



**A WHITE PAPER OF THE
GROUNDWATER RESOURCES ASSOCIATION
OF CALIFORNIA**

**DEVELOPING, MANAGING, AND SUSTAINING
CALIFORNIA'S GROUNDWATER RESOURCES**

MARCH 2003

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CONTENTS

PROLOGUE	1
BACKGROUND.....	1
SCIENTIFIC UNDERSTANDING.....	2
THE NATURAL SYSTEM.....	2
HUMAN INFLUENCE.....	4
NATURE’S LAWS AND SUSTAINABILITY.....	5
THE HUMAN SIDE OF CALIFORNIA’S WATER.....	6
ECONOMIC PROSPERITY.....	6
REGULATION OF WATER USE.....	7
CUSTOMARY PRACTICES AND PUBLIC RIGHTS	8
THE DILEMMA OF PRIVATE AND PUBLIC EXPECTATIONS.....	9
COMPETING VALUES	11
ROLE OF SCIENCE IN WATER MANAGEMENT IN CALIFORNIA.....	12
BALANCING WITH NATURE’S LAWS	12
INTEGRATED WATER RESOURCES MANAGEMENT	12
RELATED EXPERIENCES	13
SUSTAINING GROUNDWATER RESOURCES	14
MEANING OF SUSTAINABILITY.....	14
FRAMEWORK FOR ACHIEVING SUSTAINABILITY	14
Unit of Management	15
Management Objectives.....	16
Prediction and Monitoring	16
Institutional Implications	17
Economic Analyses	19
Education.....	19
RECOMMENDATIONS.....	20
EPILOGUE.....	22
ACKNOWLEDGEMENTS.....	23

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T.N. Narasimhan¹ and Vicki Kretsinger²

PROLOGUE

The application of groundwater science to water resources management is in a state of transition. For a variety of reasons, including continued population growth, unpredictable climate, and uncertainty of surface water allocations, reliance on groundwater resources is increasing. At the same time, these factors can also reduce groundwater availability. Attention is shifting from a history of exploration and development of new sources of groundwater to efficient management of groundwater as a renewable but finite resource that is a component of the natural resources system. This White Paper examines the future of groundwater management in California in the context of current scientific knowledge of California's groundwater as well as the cultural and legal traditions that govern the legal status of groundwater in the State.

BACKGROUND

The Groundwater Resources Association of California (GRA) is a nonprofit organization of groundwater professionals dedicated to resource management that protects and improves groundwater through education and technical leadership. GRA's 2002 Annual Meeting was devoted to the theme, "*Sustaining Groundwater Resources: The Critical Vision.*" In a special plenary session entitled, "Groundwater as a Component of the Natural Resources Infrastructure," this theme was explored in detail by a collection of speakers who addressed groundwater sustainability.

This White Paper is an outcome of the information presented by the speakers of the 2002 GRA Annual Meeting about the scientific, legal, and social challenges that are faced as the need to more efficiently manage water resources increases. This paper articulates, on

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behalf of GRA, the actions necessary in California and elsewhere to ensure sustained benefit from groundwater resources. This paper includes discussions of the following:

1. An overview of groundwater science, including its nature, occurrence, movement, and influence;
2. The human aspects of California's water, including history, economics, education, institutions, legal questions, and public perceptions;
3. The role of science in water management, including the meaning of the term "sustainability" and the premises providing the basis for sustainable use of groundwater resources; and
4. Recommended actions that bring together diverse aspects of California's society, including groundwater management units; coordination among hierarchical institutions; monitoring programs; education, research, outreach and training programs; development of new economic tools; and promotion of legislation and policies that are aimed at groundwater sustainability.

SCIENTIFIC UNDERSTANDING

THE NATURAL SYSTEM

California is endowed with abundant and diverse groundwater resources spread over 100 million acres of land that are vital to the State's sustenance and prosperity. The diversity stems from California's physiography, which is characterized by north-south trending mountain ranges separated by intermontane valleys, its geological history over the past few million years during which the Coast Ranges have been pushed up and continue to rise, and its climate over the past 2 million years that has been characterized by cool glacial periods and warm interglacial periods. California's vast resources extend from the rugged volcanic plains of the Modoc Plateau in the extreme north, through the shallow and deep sedimentary aquifers of the Central Valley and the many coastal aquifers, to the deserts of the east and southeast.

California's early immigrants of the 1850s recognized the land's bountiful groundwater resources in the artesian wells that flowed freely over thousands of square miles of intermontane valley floors and the hundreds of hot and cold springs that dotted the state. Despite the diversity in the manifestations, these groundwater resources are unified by the fact that they are all rain-fed over vastly different time scales, with recharge occurring from the geological past to the present day. The historically prevalent wetlands, artesian wells, and springs of California collectively illustrate that groundwater is a very dynamic part of the hydrologic cycle.

Figure 1 is a simple sketch that depicts groundwater within the larger context of the hydrological cycle in the absence of significant human activity. Rainwater that falls on the

land surface infiltrates by gravity in regions designated as “recharge” areas and starts a journey that may last a few weeks or a few million years before it returns toward the land surface. This return occurs as discharge in seeps, springs, wetlands, or surface water courses and eventually to the atmosphere in regions designated as “discharge” areas. The direction of groundwater flow and the direction of the forces that impel it change during its journey under natural conditions from dominantly downward migration by gravity in recharge areas to dominantly upward migration through regional hydraulic gradients in discharge areas.

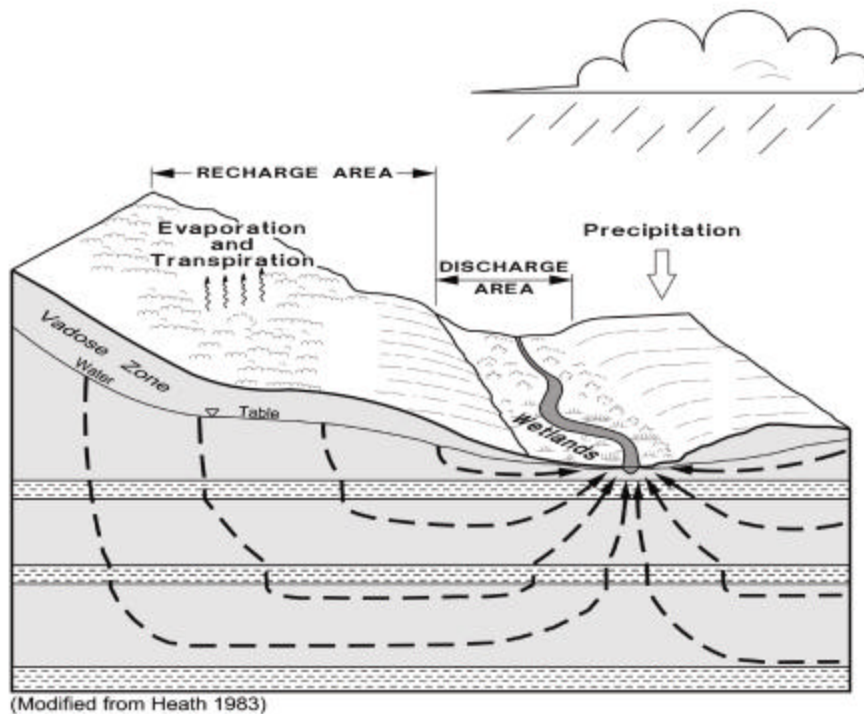


Figure 1: The status of groundwater within the hydrologic cycle in the absence of human activity.

During its voyage, groundwater resides in and wends its way through the intergranular spaces of soils and rocks, mechanically and chemically interacting with them. Water, often referred to as the universal solvent, chemically reacts with the solid components of soils and rocks as well as vapors within the interstices of the vadose zone, or the soil zone between the land surface and the water table in which water coexists with air. Groundwater generally undergoes sequential chemical changes along its path from recharge areas to discharge areas. The chemical quality of water in streams, the nature of

flora and fauna in wetlands, the chemical attributes of various soil types, and the nature and distribution of mineral deposits are a result of the geochemical transformations of groundwater during its voyage. In general, groundwater becomes progressively enriched in dissolved salts, owing to the increased residence time and opportunities for geochemical interactions as it traverses a longer flow path.

Notable geochemical transformations occur in closed or partly closed basins of arid lands such as the San Joaquin Valley. In the discharge areas of these basins, shallow groundwater close to the land surface evaporates and becomes enriched in salts. Consequently, salt encrustations and saline efflorescences may be observed in low-lying areas. Thus, discharge areas are naturally vulnerable to poor quality soils and groundwater even without human action.

As illustrated in Figure 1, under natural hydrogeologic conditions without human intervention, a balance exists among the components of the natural resources system that include groundwater, surface water, soils, and ecosystem. If this balance is perturbed, these interacting components will adjust themselves to attain a new physical/chemical equilibrium compatible with the perturbations.

HUMAN INFLUENCE

Human influence on the equilibrium of regional groundwater flow patterns is schematically portrayed in Figure 2. Under natural conditions, regional hydraulic gradients result in upward groundwater flow in valley bottoms. However, where extensive groundwater development has occurred, the dynamics of a basin invariably change due to causes such as deep percolation of irrigation water, pumping that intercepts regional recharge, and diversions that redistribute or reduce recharge. When natural discharge mechanisms are disrupted in closed or partly open basins, soil and groundwater salinization may result, particularly in irrigated lands in the lower parts of valleys such as the San Joaquin and Imperial Valleys. Near the land surface, salts concentrated through evaporation cap the zone of stagnation. In many parts of California, including the Santa Clara Valley, Chino Basin, Orange County and Santa Ana Valley, water transported via aqueducts is used to recharge groundwater basins. Such imported water can constitute an important part of the basin hydrologic budget. The imported water generally contains more dissolved salts than the local rainwater; however, the quality of imported water may be of better than that of the local groundwater. The long-term water implications of the chemical differences among local rainwater, local groundwater, and imported water need to be

monitored and assessed. In addition, groundwater contamination due to agricultural and industrial effluent is widespread throughout the State. Naturally occurring constituents, including boron, iron, manganese, arsenic and chromium, may not be of concern at certain locations in the regional groundwater flow system, but the form or concentration of these constituents may change naturally along flow paths, or through human influence, thereby becoming a concern. Other important potential consequences of excessive pumping include overdraft, seawater intrusion in coastal aquifers, and land subsidence.

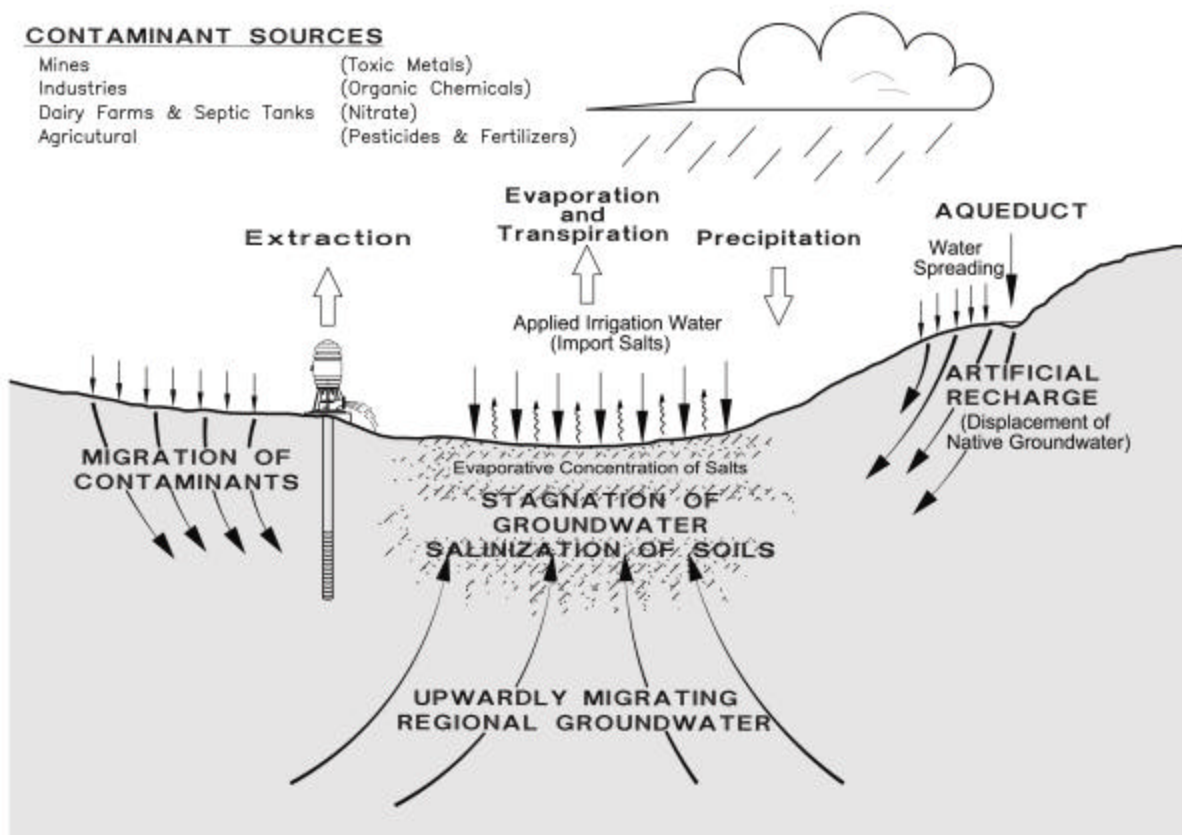


Figure 2: Regional groundwater flow system in relation to activities of a technological society.

NATURE'S LAWS AND SUSTAINABILITY

Despite the impressive diversity and abundance, California's groundwater resources are finite and their renewability is vulnerable to climatic vagaries. Even though we succeed in manipulating groundwater resources through artificial recharge, extraction, and other

ways, nature's laws ultimately control the interactions of groundwater with the atmosphere, streams, lakes, wetlands, soil, and ecosystem. Disappearance of wetlands, land subsidence, salinization of soils, and degradation of coastal aquifers are a few examples of nature's readjustment to human-induced perturbations. Groundwater systems are difficult or even impossible to restore to a pristine or background condition once they are degraded or otherwise damaged. Increasing mineral concentrations in groundwater, including nitrates, in areas of intensive irrigated agriculture, or where large volumes of wastewater have percolated, or as a result of other land uses, have been recognized for decades. Nevertheless, adverse impacts on beneficial use have not yet been widely experienced. Consequently, where groundwater quality is impaired, groundwater is extracted from greater depths, blending occurs, alternative water sources are sought, or treatment technology is employed. As Californians recognize the need for sustainable groundwater use, it is also necessary to recognize that sustainability must be achieved within the framework of physical laws that govern the hydrologic cycle. To this end, groundwater development must be accompanied by flexible and timely management approaches that recognize the functioning of the hydrologic cycle as an integrated system. These approaches are otherwise known as adaptive management. Neglecting to do so will eventually lead to a decline in the availability and quality of groundwater, and probable impairment of ecosystems.

THE HUMAN SIDE OF CALIFORNIA'S WATER

ECONOMIC PROSPERITY

California's early settlers saw limitless possibilities for harnessing abundant natural resources for prosperity, unfettered by governmental controls. The government was looked upon mainly as the facilitator of economic opportunities. Accordingly, the second half of the nineteenth century witnessed legislation that fostered economic growth. Water was viewed as a commodity and means to acquire wealth. In this atmosphere, groundwater became, as inspired by British common law, the property of the overlying landowner. At the turn of the twentieth century, California's economic boom accelerated with the evolution of large-scale industrialized agriculture, growth of commercial urban centers, construction of aqueducts and multi-purpose dams, generation of hydroelectric power, and invention of the deep-well turbine pump.

REGULATION OF WATER USE

Large-scale water development and economic prosperity came at a price. Surface water and groundwater were being developed at rates far in excess of recharge. Water was often wasted through inefficient use. As early as 1878, the First California Constitutional Convention recognized the negative consequences of rights to natural resources without associated responsibilities. To guard against this imbalance, the Convention formally incorporated a resolution that declared the use of all appropriated water in California to be public use, subject to the regulation and control of the state in the manner to be prescribed by law. This tenet later became part of California's Constitution (Article 10, Section 5).

As California's agricultural economy and urban centers grew, the progressive decade beginning in 1910 witnessed serious efforts by the state government to conserve water resources. The Civil Code of 1911 and the Water Commission Act of 1914 established new principles to guide beneficial use of the state's water resources. Section 10 of the Civil Code stated that all water within the state is the property of the people of the state, and that the right to use water may be acquired, as prescribed by law. An amendment echoing this same principle was proposed during the 1878 Constitutional Convention, but it was not adopted. The Water Commission Act required appropriators of surface water to comply with a permitting process. In 1921, a law was passed defining the use and control of water by the State. It declared that the people of the State have a paramount interest in the use of all water of the State, including surface and underground, and that the State shall determine what water can be converted to public use or controlled for public protection. In 1943, the California Water Code was created by the Legislature, building upon and expanding preexisting statutes. In this Code, the 1911 statute concerning ownership of water forms Section 102, and the 1921 statute concerning the determination of what water is used or controlled for public protection forms Section 104.

Despite the progressive steps taken during 1911 and 1914, riparian owners of water continued to waste surface water. These actions were supported by judicial decisions. In 1928, a referendum was passed declaring that all water of the State be put to reasonable and beneficial use, regardless of whether a user had riparian or appropriative rights. This declaration has since been adopted through Article 10, Section 2 of California's Constitution.

CUSTOMARY PRACTICES AND PUBLIC RIGHTS

Groundwater use in California is linked to two historically divergent paths that stem from two English common law traditions. The first is the tradition of absolute right of the overlying landowner, and the second is the more wide-ranging public rights.

When California attained statehood in 1850, British common law was formally adopted as the basis of governance, insofar as it did not conflict with federal laws. British traditions, largely ignorant of the physical laws governing the patterns of groundwater movement, held that the overlying landowner could extract as much groundwater as was possible by wells or other means, for use on the overlying land. This common law tradition bestowed on landowners an absolute ownership of all groundwater below the land owned. As groundwater usage in California increased and groundwater users on adjoining properties began impacting the availability of water on the neighboring property, especially during periods of drought, the courts intervened to resolve the conflicts by requiring adjoining owners to proportionately share the reduction in groundwater yield. This is the principle of “correlative rights”. Many groundwater users in California strongly adhere to the concept of property rights limited by the concept of correlative rights. This common law tradition has had profound implications on water management in California.

The other common law tradition, the doctrine of public trust, is rooted in Roman law traditions dating back to the sixth century A.D. Roman jurisprudence fundamentally distinguished between nature’s laws and human laws. The Romans determined that certain resources such as air, “running” water, the sea and the lands adjoining the sea were essential for all subjects and no one could be denied access to these resources. This doctrine of public trust has become part of the constitutions of many of the states of the United States. In California, the public trust doctrine has become part of the legal system through the tidelands trust. Sections 3 and 4 of Article 10 of California’s Constitution, based on public trust, decree that tidelands, estuaries, and navigable waters of the State are held by the State in trust for the public, assuring free access of these resources to all citizens. In contrast, the state of Hawaii takes a much more inclusive view of the public trust doctrine. Article XI, Section 1 of Hawaii’s Constitution declares that “[a]ll public natural resources are held in trust for the benefit of the people...”

Over the past few decades, the spirit and philosophy of the public trust doctrine has attracted the attention of legal and policy scholars as well as administrators of natural resources. At a philosophical level, the notion that vital natural resources must be protected for the benefit of all citizens transcends running water and the sea that were

specifically cited by the Romans. Legally, public trust is applied only to navigable waters and tidelands. However, with increasing awareness of the impacts of a technological society on the environment, the courts have begun to expand the scope of public trust to include environmental criteria.

In California, public trust was formally extended in the well-known Mono Lake litigation in 1983 to include ecological values of water and to non-navigable streams feeding Mono Lake, which was declared to be navigable, in keeping with the public trust doctrine. The main theme of public trust is that resources that fall within its scope are properties held without title by the people. Such properties are held in trust by the State for the benefit of the people. Beneficial use of such properties is permitted in a usufructuary sense. This means that the user implicitly recognizes the interest of the public in the resource and the resource may not be unacceptably impaired during use. There has been general consensus that surface water resources fall within the scope of public trust in California.

An important, albeit debatable, issue is whether groundwater comes within the scope of public trust in California. The common law tradition continues to be exercised by the users; this gives the overlying landowner a right to use groundwater from below the land, constrained only by the principle of correlative rights. As a result, groundwater is legally treated as real property in California. On the other hand, Section 102 of the Water Code asserts that all water in the State is the property of the people. Section 104 of the same Code declares that the use of all water, including groundwater, is subject to State control for public protection. Further, Article 10, Section 2 of the Constitution states that all water of the State shall be put to beneficial use. Philosophically, these declarations bring groundwater within the realm of public trust, if not within its legal fold.

THE DILEMMA OF PRIVATE AND PUBLIC EXPECTATIONS

How can these seemingly contradictory principles of private property and public trust be reconciled? Although the conflicts may be reconciled at a philosophical level, at a practical level the issue reduces to one of achieving a balance between private property rights and public rights. The landowner perspective holds that control of groundwater extraction may result in decreased access to an available resource, which amounts to the government taking away a property right. The impacted landowner is eligible for monetary compensation, especially for any infrastructure that might have been established to beneficially develop the resource. Public trust responsibilities of the State include long-

term protection of both groundwater quantity and quality. Individual users, particularly landowners who clearly have the associated property rights and rights to the use of resources on their property, have relatively short-term objectives, i.e., years to decades, for their beneficial use of the resources. From a scientific perspective, there is a potential conflict between objectives for short-term use by landowners and long-term use by the public.

The expectations of landowners and the public are both relevant. The resource must satisfy the needs of present and future generations. The difficulty is that the groundwater resources system is finite, subject to degradation due to continued use, and subject to climatic uncertainties. For the State to discharge its public trust responsibilities, groundwater management activities should protect the resource system from unacceptable damage related to private use, outside of individual legal determinations, to ensure groundwater resources are sustained. Reasonable compensation to the user would be a necessary part of any future protection mechanism.

In California, surface water is subject to the constraints of public trust and regulated water management; but groundwater is not, with limited exceptions. Surface water and groundwater constitute a single resource as portrayed in Figures 1 and 2. Present legislative actions have moved toward groundwater management that considers groundwater in the context of all water resources in a basin. Efforts are also underway by the California Department of Water Resources (DWR) and others to develop guidance on the essential and required components of local groundwater management plans. Coordination among local entities within a basin is essential to ensure that groundwater is managed to account for the complexities of a dynamic hydrologic system in a sustainable way. Actions by local entities statewide to improve groundwater management and monitoring are being implemented with recently enacted legislation such as AB 599 (the Groundwater Monitoring Act of 2001) and SB 221 (Water Supply Sufficiency), SB 610 (Urban Water Management Plans), SB 1938 (the Groundwater Management Act of 2002), and SB 1672 (the Integrated Regional Water Management Planning Act of 2002). Notably, SB 1938 amends Water Code Section 10750, more commonly known as AB 3030, which was the first Groundwater Management Act. If these efforts fall short of legislative directives as applicable, or State or other guidelines for implementing groundwater management are not considered, groundwater basin management approaches may be inadequate to achieve sustainability. In such an event, the means necessary to protect the long-term public benefit of all water resources will ultimately have to be applied through legislative action. In

advance of any future impetus that results in such legislative action, judicial resolution of disputes will continue.

COMPETING VALUES

Presently, nearly 80 percent of California's *developed* water resources support agricultural needs. However, a statement about water development for agricultural water demands provides an incomplete picture of total water needs now and also for a longer water-planning horizon. In intensely developed areas such as the San Joaquin and Salinas Valleys, groundwater plays a major role in agricultural economics. In Owens Valley, groundwater plays an important role in meeting the urban needs of the Los Angeles Metropolitan area. California's population is projected to increase about fifty percent from 33 million to another 15 million in the next 20 years. These population increases obviously translate to increased water demands. It is also obvious that the stress on our water supply is most apparent in our growing urban areas where difficult water quantity and quality problems already exist. In 1995, DWR reported total water needs of 79.5 million acre-feet (maf), while for 2020 it forecasts needs of 12 maf for urban use, 31.5 maf for agricultural use, and 37.0 maf for environmental use, or a total of 80.5 maf.

For close to a century and a half, agricultural economists have focused attention on strategies that would optimize agricultural productivity, while municipal water institutions have supplied water for urban growth. Historically, management methods have maximized benefits for the present generation and have given only marginal consideration to the needs of future generations. With the exception of some agencies that have employed comprehensive groundwater management programs for decades, it is only in recent years that the cost of treatment, monitoring or other long-term costs have received attention in economic analysis of water management.

Until the late 1970s, the primacy of economic benefits arising out of agriculture was accepted with such unanimity among Californians that water management was driven largely by consideration of economic values. The lack of effective groundwater management led to the unacceptable consequences of overdraft, seawater intrusion, and land subsidence. Concern about water rights, water use efficiency, instream protection, and other groundwater management issues led to the formation of the Governor's Commission to Review California Water Rights Law in 1977. Between 1977 and 1978, the Commission prepared several reports that recommended future rules for comprehensive management of surface and groundwater. Although the Commission's recommendations did not receive

attention by the legislature at that time, its future vision was part of a movement in California that has seriously questioned economics as the prime driver of natural resources management. Examples of such economics-centered resource management include the 1970s confrontation between the citizens of Owens Valley and the City of Los Angeles regarding the over-draft of groundwater from Owens Valley and also the discovery of selenium toxicity due to agricultural drain effluents at Kesterson Wildlife Refuge in 1983.

ROLE OF SCIENCE IN WATER MANAGEMENT IN CALIFORNIA

BALANCING WITH NATURE'S LAWS

Physical and legal solutions to sustain California's groundwater have existed in parts of California since at least the 1940s. However, statewide recognition of the need for employing such approaches has only recently occurred. The groundwater system is subject to the immutable laws of mechanics and thermodynamics, and is driven by unpredictable climatic forces that vary on an annual basis, or on a time scale of centuries. In contrast, human laws change with time. The ongoing struggle for balanced water use reflects the confrontation between human laws motivated by short-term endeavors of the present generation and nature's forces acting over a long period. Growing demands on California's water supplies have forced the recognition that economic growth supported by present beneficial use must provide for future beneficial use and also individual property rights and public rights.

INTEGRATED WATER RESOURCES MANAGEMENT

During the 1880s, John Wesley Powell of the U. S. Geological Survey (USGS) argued for the use of basins as the unit of water management, particularly in the arid lands of the American West. He was strongly supported in this position by Eugene Hilgard of the University of California. But, Powell's suggestion went unheeded at that time. Influenced by the attitudes of those on the humid East Coast and Europe, boundaries of water management districts were drawn based on administrative convenience and people's alliances rather than on the basis of hydrologic basins.

While a limited number of groundwater management plans have recognized the intrinsic relationship of the components of the natural resources system, newly enacted legislation, including SB 1938 and SB 1672, formally directs attention to basin-wide, integrated management.

California has recently taken steps to better manage its resources statewide. The connectedness of surface and groundwater has gained increasing attention among academics, water authorities, and practicing groundwater professionals. Initiatives for integrated resource management include DWR's 2002 effort to update groundwater basin delineations based on a hydrogeologic definition of groundwater basins and the State Water Resources Control Board's (SWRCB's) Watershed Management Initiative. Relatively few local agencies have implemented routine management of the total resource. This is changing. The Groundwater Management Act of 2002, Senate Bill 1938 (Machado), was signed into law on September 17, 2002 and requires groundwater management plans and approval of such plans by DWR if entities are to be eligible for project funding. This bill does not require integrated resource management and monitoring by all local entities, but it approaches the many issues and questions about the future of groundwater management in California that were brought forth by the staff of the Governor's 1977 Commission on Water Rights Law. Furthermore, the required monitoring component of groundwater management plans prepared to comply with the Water Code amended by SB 1938 includes monitoring of not only groundwater levels and quality, but also surface flows and quality and inelastic subsidence. On the heels of SB 1938, SB 1672 was enacted on September 20, 2002 and formally authorizes a regional group, three or more local public agencies, to prepare an integrated regional plan relating to water supply, water quality, and related matters. These plans are to develop projects or programs that include: improving source water quality; providing water supply reliability; augmenting agricultural, domestic or environmental water supply; and improving the quality or quantity of groundwater.

RELATED EXPERIENCES

Other states of the west have already heeded Powell's vision of integrated water management. Over the past four decades, the states of Arizona, Colorado, Nebraska, New Mexico, and Texas have all enacted legislation and established institutions that mandate integrated management of surface water and groundwater. In 1969, Nebraska's legislature created Natural Resources Districts, largely coinciding with hydrological boundaries. In 1975, the passage of the Groundwater Management Act gave authority to Nebraska's Natural Resources Districts over groundwater quantity and protection of groundwater quality. Together, the Natural Resource Districts and the Nebraska Department of Water Resources have authority for coordinated management of surface water and groundwater. Nevertheless, even though these states have adopted integrated water management laws,

these laws have not solved all the groundwater issues. In Nebraska, not all of the state is covered by the authority of the Act. And, in Arizona, even though there are five active management areas, groundwater extraction continues to exceed established limits. Much remains to be learned from the water management approaches used by these states. Although implementation of such mandates differs from state to state, these states have recognized the dichotomy of natural and human laws. The hydrological cycle and geochemical, erosion, nutrient, and other natural processes are all dynamically interconnected; technological affronts to these processes will cause nature to reassert equilibrium.

SUSTAINING GROUNDWATER RESOURCES

MEANING OF SUSTAINABILITY

“Sustainability” has many different meanings. Perhaps the most globally espoused view of sustainability is the continued productivity of commodities to maintain economic growth. However, sustainability as approached herein is based on physical laws that govern the behavior of Earth systems, and may be defined as follows:

“Sustainability is the condition of beneficially using groundwater in such a way that it supports the present generation, while simultaneously ensuring that the resource is not unacceptably damaged by such a beneficial use.”

Natural changes are inevitable in a dynamic earth; however, change due to human action must be managed to avoid unacceptable effects on the natural resources system. A significant challenge lies in defining what change is acceptable and what is not.

FRAMEWORK FOR ACHIEVING SUSTAINABILITY

With a century and a half of California traditions and institutions in place, the transition from an economically based water use philosophy to an inclination toward integrated adaptive water management is inherently difficult. Addressing future water challenges entails change at all levels of society from the individual to educational institutions, commerce, the profession, government, the legislature, and the judiciary. Recent California legislation demonstrates a wholesale shift in water resources management approaches. However, this legislation is new, and actions in direct response to

the legislation are just beginning. The framework and recommendations for sustainability presented below are based on the following premises.

- Surface water and groundwater constitute a single resource. Groundwater is a finite resource that is a component of a larger natural resources system.
- Development of groundwater resources for beneficial use can affect other components of the natural resources system.
- Renewal of groundwater resources is subject to climate variability. Consequently, groundwater resource development must adapt to the capacity for replenishment of the system to occur.
- Since the integrity of the natural resources system as a whole is vital, groundwater beneficial use must be managed so the rights of others to share the resource are recognized, and the resource itself is not unacceptably impaired during the process of beneficial use.

Major regions of California such as the San Joaquin, Salinas, Owens, and Santa Clara Valleys have supported extensive groundwater use by agriculture, industry, and municipalities. These resources are also presently over-developed. What is the sustainable capacity of California's basins? This is a complex question for which there are no simple answers. If there were, integrated water resources plans and optimum basin management programs would be more prevalent. Historically, groundwater development has been carried out in relative isolation from the other aspects of the natural resource system. The time has come to direct attention to the resource system as a whole. The framework needed for quantifying sustainability and better understanding the integrated nature of the hydrologic system is discussed below.

Unit of Management

A fundamental requirement for sustainable management of groundwater resources is a consistent unit of management. Groundwater basins defined by physical rather than political boundaries, with the exception of adjudicated basins, are becoming the basis for comprehensive groundwater management in part as a result of the activities of DWR and recently enacted legislation (SB 221, 610 and 1938) that requires consideration of basin-wide groundwater conditions.

DWR is in the process of updating information on the boundaries and characteristics of 525 California groundwater basins. This information is posted on DWR's web site at http://www.waterplan.water.ca.gov/groundwater/118gmpcomp_main.htm and will be

presented in the Bulletin 118 Update, which is planned to be published in May 2003. Although DWR has implemented efforts to make available information on California's groundwater basins, there is a need to better understand the physical boundaries of these basins and also the storage capacity of the basins in relation to available water supplies, historical and projected water demands, land use strategies, and the capacity for natural and augmented groundwater replenishment.

Management Objectives

Sustainability has historically been identified with continued economic growth. Future groundwater management requires shifting to efficient use of available natural resources within the sustainable capacity of the system. As such, it also requires consideration of the limiting thresholds of development and the means for recognizing such thresholds. Regardless of whether a local entity elects to respond to specific legislation, such as preparation of an AB 3030 Groundwater Management Plan, a plan is necessary to manage groundwater on a sustainable basis. Critical components of that plan are the management goals or objectives for the basin that are designed to meet water demands under a wide range of wet and dry conditions that affect the short- and long-term availability, reliability and beneficial use of water resources without impairing the long-term benefit of the resource. In general, it is expected that detailed objectives for basin management, within the broad goal of meeting the estimated average annual sustainable basin yield, will be developed from a combination of physical basin conditions, timing and quantity of available surface water, and desires of local entities and other participants in the basin. It is recognized that management programs may vary significantly due to regional differences, other factors that define management objectives, and desired local management objectives. In that light, examples of objectives include: determine long-term pumpage goals in relation to sustainable yield, protect and enhance groundwater quality, coordinate groundwater use among local entities, employ conjunctive water management to improve supply reliability, preserve interconnected surface water resources, and agree on other water conservation goals to ensure water resources sustainability in the basin.

Prediction and Monitoring

Long-term, large-scale water use can ultimately affect other components of the natural resources system. In some instances, large-scale water development may also affect biological resources. Precise long-term prediction of the complex behavior of the system,

especially climatic uncertainty, is almost impossible even with modern computers. Computer models are, however, valuable tools, helpful in forecasting the potential response of systems over shorter time periods as a consequence of alternative development strategies and management approaches. Modeling is moving toward improved linkages between hydrologic system components that will enable more accurate understanding of total system responses to different groundwater management schemes.

Because of the fundamental limitations to precise prediction, ongoing systematic monitoring becomes an essential part of groundwater management. The purpose of monitoring is early detection of unacceptable impairment to the physical, chemical, or biological attributes of the hydrologic system. Newly enacted legislation relating to monitoring includes AB 599 and SB 1938. AB 599 focuses on coordinating current State agency monitoring efforts under the State Water Resources Control Board to develop a comprehensive statewide groundwater monitoring approach. It is also directed toward integrating data and making those data more accessible. SB 1938, Water Code Section 10753.7, specifies comprehensive monitoring program elements directly linked to requirements for groundwater management programs.

Although the AB 599 and SB 1938 legislative actions reflect progress toward managing California's water resources, the most challenging problems await as California's population expands and as the effects of more than a century of intensive groundwater production that supports California's agricultural economy become increasingly apparent. The expected unprecedented stress on our water resources requires careful, complex, and creative management approaches. Basic data need to be evaluated and fully used to better understand total system dynamics, particularly when optimal use of basin groundwater storage capacity is a key objective, or varied climatic conditions dramatically affect basin management scenarios. It is important that comprehensive, integrated monitoring programs are compatible with resource management and protection objectives. Quantifiable measures of unacceptable consequences are needed. Monitoring data are necessary to evaluate whether the natural resources system is overtaxed through resource development for beneficial use. Monitoring is therefore crucial for modifying management approaches to avoid detrimental impacts.

Institutional Implications

Although California's Constitution and its statutory laws assert public ownership of the State's water and articulate the State's responsibility to conserve water for its beneficial

use, groundwater development is largely unregulated in California. Science has demonstrated that integrated surface and groundwater management is essential, and the legislature has begun to reflect that knowledge through recently enacted legislation.

Local, state and federal agencies and institutions collectively have important roles in statewide resources protection. Local and state institutions, at two different tiers of management responsibility, will frame policies, maintain an inventory of wells, approve management plans, monitor compliance with management plans, design and maintain monitoring networks, disseminate data, and initiate appropriate steps should unacceptable damage occur that extends beyond the management authority or capability of the local agency to mitigate the damage. Examples of coordinated activities include surface and groundwater monitoring program efforts through Cal/EPA and others, evaluation of issues concerning the Delta and beyond by CALFED, and the next evolution of multi-disciplined earth science research through academia, the USGS, and others. With the enactment of SB 1938, DWR must now determine whether groundwater management plans submitted under the newly amended Water Code, Part 2.75 Groundwater Management, Sections 10750-10755, meet the stated requirements and whether the submitting local agency seeking funds is eligible for state funds administered by the Department. As concluded by the Governor's Commission on Water Rights Law, integrated resource management is important and should start at the local level. Particularly, the Commission proposed legislation finding and declaring "... the people of the State have a primary interest in the protection, management, and reasonable beneficial use of the water resources of the State, both surface and groundwater, and that the integrated management of the state's resources shall be attained to the extent feasible." The Commission further proposed, "... local groundwater management entities shall have primary responsibility for the protection and management of the groundwater resources of the State." While the language in the Integrated Water Resources Management Planning Act of 2002 (SB 1672) is broad, it formalizes, nearly 25 years after the Commission's recommendations, local agency management to protect and improve water resources of the State. Statewide guidance is essential for facilitating local program development and implementation, and for coordinating a central data center for the collection, storage, exchange, and evaluation of data gathered at the local level or by other agencies. These data are critical for statewide evaluation of resource conditions and identification of future planning issues and needs.

Economic Analyses

Economic analyses for water management seek to identify methods that will achieve short and long-term private and public objectives in the most monetarily efficient ways. New economic tools and incentives are evolving that account for the long-term integrity and benefit of the natural resources system. For example, SB 1938 requires approval of a groundwater management plan for local agencies seeking funding to be deemed eligible for state funds for water related projects. It is only in recent years, particularly as a result of emerging and persistent contaminants, that the present and long-term costs of treatment, monitoring or other related measures have received attention in the economic analyses of water management. Economic analyses should also consider the long-term cost savings achieved by conducting monitoring and mitigating the need for future treatment.

Education

Numerous investigations during the first half of the twentieth century, including those of O.E. Meinzer, known as the “father of modern groundwater hydrology”, from 1912 to 1946, paved the way for a better understanding of the physical occurrence of groundwater. The seminal work of C. H. Lee, W. C. Mendenhall, O. E. Meinzer and others in Owens Valley, San Joaquin Valley, Santa Clara Valley and elsewhere was far-reaching in describing the groundwater system within the framework of the entire hydrologic cycle. Notably, in California, Cyrus F. Tolman initiated a program in groundwater at Stanford University in 1927. His book, “Ground Water”, based on the course syllabus and published in 1937, became the first general treatise of the science published in English. It was also reported by the author to be the only one at that time to attempt a summary of the intensive study of subsurface water in the western United States. He had hoped that his book, especially the review of general scientific principles, would assist in preparing attorneys for litigation involving subsurface water and in the “development of sound ground water law founded in present-day scientific principles”. During the 1930s, groundwater hydrology shifted its emphasis from the integrated perspective to the quantitative-mathematical perspective of hydraulics, following the contributions of C.V. Theis and C. E. Jacob. At the onset of the twenty-first century, geoscientists have begun to recognize the importance of the pioneering approach of Lee, Mendenhall, Meinzer, Tolman, and others. The training of future geoscientists and groundwater practitioners must include the science of the regional hydrologic framework and the quantitative aspects of individual processes such as groundwater movement, chemical transport and transformations, evapotranspiration, and subsidence.

A groundwater education would be incomplete without an awareness of the role of science professions in society. Scientists must communicate to others the importance of groundwater as a component of an integrated system, particularly since future resource management lies in collective decision-making by experts and the public. Such a coming together of science and humanity is at the core of a liberal arts education. Students and practitioners need to appreciate ethical values that relate to the access and protection of natural resources.

Future public outreach efforts must influence society's support for scientific training at all levels, research, and the application of theory to practice. In spring 2002, GRA initiated an educational and outreach forum for legislators and others concerning groundwater issues and challenges facing California by working with Assemblyperson Carol Liu, and her Select Committee of legislators. Collaboration across the spectrum of academics, agencies such as DWR, Cal/EPA, USGS, USEPA, USBR, and CALFED, and the private sector is key to continued transfer of knowledge and technology.

RECOMMENDATIONS

The recommendations listed below have in part been formalized with recent California legislation that demonstrates a statutory shift to integrated and sustainable water resources management approaches. For some water entities, these approaches are not new and simply confirm the vision and wisdom of giving attention to integrated water resources management.

1. ***Groundwater basins and watersheds as units of management:*** Legislation is beginning to more directly recognize basins and watersheds as official groundwater management units. Although legislation such as SB 221 directly requires, for its specific purpose, consideration of the groundwater basin information compiled by DWR, there are more current data and reports not yet assimilated by DWR. DWR is actively seeking this information for the forthcoming Bulletin 118 update "California's Ground Water." Even with current data, much remains to be done to expand our understanding of basin heterogeneity and important basin recharge and discharge processes. It is recommended that local entities and others involved in groundwater resources investigations and studies provide DWR with updated groundwater information, including: surface and subsurface geologic information that has been developed to better understand physical basin boundaries and subsurface hydrogeological conditions; updated evaluations of groundwater storage, including variable storage under different hydrologic conditions; current and

projected water use; present and probable future availability of supplemental water supplies; and existing or potential issues of concern such as water quality degradation, persistent groundwater depletion, subsidence, soil salinization, or other significant environmental impacts. Additionally, funding is needed in order for DWR to adequately carry out the directives that groundwater data be updated by the Department and made publicly available.

2. ***Hierarchical objectives:*** Sustainable management of groundwater resources must consider the needs of individual users as well as the needs of the community and the environment. To this end, a hierarchy of institutions, from the local level to the State, needs to coordinate activities so that each agency is cognizant of its own role within the larger context. Cooperative efforts among local entities within a basin or watershed are critical to establish clear management objectives for the basin as well as objectives that may be specific to the areas directly under the purview of a single entity. Importantly, all objectives should be developed within the overall premise of achieving sustainability.
3. ***Monitoring, an essential part of management:*** Because climate is unpredictable, and components of the natural resources system interact in complex ways, ongoing systematic monitoring must become an integral part of resource management. The goal of integrated monitoring of surface water and groundwater, and other components of the natural resources system as appropriate, is to regularly assess the data and detect, in a timely fashion, any unacceptable changes so as to initiate mitigative measures. Regional monitoring networks will ideally be established, or maintained, based on an understanding of regional groundwater flow systems. An expanded statewide program is needed for the collection, storage, and dissemination of groundwater-related data that will facilitate evaluation of the State's groundwater resources for future planning and management programs and activities. It is recommended that consistent and uniform standards be developed to facilitate coordinated basin-wide monitoring among local entities, and the transfer of local groundwater data to the State.
4. ***Supporting Research:*** The fundamental goal of achieving sustainability is complex and initiates many new questions that require further research, which in turn requires multi-disciplinary collaboration and funding. The research, investigation, and educational programs would be performed by academia and public agencies; for example, the development of improved methods and technology for quantifying individual processes of the hydrologic system, the interrelationship of multiple-system processes, and the development of methodologies for sustainable development, conservation, recycling, and reuse. In addition, the goal requires continuing evolution of the tools used for gathering field data used to assess management approaches. Systems such as the Imperial Valley and the San Joaquin Valley have shown the result of being over-stressed to support present levels of

economic productivity. The supporting research would immeasurably benefit such systems.

5. ***Economics:*** Economic analyses applied to future water management must consider the institutional and management tools necessary to achieve sustainability within the constraints of the physical and chemical attributes of the natural resource system. With increasing awareness of the State's public trust responsibilities in the beneficial use of water resources, novel tools and methods for economic analyses need to be developed that can better account for future interests in the integrity of the natural resources system. The economic consequences of alternative management programs, including programs that constrain groundwater development, should also be considered. Other economic considerations include the costs and benefits attached to a desired level of certainty for attaining sustainability. There is a balance in the level of monitoring and evaluation that is reasonable and necessary as compared to an excessive amount that provides no further assurance of a sustained water supply. While this White Paper highlights the present need in most basins for more comprehensive monitoring and evaluation, it is not intended to create a quagmire of potentially meaningless data at exorbitant cost that are then ignored.

6. ***Education:*** The future of sustainable water management depends very much on the water literacy of the general public, as well as well-rounded education and training of surface and groundwater management professionals. The importance of science education and the application of earth sciences, including hydrology and hydrogeology, and engineering in sustaining groundwater resources must be recognized. Public outreach programs on water education need to be supported and expanded; society's understanding of the need for creative management programs, including conjunctive management, water transfers, recycled water use, efficient water use and potential long-term costs, will become increasingly important.

EPILOGUE

California is blessed with abundant but finite groundwater resources. This renewable resource is intrinsically connected to surface water and subject to climatic uncertainty. As California's population expands, and Californians seek continued prosperity amidst a high quality environment, groundwater resources must be managed equitably and wisely. The measure of California's success in sustaining water resources will be reflected in an unprecedented coming together of the sciences and the humanities, directed toward balancing individual rights and social obligations.

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