of facilitating adaptation to climate change. The challenge is to determine the most effective way to enhance adaptive capacity in each institutional setting. Within both systems, water laws have accommodated considerable change in the level and nature of human demands on water resources. As individual states have experienced changing demands they have consciously or unconsciously made tradeoffs between the up-front costs of modifying water statutes or administrative procedures to clarify the dimensions of individual water rights and the subsequent dispute- related transaction costs arising from the efforts of water users to modify or expand their water uses. This investment problem is a continuing phenomenon that separate jurisdictions have handled differently. For example, some states have made greater efforts to document existing water uses than have others.

The prospect of climate changes makes it more important to give explicit attention to the tradeoff between the initial costs of clarifying the rights of multiple water users and the future costs of conflicts that may arise if water availability changes. The desires of competing water users for certainty, flexibility and protection of environmental values must now be accommodated within the context of increasing hydrologic uncertainty. This suggests a number of factors that policymakers should consider in the upcoming decades as water statutes are modified, as adjudications are carried out, and as decisions are made regarding water transfers, issuance of new permits and protection of environmental values.

A. *Improve the Predictability of the Limits of Individual Rights under a Variety of Possible Climatic Conditions:*

While the prior appropriation system clearly defines the relationship between streamflows and diversion rights, other dimensions of a right such as allowable consumptive use can vary, to the detriment of other users, as climatic conditions change. This is due to the fact that the relationship between the quantity of water diverted and consumptive use of that water is not constant. Under warmer conditions, a larger fraction of the water is likely to be lost to evaporation from conveyance channels and to crop evapotranspiration, thus reducing return flows. It may be valuable to define limits on allowable consumptive use as a basis for reducing the adverse impacts of climate change on junior users and instream flows. For example, state regulations could specify consumptive use thresholds at which owners of existing water rights could reasonably be required to modify their diversions and application practices as climatic conditions change. State water authorities should explicitly incorporate such conditions in the specification of any new water rights.

Under the permit systems in eastern states, water authorities could provide better predictability by clarifying how they are likely to reduce the right when streamflows decline. They could lay out conditions at the time of initial permit issuance and

update them according to published rules at each permit-renewal interval. Such improvements in the definition and predictability of water rights would enhance transferability by providing better security to purchasers and potentially affected third parties.

B. *Further Document and Clarify Consumptive Use Rights:*
The prospect of climate change suggests that it may be valuable to better document water withdrawals and consumptive uses, as well as natural variations in streamflows and groundwater levels. Such efforts should be targeted at reducing the basis for future disputes and providing adequate information for water transfers should water scarcity become more prevalent. In pursuit of this objective, water authorities should attempt to balance the likely value of additional information against the potential costs of 'information overload'. Parsimony in data reporting requirements and the design of efficient systems for the storage and timely retrieval of relevant information should be guiding principles. The benefits of improved documentation are likely to accrue both to parties who currently withdraw water for exclusive uses and to the broad public interested in preserving environmental, aesthetic and recreational values associated with water resources. This suggests that the costs of improved documentation should be borne by both current water users and general taxpayers. The appropriate level of investment and distribution of the cost burden are inherently public decisions.

C. *Better Integrate Groundwater and Surface Water Rights:*
Possible changes in the hydrologic interactions between groundwater and surface water systems may reinforce the value of clarifying the rules for enforcement of rights within such interconnected systems. There is an inherent lag between changes in groundwater extractions and resulting changes in streamflows. This makes short-term administration of withdrawals an ineffective method of enforcing the rights of downstream surface water users against parties pumping water from a tributary aquifer. More effective options for offsetting the impacts of groundwater pumping are available (MacDonnell, 1988) and their application may become increasingly necessary to ensure a fair balancing of the rights of users of surface water and groundwater. In planning for the integration of groundwater and surface water rights, water authorities should give attention to how the hydrologic interactions between groundwater and surface water sources may be affected by a range of possible future changes in the local and regional climate.

D. *Plan for Adaptation:*
State and local planning would reduce the likelihood of implementing programs that are later revealed to be unnecessary or inordinately controversial. Responses could be phased in as the actual hydrologic effects of climate change become more evident. It would be valuable to begin planning both for the management of increased flood risks and for water allocation in the event of increased scarcity, in

each case identifying policies to be pursued if conditions become wetter or drier. In addition, policymakers should attempt to assign planning, data collection and administrative responsibilities to make most effective use of evolving information about water supply conditions and water-use values.

It may also be valuable to re-establish interstate or national-level forums for water resources planning. Interstate river basin commissions could facilitate the development of flexible options for responding to the uncertain impacts of climate change. The report of the Office of Technology Assessment (OTA, 1993) discusses the advantages of comprehensive water resource planning and management at the basin level. For example, basin-wide coordination may allow multiple demands to be met more efficiently than would be possible with uncoordinated reservoir management. The value of such coordination may increase if there are significant changes in water availability or streamflow variability. In addition, as the scope of planning and coordination are expanded, a wider range of options for responding to changing water supplies and demands is likely to be available.

At the national level, Congress could reactivate the National Water Council or create a similar high-level coordinating body. The OTA report argues that such a body ". . . could play an important role in improving cooperation and coordination among the many Federal agencies with water- related responsibilities and among Federal State, and local governments and the private sector" (OTA, 1993, p. 249). It could also serve as a clearing house for research and data relating to changing hydrologic conditions.

E. *Create Flexibility to Move Water to More Valuable Uses:*

Flexibility in water allocation can be achieved either through markets or through administrative action. The key is to ensure that the method chosen provides a fair and efficient means of moving some aspect of the water resource to a more valuable use. Unproductive disputes, efforts devoted to lobbying for bigger shares of the resource and excessive search costs must be avoided, because these tend to waste the potential gains from reallocation of the resource. Among the important considerations in determining the appropriate locus for decision making are access to information and incentives to act upon that information. For water uses that are primarily exclusive in nature, Trelease (1977, p. 82) argues that water users themselves have the best information about the value of the water, and their self-interest will channel the resource from low valued uses to more highly valued uses if water becomes scarcer relative to their demands.

> The bureaucrat trying to decide the best use of water as between agriculture and industry will have to investigate, hold hearings, hire experts, finance a university study and make findings. The manager of the Tootsie Textile Company and Farmer Jones, sitting at the bargaining table, can tell the answer in a minute by a glance at the bottom line of last year's books.

This argues that voluntary reallocation should play an important role in determining the future distribution of scarce water among competing uses. As noted previously, this method of allocation may be less effective where non-exclusive uses are involved, but public agencies could represent such interests in a market setting if they are provided with budgets to buy or rent water rights for environmental purposes.

The effectiveness of water marketing in promoting flexible adaptation to prospective climate change will depend on the nature of the markets. At present, the process for approving water transfers in the western states involves considerable transaction costs (MacDonnell, 1990b). As a result, most transfers between different types of uses tend to be permanent transfers of large blocks of water. Such large transfers are not a particularly effective tool for responding to the effects of climatic variability or to the uncertain prospect of climate change. Rather, policymakers should focus greater attention on promoting shifts of small quantities of water and temporary transfers from senior to junior users during periods of low flows. This could be accomplished by streamlining administrative procedures for temporary transfers or by establishing formal water banks. California used such banks in 1991, 1992 and 1994 to mitigate the uneven impacts of a persistent drought. Although there have been only a few other examples of functioning water banks to date, experience suggests that rules and procedures can be designed to allow timely transfers of water from lower to higher valued uses while effectively managing the possible environmental and third party impacts of the altered pattern of use (MacDonnell et al., 1994).

Similar mechanisms could be established as needed in the eastern states, but to function effectively, the quantitative limits of the entitlements would have to be clearly established for the period to be covered by the bank. For example, a water authority could announce firm cut-backs of permit rights during a drought but allow permit holders to sell part of their entitlements or purchase additional water through the bank. Temporary and partial transfers as through a water bank could allow water users to improve upon the distribution of entitlements established by the permitting agency and could ease the burden of adjusting to any reductions in permit rights instituted in response to the effects of climate change.

F. *Enhance the Ability to Condition Rights in a Fair and Efficient Manner to Provide Appropriate Protection for Environmental Values:*

Given established patterns of water use and established expectations, efforts to mitigate the degradation of streams, lakes and wetlands that may result from climate change will raise difficult questions of equity and efficiency. Careful attention to the proper roles of market allocation and administratively imposed limits on the exercise of individual water rights will be important to ensure efficient protection of the public trust, but there is also an inherent distributional question. That is: who should bear the cost of environmental preservation and restoration when climate change is a factor in the degradation?

Should the water users bear the full cost of preserving environmental values in the presence of such a change or should their liability be limited to not increasing their own consumptive use in response to warmer temperatures, reduced precipitation and higher rates of evapotranspiration? Provided with adequate budgets, public agencies might be able to preserve streamflows and water quality by buying water from existing users, but that option assumes that the public at large should bear the entire burden of preserving public trust values in the presence of climate change.

Advanced consideration of the distribution of rights and responsibilities in the event of significant change in the hydrologic regime could help to avoid costly future disputes. Open discussion of the criteria by which policy options should be evaluated will also be valuable. Authorities could specifically condition new water rights to alert users to possible future modification of the rights and to explicitly spell out the climatic and environmental conditions under which such modifications can be expected. In addition, it would be valuable to develop clear policy statements regarding modifications of established rights in the event of future climate change or long-run drought, together with explicitly stated standards of evidence that will be used to determine when hydrologic conditions have changed sufficiently to warrant implementation of the regulations.

G. *Create and Preserve a Water Supply 'Safety Margin':*

Where no buffer of unappropriated water exists, it is inevitable that some water users will be made worse off if conditions become drier. Even where streamflows are not so fully allocated that junior out-of-stream users face a significant risk of being unable to exercise their rights, public instream values may suffer under drier conditions. The possibility of conflicts between competing water users might be reduced if instream flows are explicitly treated as a buffer to be used to absorb the impact of changing climatic conditions. Rather than setting a single minimum flow standard to be used as a target for avoiding serious adverse impacts on fisheries and other aquatic resources, a range of environmentally desirable flow levels could be defined. The lower level might serve as a trigger for water authorities to enhance instream flows by purchasing water or implementing restrictions on existing rights, while the upper level would be used as the target for conditioning new rights. For example, administrators could grant new permits subject to the condition that they not deplete streamflows beyond the upper flow- level target. If flows increase, water users could fully exercise the new rights. If flows decline, the impact would fall first on the conditioned permits, then on the buffer and finally on current water uses. Where water is already fully appropriated, authorities could create such a buffer by purchasing water rights from willing sellers to reduce existing consumptive uses. Where unappropriated water is available, they could more easily create such a buffer by incorporating appropriate conditions in the definition of new rights and by closing some streams to new appropriations unless and until there is considerable evidence that wetter conditions are likely to prevail.

5. Conclusion

The time has come for innovative thinking on the question of how our water allocation institutions should function to improve our capacity to adapt to the uncertain but potentially large impacts of global climate change on regional water supplies. Given the climatic uncertainties and the very different institutional settings that have developed in this country, there is no simple prescription for adaptation.

We have identified several elements that decisionmakers should keep in mind for the design of more adaptive water institutions. By pursuing these goals as water laws and administrative procedures are updated, it should be possible to reduce the disruption, potential for disputes and resource degradation that might otherwise result if climate change significantly alters regional hydrologic regimes.

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(Received 11 October 1995; in revised form 9 September 1996)