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Water Appropriation and Transfer in a General Hydrogeologic System

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ABSTRACT

The hydrology of surface water and groundwater is compatible with the water rights system of prior appropriation. Prior appropriation accounts for the variability of surface water by apportioning the available supply to the earliest users. The priority system can be extended to the administration of groundwater by recognizing two components of the groundwater account: stored groundwater and induced recharge of surface water. Groundwater users are held accountable for effects on the baseflow of streams when hydrologic models link the well withdrawals to stream depletion within a planning horizon. Superimposing the ladder of priority on a generalized flow-duration curve shows the impact of surface-water depletion from wellfield development. Wellfield pumpage reduces the duration of baseflow and generally affects the rights of the earliest surface-water users. Groundwater storage provides a transient source of water which gradually converts to surface-water depletion.

Groundwater mining is viewed herein as a phase of development when groundwater storage provides 98 percent or more of the sources of water to wells. The timing of the transition to reliance on induced recharge of surface water is highly variable from case to case. The shape of the transition curve is determined through the use of comprehensive hydrologic models.

Applying an economic standard for impairment can protect established rights to surface water and groundwater. The priority system has the potential to resolve many water controversies involving transfer of water to higher social and economic uses. Full application of the priority system in a water rights market awaits general stream adjudication, adoption of uniform standards for evaluation of impairment, and a consensus in the use of hydrogeologic models.

INTRODUCTION

Hydrologic information becomes a central part of the process of water rights administration when enforcement of rights is necessary because of

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a new appropriation or upon transfer of water to new places or purposes. The cause of a shortage of surface water can be identified through hydrologic analysis when a water-short user calls for his share of the supply. A water transfer to a new use must be quantified in terms of hydrologic effects before the question of impairment to existing uses can be settled. Causal hydrologic models serve in these cases to link the proposed action to its hydrologic effects.

Administration of groundwater has been impeded by conflicting concepts of tributary and nontributary groundwater, safe yield versus mining, and the meaning of impairment of a groundwater supply. Hydrology as a science has not been markedly successful in communicating its basic principles, such as mass-balance. A water policy study team advising the New Mexico legislature concluded that "[t]his concept and its ultimate impact on the environment . . . is little understood by hydrologists and lay people alike."[1] Other questions commonly arise as to the significance of empty rights (rights having a valid claim to water but lacking a full and physically available supply), the accounting of water sources, and the right to an annual volume or an instantaneous rate of flow from the source.

The body of knowledge within hydrology and hydrogeology can aid in the resolution of these as well as more policy-oriented questions. Water policy issues include the water supply consequences of enforcing a priority system of water rights, the effect of transferring an empty right rather than one with a demonstrable history of exercise to a new place or purpose of use, and policies for avoiding resource depletion. Adjudication of a stream system and its associated groundwaters must address the exceptional extent and continuity of the groundwater component.

This review outlines the physical implications of applying the water rights rule of prior appropriation in a general hydrologic system of surface water and associated groundwater. The principles underlying the system of prior appropriation are fully compatible with the physical understanding of hydrologic systems. Wide application of the priority system to both surface water and groundwater supplies will enhance protection for existing rights, and can expedite the transfer of water to new uses. Administration of the priority system will be considerably aided by adjudication

1. DuMars et al., *1986, State Appropriation of Unappropriated Groundwater: A Strategy for Insuring New Mexico a Water Future*, 200 N.M. WATER RESOURCES RES. INST. AT 16, 17 (1986) [hereinafter DuMars]. In hydrology, "mass balance" denotes the idea that inputs to the hydrologic system from all sources are equal to outputs. This balance applies for the system as a whole and for each of its parts, on every scale of time, and equally to water and its dissolved constituents. Changes in storage within the system (surface water and groundwater) may be either positive or negative, but storage must be counted in the mass balance. The impact on water policy is in the recognition that groundwater is not a new source of water in the long-term. There is no free drink with lunch.

to establish marketable and enforceable rights, by administrative adoption of an economic standard for impairment, and by use of comprehensive hydrologic models to identify the effects of a proposed change in the pattern of water use.

HYDROLOGY OF WATER APPROPRIATION

The Hydrogeologic System

Groundwater is the extensive volume of water in the saturated parts of the earth's crust. It has an upper boundary at the water table or at the saturated land surface, but, being a global feature, it has no absolute lateral boundaries or bottom boundary. As a system, it is not delineated by rock types, permeability variations, or chemical quality. Groundwater flow systems may cross aquifer boundaries and may be local, regional or continental in scale.[2]

Surface water consists of overland runoff of snow melt or rain, and baseflow. Baseflow is the discharge from the groundwater system. Surface water is located outside of the upper boundary of the groundwater system. Neither is viewed as a closed system, however, and water is exchanged where surface and groundwater contact the saturated land surface.

As to the size of each resource, about 70 percent of the annual output of the world-wide hydrological cycle is discharged as runoff and 30 percent is discharged through the groundwater component.[3] Surface streams typically flush through a complete cycle of their contents dozens of times each year, whereas the much larger volume contained in groundwater flow systems is cycled out more slowly, commonly on a time-scale of centuries.

Water System Yield

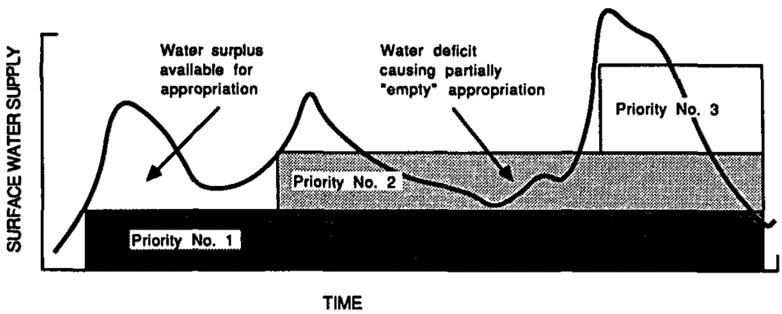
The variable flow of a surface water system is illustrated by the hydrograph in Figure 1. The ladder of priority, wherein senior rights to divert and use the water are held by the first appropriator, is superimposed. The figure reflects the general pattern of development of arid lands, wherein the reliable baseflow of streams was diverted early for irrigation. Ancient irrigation was in place even before United States' occupation in the American southwest.[4] Reclamation projects later stored the winter and peak

2. F. BREDEHOEFT, W. BACK, & B. HANSHAW, REGIONAL GROUNDWATER FLOW CONCEPTS IN THE UNITED STATES: HISTORICAL PERSPECTIVES, 297–316 (1982) (Geol. Soc. of America Special Paper 189, Recent Trends in Hydrogeology) [hereinafter BREDEHOEFT I].

3. Lvovitch, *World Water Balance*, in SELECTED WORKS IN WATER RESOURCES, INT'L WATER RESOURCES ASSOC. 41–55 (K. Biswas ed. 1975).

4. Follett, *A Study of the Use of Water for Irrigation on the Rio Grande Del Norte*, S. DOC. NO. 229, 55th Cong., 2d Sess. 117 (1898).

FIGURE 1 - THE PRIORITY APPROPRIATION SYSTEM SUPERIMPOSED ON A GENERALIZED SURFACE WATER HYDROGRAPH



flows and claimed much of the remaining yield from the river systems. Groundwater development followed in the 20th century and has reduced the baseflow of many streams.

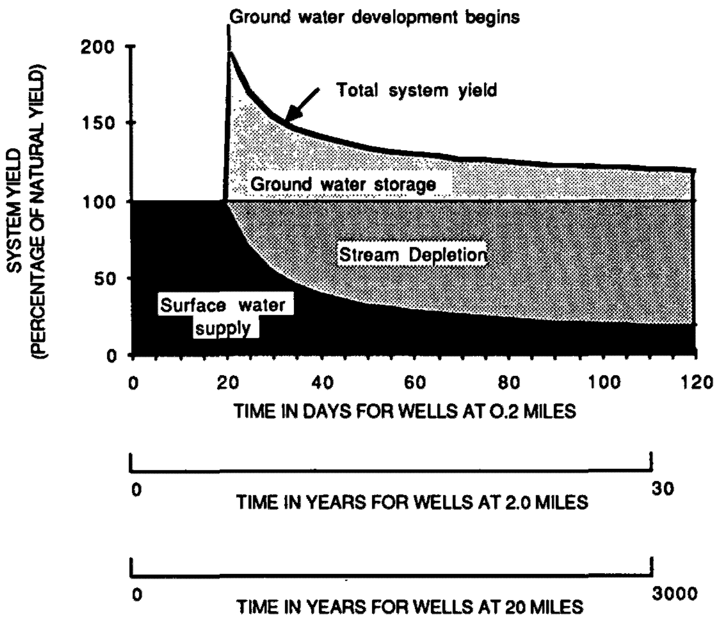
The original goal in operation of the priority system is clear: protecting the earliest diversions during natural variation of the supply. Even artificially stored reservoir water may be distributed in order of priority. The practical matter of scheduling variable instantaneous flows to meet a variable demand at a large number of diversion points in the order of priority is not so readily tractable,[5] but the objective at least is clear.

The degree of effect on a stream due to groundwater development varies in each case. The effects on some streams are insignificant, while other stream reaches have changed from perennial to intermittent flow because the regional water table has declined below the stream bed.[6] Figure 2 contrasts three cases of differing rates of effects on the yield from a stream system due to groundwater development. With wells nearby the surface streams, the total system yield may be expanded in the short term. The system then rapidly adjusts to a new equilibrium with little net gain in system yield. At greater distances from the surface water bodies, the spacing of the wells and the groundwater hydraulics may allow major expansion of the total supply for centuries. In all cases, the eventual reduction in surface water supply as a result of groundwater development creates an issue in water rights administration.

5. Eheart & Lyon, *Alternative Structures for Water Rights Markets*, 19 WATER RESOURCES RES. 887 (1983) [hereinafter Eheart].

6. Osterkamp & Hedman, *Discharge Estimates in Surface Mine Areas Using Channel-Geometry Techniques* (Dec. 1979) (U. of Ky. Symp. on Surf. Mining Hydrology, Sedimentology and Reclamation).

FIGURE 2 - EFFECT ON SYSTEM YIELD WITH THREE WELLFIELDS AT 0.2, 2.0, AND 20 MILES FROM A SURFACE STREAM



Groundwater

The administration of groundwater in the priority system is not straightforward because the source of groundwater has two components: groundwater storage and induced recharge of surface water. Development of aquifer storage interjects an additional source of water into the otherwise well-ordered surface water scheme. Groundwater storage is relatively large. Variation in supply is not a consideration until the decline in water level becomes an economic problem. Diversions from wells, however, are physically linked to surface depletions in the form of induced recharge from the surface streams.[7] In the 1980s, three-dimensional numerical

7. Theis, *The Source of Water Derived from Wells: Essential Factors Controlling the Response of an Aquifer to Development*, 10 CIVIL ENGINEERING 277 (1940). Theis noted that "All water discharged by wells is balanced by a loss of water somewhere. Some groundwater is always mined . . . further discharge by wells will be made up at least in part by an increase in the recharge [and] in part by a diminution in the natural discharge."

models of the complete hydrogeological system have been put to use for water rights purposes.[8] These models provide a predictive tool explaining the connection between wellfield withdrawal and surface water depletion at particular sites.

The timing of effects on adjacent streams caused by groundwater withdrawal depends upon the aquifer diffusivity[9] and the distance from the wells to the surface water body. The major factor in determining the rate of effects on surface supplies is the distance of withdrawals from the surface sources. For radial flow of groundwater, a 10-fold increase in distance from the surface water body causes a 100-fold delay in the response time, whereas a change in diffusivity is linearly proportional to the response time.

Surface streams commonly lie in contact with different sedimentary units than those rock layers in which wells are perforated. Hydrologic stresses propagated from one rock unit to the other must cross vertical layering in permeability (hydraulic conductivity) and storage properties. Thus, the three-dimensional aspect of diffusivity and distance becomes important for accurate simulation of effects on rivers or on water levels at various depths in the aquifer. The vertical component of groundwater flow is usually retarded relative to horizontal flow in sedimentary rocks. In some cases, response time may be accelerated through vertical fractures in fine-grained or crystalline rocks. Most large-capacity wellfields, however, produce from layered sedimentary rocks where the three-dimensional aspects of flow serve to delay the effects on adjacent surface water bodies.

Depletion of Surface Water by Wells

When a serviceable hydrogeologic model is available, the effect of groundwater usage can be quantified in terms of the availability of the surface supply to serve prior water demand. The yield of a surface system is not viewed as a simple average annual supply, reliably available, and apportioned to a fixed number of claimants. The priority system would have no purpose if the yield of the system was constant each year and reliable at all times. The priority system deals with the variable duration of surface water flow. The flow-duration curve is a standard hydrologic

8. Hearne, *Mathematical Model of the Tesuque Aquifer System Underlying Pojoaque River Basin and Vicinity, New Mexico* 181, U.S. GEOL. SURVEY REP. 80-1023 (1980).

9. Aquifer diffusivity is a physical constant for a given aquifer which describes the rapidity with which a transient change in head will be transmitted throughout the system. It has horizontal and vertical components and is expressed as the ratio of the permeability-thickness product to storativity. Permeability is a measure of the rate of groundwater movement under standard conditions, and storativity is a measure of the effective water content in the earth's crust. The dimensions of diffusivity are Length • Length/Time.

approach showing the percent of time that flows of certain magnitudes are available from a stream system. Water rights cannot be exercised when there is no flow to divert. Figure 3A illustrates the percentage of time when water claims are "empty" by superimposing the ladder of priority on a typical flow-duration curve.

The flow-duration curve for a stream reach can be adjusted to show the effect on future flow availability when groundwater depletions subtract from the baseflow of the stream. Depletions grow with time, so several adjusted curves may be needed. The starting and ending points of an illustrative adjusted duration curve reflecting the depletion of 150 units of flow are shown in Figure 3B. With the ladder of priority superimposed on the adjusted flow-duration curves, the hydrologic effects on water rights become clear. Groundwater development initially expands the basin yield, as shown by the hachures in Figure 3B, but eventually the baseflow of surface streams adjusts to restore the original net basin yield. The loss from surface water availability is shown by the black interval in Figure 3B. Although all surface water flow is affected, the supply of water available to serve priority number one experiences the largest percent reduction. Users of the groundwater source, however, receive the full benefit of their continuously available supply. The effect is to move supplies from early surface diversions to later groundwater users.

Typical streams in the western United States are water short when compared to the total size of water claims.[10] Even the earliest priorities may not be fully served each year. The order of priority of water claims establishes their utility and, thereby, their value. Later priority implies access to a lesser duration of flow and a correspondingly larger fraction of empty water claims. Many late priority water claims are seen to be predominantly empty. The senior users may represent the only water claims with a substantially full natural supply. Even the most senior surface water users may be affected by diversions from groundwater, which are ultimately a diversion from the stable baseflow of nearby streams. The baseflow is relied upon most by the original surface water user.

Figures 2 and 3 illustrate that the losses borne by the surface water system are offset by the new supply of water developed from groundwater storage. In some cases, return flow from groundwater withdrawal directly increases the local stream flow.[11] With groundwater development, the total system yield available to support beneficial uses increases until surface water depletion approaches the magnitude of the groundwater

10. *Mineral and Water Resources of New Mexico*, 87 N.M. BUREAU OF MINES AND MINERAL RESOURCES BULL. 425 (1965).

11. Hearne, *supra* note 8.

FIGURE 3 A - THE PRIORITY SYSTEM APPORTIONS THE NATURAL FLOW TO A SEQUENCE OF WATER CLAIMS.

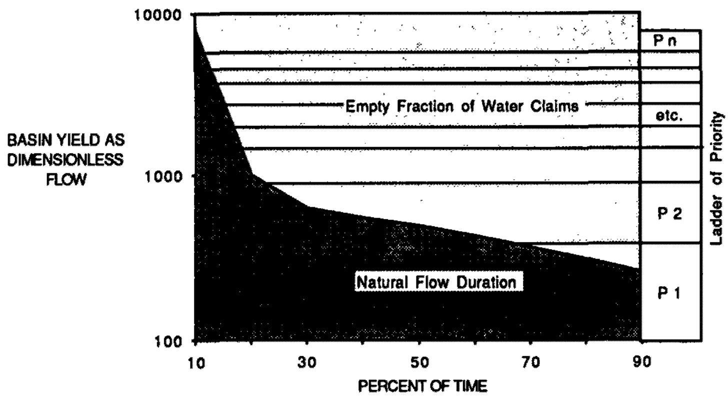
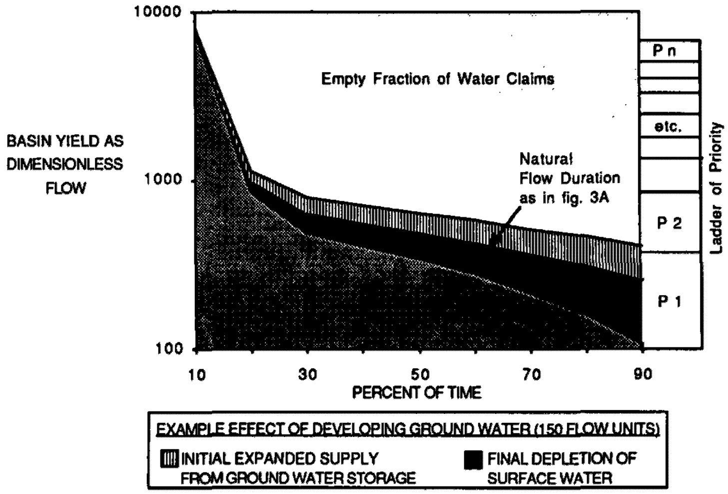


FIGURE 3 B - GROUND WATER DEVELOPMENT INITIALLY EXPANDS THE SUPPLY. BALANCE IS RESTORED BY DEPLETION OF BASEFLOW.



development. The duration of the net benefit may be months or millenia depending upon two factors: diffusivity and distance. Table 1 shows the variable time period for groundwater pumpage to be balanced in part by surface water sources as predicted in some recent three-dimensional groundwater models. As shown in the last column (surface water deple-

Table 1. Sources of water (surface water depletion and groundwater storage) supporting groundwater withdrawals as predicted by 3-D groundwater models in New Mexico.

Author	Distance to surface water (miles)	Geologic units	Time period (years)	Wellfield drawdown (feet)	Source of water (percent of withdrawal) Groundwater storage	Surface water depletion
Billings (1984)[12]	1 to 7	Permian Limestone	11	30	37.6	62.4
Faust et al. (1984)[13]	4 to 20	Tertiary volcanics	34	600	54.3	45.7
Hearne (1980)[14]	1 to 10	Tertiary sediments	50	300	88.8	11.2
HGC (1982)[15]	15 to 20	Jurassic sediments	30	2300	98.4	1.6
HGC (1983)[16]	12	Permian sediments	50	138	96.8	3.2
Lyford et al. (1980)[17]	40	Jurassic and Cretaceous sediments	47	3900	99.2	0.8
Peterson et al. (1984)[18]	12	Tertiary sediments	100	200	49.6	50.4
Kernodle et al. (1987)[19]	1 to 8	Tertiary sediments	72	60	25	75

12. Billings and Associates, *Hydrogeologic Investigation to Evaluate the Effect of Plains' Application, File Number B-167-A into 1605 and B-17 et al. Comb.*, 19 (1984) (submitted to New Mexico State Engineer Office).

13. Faust, Mercer, Thomas, & Balleau, *Quantitative Analysis of Existing Conditions and Production Strategies for the Baca Geothermal System, New Mexico*, 20 WATER RESOURCES RES. 601 (1984) [hereinafter Faust].

14. Hearne, *supra*, note 8.

15. Hydro Geo Chem, Inc., *Effects of Uranium Mine Dewatering on the Water Resources of the Pueblo of Laguna, New Mexico* (1982) (Report for Pueblo of Laguna, New Mexico).

16. Hydro Geo Chem, Inc., *Numerical Simulation of Pajarita Well Field, Mescalero Apache Indian Reservation* (1983) (Report for Bureau of Indian Affairs, Albuquerque, New Mexico).

17. Lyford, Frenzel & Stone, *Preliminary Estimates of the Effects of Uranium Mine Dewatering on Water Levels in the San Juan Basin, New Mexico*, 46 (1980) (San Juan Basin Regional Uranium Study Working Paper No. 37).

18. Peterson, Khaleel & Hawley, *Quasi Three-Dimensional Modeling of Groundwater Flow in the Mesilla Bolson, New Mexico and Texas*, 178 N.M. WATER RESOURCES RES. INST. REPT. 185 (1984).

19. Kernodle, Miller & Scott, *Three-Dimensional Model Simulation of Transient Ground-Water Flow in the Albuquerque-Belen Basin, New Mexico*, U.S. GEOL. SURVEY WRI 86-4194, at 86 (1987).

tion), the expanded yield of the total system comes at the eventual cost of a reliable supply for surface water diversions.

Groundwater Mining, Natural Recharge, and Planning Policy

Groundwater mining remains under discussion in the current water policy literature.[20] Groundwater mining is generally described as the opposite of safe-yield management and as appropriate for unrechargeable or nontributary groundwater basins. Some groundwater systems have low diffusivity, are located relatively far from surface water bodies and, therefore, have a low potential for inducing recharge. Such groundwater systems warrant special consideration in water policy questions due to their relative isolation from external water bodies.

Every groundwater development, whether from a local river bed or a continental-scale flow system, begins with 100 percent of withdrawals being derived from storage. The timing of the change from storage depletion (mining) to induced recharge from surface water bodies is key to the water policy question. The shape of the transition curve for a two-dimensional system is shown in Figure 4 in nondimensional form based on Glover's tabulation.[21] The general shape of the growth curve is retained in systems with appreciably different boundaries and parametric values.[22] The management category of mineable, nontributary or unrechargeable water is a reasonable one to apply to wellfield areas that would not progress beyond the earliest stages of the Figure 4 curve (98 percent storage) within a reasonable planning horizon. Two of the modeling studies in Table 1 (both in Jurassic sediments of the San Juan Basin) fall in this category and demonstrate that some groundwater resources can be developed properly as mineable water.

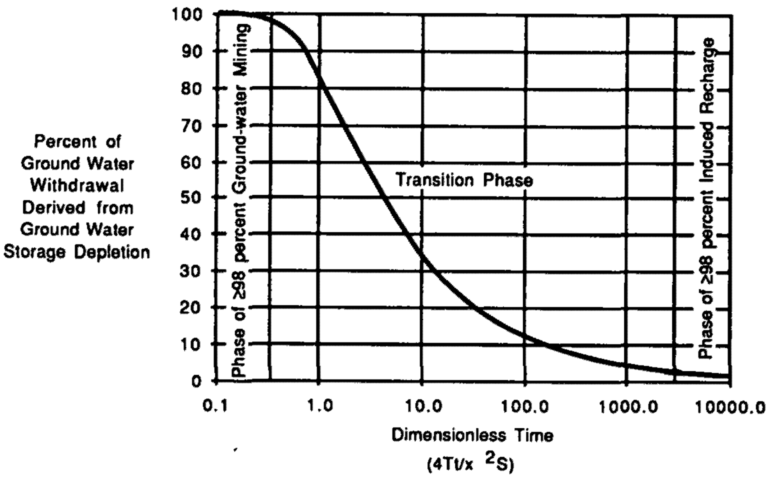
The rate at which dependence on groundwater storage converts to dependence on surface water depletion is highly variable and is peculiar to each case. Table 2 illustrates a broad range of effects. The initial and final phases of the growth curve on Figure 4, representing mining and induced recharge, are separated in time by a factor of nearly 10,000; for

20. Western States Water Council, *Indian Water Rights in the West* (1984) (Study prepared for the Western Governors Association); Edison Electric Inst., *Trends in U.S. Groundwater Law, Policy, and Administration* (1984) (report by EEI, 1111 195th St. NW, Wash., DC 20036); DuMars, *supra* note 1, at 46; Eheart, *supra* note 5, at 891; Holzschuh, *Ground-Water Mining—An Often Misused Term*, 25 GROUNDWATER (Readers' Forum No. 3, 1987).

21. Glover, *Transient Ground Water Hydraulics*, at 413 (1974) (Dept. of C. Engr., Colo. State Univ.).

22. Bredehoeft, Papadopulos & Cooper, *Groundwater: The Water Budget Myth*, in SCIENTIFIC BASIS OF WATER RESOURCE MGMT. 51–57 (1982) (NATIONAL ACADEMY PRESS, STUDIES IN GEOPHYSICS) [hereinafter Bredehoeft II]; (Depletion growth curve at figure 4.8); Faust, *supra* note 13. (Growth curve at figure 15.) The "S" shaped curve of growth in effects is seen in two-dimensional systems with regular linear boundaries and also in three-dimensional models with irregular boundaries.

FIGURE 4 - TRANSITION OF SOURCES OF WATER TO WELLS FROM RELIANCE UPON GROUND WATER STORAGE TO INDUCED RECHARGE OF SURFACE WATER



Theis model,2-D, isotropic system:
T/S = Diffusivity (L^2/T)
x = Distance from well to surface water stream (L)
t = Time
Data from Glover (1974)

Table 2. Example rates of transition from groundwater mining to induced recharge.

	Time on transition curve of Figure 4[a]			
Sources of water	Example A[b]	Example B	Example C	Example D
Mining Phase	1 second	1 day	1 week	1 year
90 percent storage	2 seconds	2 days	2 weeks	2 years
50 percent storage	12 seconds	12 days	3 months	12 years
10 percent storage	6 minutes	11 months	6.5 years	340 years
Induced Recharge Phase	2 hours	23 years	160 years	8350 years

[a]Based on Glover (1974) model.[23]
[b]The hydrologic parameter T/Sx^2 (aquifer diffusivity/distance squared) ranges over 7 orders of magnitude in examples A–D.

23. Glover, *supra* note 21.

example, one week of mining implies a transition to steady recharge 8,000 weeks or 160 years later. The curve is disproportionately steep in the early transition toward induced recharge. In example C (Table 2), storage provides 90 percent of the source of water after two weeks and only 10 percent after 6.5 years. The progression to full reliance on indirect recharge, above 98 percent, is extremely slow. The distinct category of groundwater mining depends entirely upon the time frame. All groundwater developments initially mine water, and finally do not.

The distinction between natural recharge and induced recharge also complicates water rights administration. Natural recharge is that water moving through the groundwater system under the boundary conditions imposed by natural topography and climate. Induced recharge is surface water added to the natural groundwater system in response to artificial boundary conditions imposed at wellfields, drains, recharge basins, reservoirs, and other boundary conditions. Induced recharge and groundwater storage are credited as the two sources of water to balance artificial groundwater withdrawals. Natural recharge balances natural discharge and does not enter the artificial water account.

Natural recharge is already generally appropriated at its downstream discharge point as the reliable baseflow of springs, wetlands and rivers. Natural recharge is a spurious part of the wellfield water budget and is irrelevant to the magnitude of an artificial groundwater development. Freeze and Cherry, commenting on groundwater resource evaluation, stated that:

> Some authors have suggested that the safe yield of a groundwater basin be defined as the annual extraction of water that does not exceed the average annual groundwater recharge. This concept is not correct.[24]

Bredehoeft noted that:

> Perhaps the most common misconception in groundwater hydrology is that a water budget of an area determines the magnitude of possible groundwater development.[25]

There is no valid generic rule, such as pumping the natural recharge, that will lead to a desirable economic or stable (non-depleting) level of groundwater development. Subject to local permeability and storage conditions, such a rule can cause either greatly excessive and increasing drawdown or costly constraints on resource usage regardless of the rate of natural recharge.[26] Despite the irrelevance to hydrologic effects, a groundwater

24. R. FREEZE & J. CHERRY, GROUNDWATER, at 604 (1979).

25. Bredehoeft II, *supra* note 22.

26. The effects of concern to water policy are primarily aquifer drawdown and surface water depletion. Both are functionally related to pumping rate, aquifer diffusivity, location, and time of pumpage. The natural recharge rate is unrelated to any parameters controlling the primary water policy concerns.

policy based ostensibly on a steady state with use balanced by recharge remains attractive to policymakers. In Santa Fe County, New Mexico, a policy based on the natural recharge rate was used for land use planning where "[t]he quantitative approach . . . gave the Plan scientific credibility and public political acceptance."[27] Water policies should be publicly understood and accepted, but public purposes are not served by adopting an attractive fallacy that the natural recharge rate represents a safe rate of yield.

A suitable hydrologic basis for a groundwater planning policy aimed at determining the magnitude of possible development would be a curve as in Figure 4 coupled with a projected pattern of drawdown for the system under consideration. The level of groundwater development is calculated using specified withdrawal rates, wellfield locations, drawdown limits and a defined planning horizon. Groundwater models such as those in Table 1 are capable of generating the response curve for any case by simulating the management or policy alternatives in these terms. A specified withdrawal rate, well distribution, and drawdown of water levels to an economic or physical limit are used in the model to project the sources of water from groundwater storage and from surface water depletion throughout the area of response. The area of response is not known in advance of such a projection. A planning horizon must be defined to assess which phase of the transition curve will apply during the period of the plan or policy. The withdrawal rate selected in this way relies first on aquifer storage and secondly on the potential for induced recharge. The plan can contain explicit physical and economic limits on drawdown and induced recharge rates but the analysis is unrelated to the initial natural recharge.

The ultimate limit on groundwater withdrawal is equal to the yield of the induced-recharge phase, but this limitation is of little interest if it applies only after several thousand years. Induced recharge, of course, implies the reduction of supplies for existing uses of the captured surface water. Such concerns may direct the policymakers to avoid major groundwater development, particularly if the protection afforded by the priority system is not available within the planning area.

PRINCIPLES OF THE APPROPRIATIVE WATER RIGHTS SYSTEM

Prior Appropriation System

Under the prior appropriation system, the appropriation of surface water or groundwater for beneficial use creates a right to continued use of water in arid lands where water demand exceeds supply.[28] The right is retained by the user despite changes in sovereignty over the lands and population

27. Wilson, *A Land-Use Policy Based on Water Supply*, 19 WATER RESOURCES BULL. 937 (1983) (AM. WATER RESOURCES ASSOC.).

28. *Water Laws in Moslem Countries, Irrigation and Drainage*, 20 U.N. FAAO 1 (1973).

where the water is used.[29] Water rights may originate by aboriginal possession, by declaration, by issuance of a state permit or license, or by government reservation. An appropriative water right is defined, as illustrated in Figure 5, in terms of the diversion point, amount of diversion, place and purpose of use, the period of use and continuity thereof, and often the consumptive use and return flow fractions.

Claims become readily enforceable upon recognition and final decree by a court after adjudication of conflicting claims. Enforcement is made by a call for water which may require that junior users cease diversions while senior users are served by the available supply. Wasteful use or speculation in water rights is not generally endorsed under the appropriation system.

The appropriation system presumes a priority of rights to use a scarce resource. In principle, junior appropriators are served less frequently than senior appropriators. The ladder of surface water priority includes increasing fractions of empty rights among the late water claimants, as illustrated in Figures 1 and 3. Empty claims may come about through an insufficient physical supply. An insufficient physical supply of surface water can result from unrecognized or unaccounted depletion of surface streams by groundwater withdrawals, causing formerly fully served prior rights to become artificially empty. Empty claims may also result from an inadequate economic capacity to divert and deliver the supply. Due to changes in economic conditions, the on-going cost of construction, operation, and maintenance of diversions, ditches, reservoirs, and deep wellfields may exceed the capacity to pay under the original purpose of use. In such a case, the right may be abandoned or it may be transferred to a new purpose with a greater economic benefit and corresponding capacity to pay the water delivery charges.

A rule against impairment tends to preserve senior rights without foreclosing the opportunity for new uses. The appropriation system accommodates new water diversions that do not impair existing uses. For example, one could claim a right to the unappropriated surplus waters from a rare flood-flow and have the claim recognized for exercise by diversion only of the flood-flow waters.

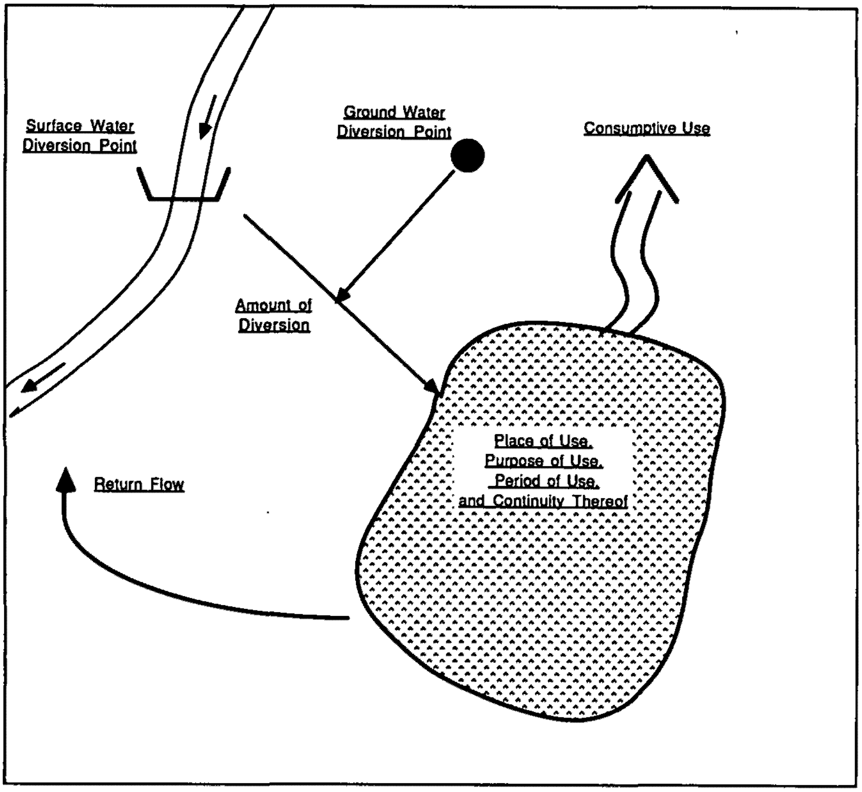
The meaning of impairment or detriment to existing uses often is not defined by clear standards of evaluation but is left to the findings of a state administrative officer, or "water czar," on a case-by-case basis.[30] An economic standard[31] for impairment is possible using cost factors such

29. H. Becker, Prepared Statement for the Water Usage and Resources Committee on the Federal Perspective of Indian Water Rights (July 29, 1983).

30. Dewsnup & Jensen, *A Summary Digest of State Water Laws*, 826 (1973) (Nat'l Water Comm'n Rept.).

31. Grant, *Reasonable Groundwater Pumping Levels Under the Appropriation Doctrine: The Law and Underlying Economic Goals*, 21 NAT. RES. J. 1 (1981).

FIGURE 5 - INFORMATION REQUIRED
FOR DEFINITION OF AN APPROPRIATIVE WATER RIGHT



as pumping lift, conveyance distance, storage or treatment costs as discussed below.

Diversion from Groundwater in a Priority System

Groundwater development in a priority system may be treated as an appropriation, relying initially on stored water, but with a growing effect on the senior surface water rights. The users of groundwater are responsible for compensating the affected users of surface water when the transition to induced recharge begins. Enforcement of priority under this approach implies that the stored groundwater right may be utilized on the condition that the senior surface water rights are compensated to the degree that they are impaired. The impairment will grow with time. It would be hydrologically inaccurate and economically inefficient to ignore the transition period and to assume that groundwater is only of two types:

100 percent mined or 100 percent recharged by surface water.[32]

The priority system is distinctive in that it directs compensation in the order of priority, rather than to all prior rights equally. After adjudication of priority, impairment is more in the nature of a trespass against a particular party, and not a generalized external cost to be accounted for in the common pool of the marketplace. Where priority is not enforced, as in unadjudicated basins, groundwater development takes its supply physically from those with senior water rights, while accounting for the effects, if at all, with exchange of generally lesser-valued, junior, empty, or otherwise unexercised basin rights. The exchange may be in the form of a retirement of rights to irrigated acreage to meet the conditions for approval set by an administrative officer. The process is vulnerable to the inequities arising from the off-set of rights of equal administrative status, even though the rights being exchanged have unequal access to water. Low-value water rights are more readily available in the marketplace and are commonly the ones acquired and retired in a transfer of rights in unadjudicated basins.

Groundwater withdrawn from the mineable category (more than 98 percent from storage) does not cause any significant surface water effect and could be granted a full appropriative water right. In such a case, priority to mineable groundwater becomes an economic right to protection from later depletion of aquifer water levels. An economic standard for evaluating impairment in this sense is discussed in a following section on acquisition of water rights. Priority in access to stored groundwater appears to have no other significance than economic protection. Neither private property interests nor the public trust are enhanced by a reservation of "dead storage" excluded from the resource base.

Adjudication of Priority

The operation of the priority system is impeded by the slow progress of adjudication of competing claims. The initial conditions of water right ownership are established by court adjudication. Decree of the historical distribution of water-right ownership is the first step toward operation of a water market. Transactions in the marketplace may then move forward to redistribute water efficiently and beneficially. Few basin-wide stream systems have reached a final decree in the western United States. Priority is not readily enforced in unadjudicated stream systems. The supposed concern that enforcement of priority will deny water to necessary new developments is not warranted in a fully operational water rights market.[33]

32. Martin, *Conjunctive Use of a Tributary Aquifer System: The New Mexico–El Paso Case*, 5 THE SOUTHWESTERN REVIEW 1 (1986).

33. Saliba, *Do Water Markets "Work"? Market Transfers and Trade-Offs in the Southwestern States*, 23 WATER RESOURCES RES. 1113 (1987).

Recognition that access to water supplies of any desired degree of reliability will be available by purchase to those with superior economic purposes of use should allay such concerns.

Existing rights on unadjudicated streams in New Mexico are placed in a common pool for administrative purposes. Approval of new appropriations or new places and purposes of use is subject to a finding by the State Engineer of no impairment to the pool of existing rights, but a pooled water right with a claimed origin from reliable surface flows in the 18th century is not administered as superior in standing to a largely empty claim originating during the 20th century. Water itself is a commodity, but water rights are distinctly different from one another insofar as they rank the access to water. Empty rights, whether empty for hydrologic or economic reasons, are not of equal value to rights with ready access to water. Administration of water rights as a common pool ignores the inherent ranking that is the basis of the priority system. The priority system requires adjudication to be effective.

The extensive and continuous groundwater system raises a further question about the nature of the associated groundwaters usually adjudicated along with a surface stream system. A surface stream system is defined by its topographic drainage-basin boundaries, but the associated groundwater system cannot be delineated in the same way.[34] The limits of the area of groundwater influence may prove to be less than or greater than the topographic boundaries, but the affected groundwater region is known only after the response to a particular withdrawal is modeled. Wells outside topographic drainage boundaries can be a source of significant stream depletion of surface water inside the drainage basin.[35] The adjudicated prior rights within a stream system can be protected, however, if wellfields external to the basin account for any in-basin depletion by being brought into the terms of the decreed priority and by correctly compensating the affected prior users.

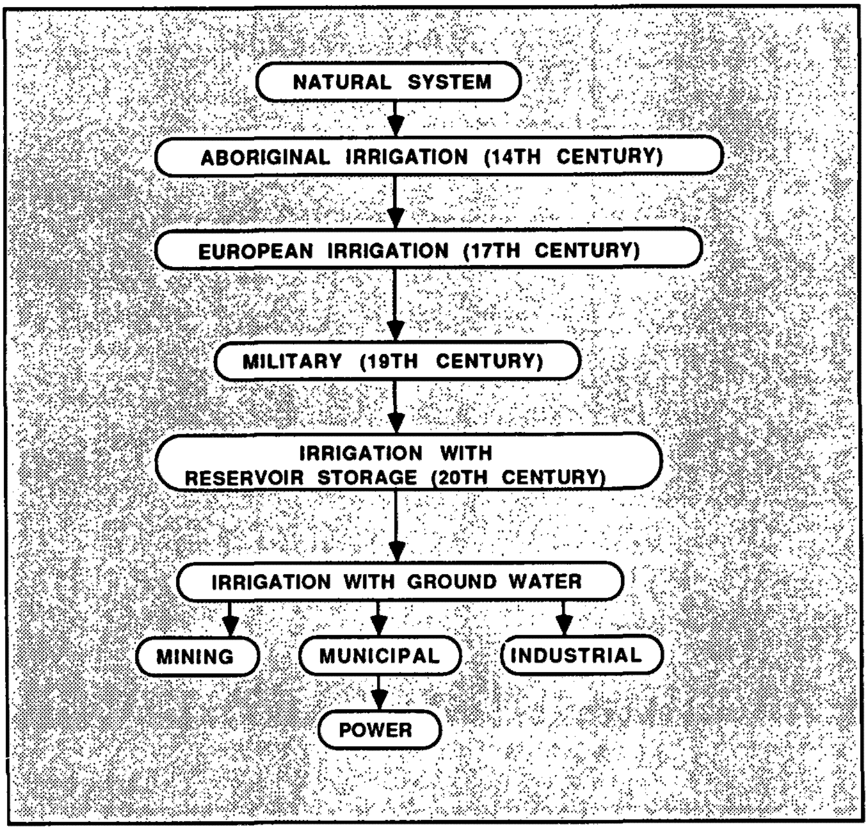
ACQUISITION OF WATER RIGHTS FOR NEW PURPOSES

Sequence of Water Usage

Essentially all water supplies are presently in use, although the degree of protection for those uses varies greatly.[36] New purposes for using water accompany economic change and require a transfer from the former use. Figure 6 indicates the changing uses of a typical tributary of the Rio Grande. The new purposes usually produce higher economic benefits,

34. Bredehoeft I, *supra* note 2.
35. Hearne, *supra* note 8.
36. Bishop, *Water Management Problems*, in 1 WATER FOR THE HUMAN ENVIRONMENT, 71–80 (1973) (First World Congress on Water Resources).

FIGURE 6 - SEQUENCE OF TRANSFERRED PURPOSES OF USE OF WATER IN A TYPICAL TRIBUTARY OF THE RIO GRANDE



and a greater capacity to pay the costs of obtaining water. When the prior right to use the water is held for the less economic purpose, water rights markets are desirable mechanisms for the transfer of water to uses of more value to society. A fair marketplace also transfers economic benefits to the prior owner of the water resource. Water flows to wealth, while wealth properly flows to the prior user of the water in an equitable exchange.

Acquisition of water for new uses is accomplished by a variety of mechanisms. New appropriations, plans of replacement, transfer within one ownership, and transfer within the marketplace are practical options. All mechanisms require administrative approval and evidence that the

pool of existing uses are protected. Protection of priority is administratively necessary in New Mexico only in adjudicated basins.

Transfer of Unadjudicated Empty Rights

The administration of empty rights in overappropriated but unadjudicated basins generally detracts from the protection available to senior rights. Enforcement of priority is not undertaken by administrative officials but may be sought in court by individual parties. The common pool of unadjudicated rights contains a range of water claims including senior fully served rights, junior partially served rights, and later or uneconomic, largely empty, water-rights claims. Although the claims differ in access to water, value of use, and history of exercise, all may have equal administrative standing without an adjudicated decree of priority. Dormant claims abound where forfeiture or abandonment are not enforced. New Mexico courts traditionally have not favored forfeiture.[37]

Without the jurisdiction to determine the priority or validity of water claims, the state administrator nevertheless has the discretion to approve the transfer of an empty right to a new economic purpose, whereupon the formerly unexercised right becomes exercised for a new purpose. Although there is no change in the number or legal standing of water claims in this case, the capacity to exercise the claim is markedly increased to the detriment of the limited supply available for other users. Groundwater diversions are at an advantage under this administrative system. Wells have constant access to water within the economic limitations of the particular purpose of use, whereas many senior surface rights with equal administrative standing are left physically water short.[38]

Alternatives to Adjudication

Unadjudicated water claims disrupt the water market because an efficient marketplace requires good title. An adjudicated water right ensures that the buyer is getting a supply of known reliability and that the supply for third parties is not being sold out from under them. The National Water Commission 1973 report, "Water Policies for the Future," recommended the refiling of all water claims in the western United States. The Commission stated that "any water right not properly recorded . . . should lose its priority."[39]

37. DuMars, *New Mexico Water Law: An Overview and Discussion of Current Issues*, 22 NAT'L. RES. J. 1045 (1982).

38. *See infra* figure 3. A series of N.M. State Engineer hearing records beginning with SEO Bluewater Basin File B-72 in 1984, through file B-7 heard in 1987, as well as other cases in other basins illustrate the problem of devalued, empty rights being transferred for exercise at a new place and purpose of use.

39. NAT'L WATER COMM'N, WATER POLICIES FOR THE FUTURE, 261 (1973).

More recently, DuMars in "State Appropriation of Unappropriated Groundwater: A Strategy for Insuring New Mexico a Water Future," concluded that "[s]tate appropriation or purchase of groundwater could permit the state to develop and coordinate water transfer projects."[40] The trend is toward expediting transfer of water toward more beneficial uses, while discounting the property interests of the prior users. "Water uses will be allowed when and where such uses can be of maximum benefit . . . not [based] on the antedeluvian concept of temporal priority."[41]

A further justification for state appropriation of groundwater is to reserve water for future in-state uses and to protect the resource from out-of-state appropriation. This is in the nature of a state reserved water right analogous to the well-established Federal reserved right. The justification loses weight, however, recognizing that essentially all water supplies, particularly those in the mineable category, are presently in use to some degree. Even water not diverted and put to private beneficial use is gaining protection under theories of public trust, interest, or welfare. After adjudication, future appropriation for either in-state or out-of-state use, would be held to the requirement that prior uses and the public interest be kept whole.

Many current proposals involve statutory forfeiture or state condemnation of prior water rights to expedite the transfer of water rights to higher social purposes. It is doubtful whether novel approaches to reserve and redirect water to new purposes are more desirable than adjudicating and reaching a final decree on ownership, thereby allowing future transfers to occur in the marketplace and preserving existing property rights.

Impairment

In common with many other exchanges in ownership and usage of property such as automobiles, corporations, or toxic materials, when water is moved to new places or purposes, an administrative review ensures that third parties and the public are not unreasonably harmed or their rights impaired.[42] The outcome of such an administrative review becomes more predictable when based on consistent standards of evaluation. Without acknowledged standards, the case-by-case findings of a "water czar" are unknowable by the parties involved. Uncertainty in the outcome of a proposed change in use is costly and discourages economically beneficial changes.

The validity of an economic measure of impairment has been recog-

40. DuMars, *supra* note 1.

41. Sherk, *Federal Legal Trends, Megatrends in Water Resources*, 116 N.M. WATER RESOURCES RES. INST. REPT. 29 (1985) (30th Annual New Mexico Water Conference).

42. Demsetz, *The Exchange and Enforcement of Property Rights*, 7 J. L. & ECON. 11 (1964).

Table 3. Impairment of water right defined by an example economic standard.

Impairment threshold (present value)	Domestic use $100	Commercial use $1,000
Conveyance, horizontal	100 feet	100 feet
Vertical lift	100 AFY-ft	1,000 AFY-ft
Storage	500 gallons	5,000 gallons
Treatment	$10 per year	$100 per year

Note: AFY-ft = the product of acre-feet per year × feet of lift.

nized in the water policy literature.[43] The technical assessment of a proposed change in use is compatible with a set of economic criteria for defining impairment. The parameters of impairment are fully described by any consequent change in the costs imposed upon existing water users. Water-cost parameters are: a) conveyance; b) pumping lift; c) storage; and d) treatment, including heating or cooling.

An economic threshold assigned to each of these defines the categories of *impaired* and *unimpaired* existing rights. Water right hearing fees in New Mexico are typically $250 per party, and transaction costs sometimes exceed $10,000 in a protested proceeding. An economic standard (present value) of $100 for domestic use and $1,000 for commercial use illustrates the threshold value for impairment in the example used in Table 3. The illustrative threshold is arbitrary, but presumably should be set at a level higher than the cost of the procedures for protection of the rights involved. Very small damages need not be policed because doing so would decrease rather than increase the net public benefits. This economic threshold may be measured as a change in capital cost for new equipment, or converted to a conveyance distance, a volume-head product for lifting water, a volume of storage or an annualized water treatment cost. Each term is approximately equivalent to the present value adopted as a criterion for the existing property interest being protected from the effects of a new use. A finding that either groundwater levels or surface flows would change to the extent that an existing user would be required to exceed the threshold of water transport, lift, storage or treatment costs to restore his original supply, would be sufficient to show impairment. The uniform standard could apply to surface water or to either component of a groundwater right, stored water or induced recharge.

For the most part, an applicant for administrative approval of a new use could have some confidence in advance as to the effects of his pro-

43. Schaab, *Prior Appropriation, Impairment, Replacements, Models and Markets*, 23 NAT. RES. J. 25 (1983); Grant, *supra* note 31.

posal. An applicant could then offer a plan of replacement, or other mitigation, including purchase of the affected rights, as part of the proposal for administrative approval.

Validity of Hydrologic Models

Hydrologists participate in the western water rights system to provide the hydrologic models needed by the fact-finders and the parties in each case. There are cases in which alternative models by professional hydrologists have predicted results not merely different in the size of effects from a proposed withdrawal of water, but different in direction, that is, a consumptive use that increases the water supply instead of depleting the net supply.[44] Hydrologists are admitted to the process as expert witnesses to serve the court or the administrator's need for sound information, and are required to advise upon which outcome applies and to what degree before the administrative system can be effective.

The greatest conflicts in prediction of hydrological effects do not arise from disputed understanding of hydrologic parameters or boundaries,[45] but rather from the assumptions behind the stresses simulated by the models.[46] For example, simulating an historically empty right as though it were a fully exercised one results in greatly different predicted effects on the hydrologic system. The diversion scenario (whether a change in rights or a change in actual withdrawals is simulated) can greatly alter the outcome of the calculation of effects. In all cases, the timing of groundwater effects is important. No single point on the transition curve of Figure 4 represents the entire period of interest for water rights purposes. The hydrologist must make explicit the history of diversions and the planning period for future diversions. Hydrogeological information based on accurate models of actual conditions is required for effective administration of the priority system in general.

CONCLUSION

Water rights administration is concerned with ensuring that the property interests of prior appropriators are protected when supplies are short, and has the parallel goal of expediting the transfer of water to higher economic purposes. The newer, more economically and socially productive purposes of use, such as municipal, industrial, power generation, recreation, and other purposes, commonly bid against the historical use of irrigated

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44. Faust, *supra* note 13, discussion of five alternative expert studies.

45. U.S. ARMY CORPS OF ENGINEERS, *A Comparative Analysis of Groundwater Model Formation, the San Andres-Glorieta Case Study*, 75 (1984) (The Hydrologic Engineering Center).

46. Konikow, *Predictive Accuracy of a Ground-Water—Model-Lessons from a Postaudit*, 24 GROUND WATER 173 (1986).

agriculture for a limited water supply. During administrative review of this competitive process, hydrologists are asked to explain the factual basis underlying the effects of proposed new uses or changes in use. The proper outcome of the process is a flow of water to the more socially beneficial uses, and a counterbalancing flow of value to the displaced prior users. The exchange is brought about best through a marketplace transaction. Adjudication of the priority and amount of water right ownership should be expedited to establish marketable title to water and to facilitate water rights administration.

An economic definition of impairment has the potential to rationalize protection for prior uses while aiding the transfer of water to new purposes that deplete either surface water flows or groundwater storage.

The system of prior appropriation is fully compatible with the hydrogeologic view of regional groundwater and surface water systems. The variability of surface water supply is reflected both by the flow-duration curve and by the ladder of priority. The ladder of priority results in an ordered ranking of water rights based on the value and utility of access to the variable surface water supply.

Groundwater appropriations consist of water from two sources: groundwater storage and induced recharge from surface water. Natural recharge does not enter the water account for artificial groundwater diversions. The duration of flows serving surface water claims is changed by groundwater development. The total basin yield is expanded by groundwater development until baseflow is eventually depleted to restore hydrologic balance. In the process, benefits are generally shifted from senior to junior users. The consequent induced depletion of surface water must be correctly appraised to compensate those with prior rights. Basin-wide three-dimensional hydrogeologic models developed since 1980 are adequate for this purpose.

The prior appropriation system is superior to alternative mechanisms, such as condemnation, forfeiture or state appropriation for protecting existing property interests while expediting transfer of water to socially beneficial ends. Basin adjudication, objective standards of evaluation, and accurate hydrologic models are needed to provide predictable and equitable outcomes of water rights issues.