HYDROLOGIC MODELING BENCHBOOK

DIVIDING THE WATERS

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Dividing the Waters

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FOREWORD

The National Judicial College is honored to host and participate in the invaluable work of the Dividing the Waters initiative. Dividing the Waters began in 1993 as a small group of adjudicators who wisely saw the benefit to be gained from "adjudicators" sharing their specialized knowledge, skills and experiencing in addressing water law issues. Today, the initiative has developed into a strong collaborative judicial network of state and federal judges, special masters, magistrates and administrative officers who preside over water rights adjudications, interstate cases arising out of water issues, or other water-related litigation. Through its 17 year history, the Dividing the Waters initiative has held true to its core mission of "better judicial decision-making through reliable evidence." Twelve major conferences and nine workshops later, Dividing the Waters continues to enhance and improve judicial understanding of the challenging issues impacting water adjudication: Case management; Writing a decree that is final yet living; Exploring evidence offered pro/con on climate change; Dispute resolution strategies that work in this complex arena; Groundwater resource management; and Understanding and applying science to water litigation.

It is my privilege to contribute this foreword for what is an essential reference guide for water law adjudicators. The Hydrologic Modeling Bench Book builds upon the work of the Dividing the Waters co-conveners and the judicial officers, lawyers, scientists, and academics who contribute to its programs - those for whom water adjudication is a calling and a passion. The complexity of hydrological modeling and its growing use in water litigation is why Dividing the Waters commissioned Dan Luecke, PhD, noted hydrologist, environmental scientist, and Dividing the Waters science advisor, to draft a bench book that helps judges decode, digest and understand how to give appropriate weight and value to hydrologic models offered in support or opposition to positions asserted in a given water action. Mr. Luecke's work, in which he was ably assisted by attorney Chris Fry, makes information that initially appears incomprehensible clear, concise, and usable.

In closing I would be remiss if this foreword did not recognize and thank those who have played a vital role in creating the Dividing the Waters initiative that today stands as the essential voice for this country's water adjudicators: Judge John Thorson, Judge Dan Hurlbutt, Justice Gregory Hobbs, Justice Ron Robie, Special Master Ramsey Kropf and Dividing the Water's former Executive Director Carolyn Brickey. The National Judicial College looks forward to being the home of Dividing the Waters, and to our collaborating on creating challenging education programs and resources such as this bench book. I would also like to acknowledge both the William and Flora Hewlett Foundation and the Compton Foundation for their support of Dividing the Waters science initiative, support that made this bench book possible.

William F. Dressel, President
The National Judicial College

PREFACE

The quality and reliability of hydrologic models is a regular feature of surface water and groundwater disputes that are challenged in court. These models can be enormously useful, but at the same time are often suspect because of their complexity, the paucity of data used in calibration and validation, and their lack of transparency. In this benchbook we describe the kinds of water cases in which hydrologic models often appear, why use of these models are often essential, how the models are constructed including their data requirements and various means, both technical and legal, of assessing the models' quality (e.g., the Guidelines of the American Society of Testing and Materials and *Daubert*). Our underlying assumption is that better understanding of hydrologic models and their usefulness – both their benefits and their flaws – combined a fuller comprehension of the processes by which they are assessed can lead to better models in the courtroom, and ultimately, to fairer and more efficient outcomes.

To do this, we will summarize a variety of kinds of the cases in which models have appeared, review some of the literature on model building and testing, describe some of the proposed guidelines on a number of the features of model construction and testing, and present techniques for case management in the context of handling complex models. We will also look at four cases in which models played a central role, the Arkansas River Compact altercation (*Kansas v. Colorado*), the Republican River Compact dispute (*Kansas v. Nebraska and Colorado*), a case from South Platte (*In the Matter of the Application for Water rights of Park County Sportsmen's Ranch, et al. v. Colorado State Engineer*), and a case from the Rio Grande (Rules Governing New Withdrawals of Ground Water in Water Division 3 Affecting the Rate or Direction of Movement of Water in the Confined Aquifer System).

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SECTION I
WATER ISSUES, LITIGATION AND MODELS

1. INTRODUCTION

The fundamental challenges which this benchbook seeks to address are improving judicial understanding of hydrologic modeling and establishing standards by which to evaluate its use in the courtroom. Hydrologic models, often cloaked in the arcane language of computer code and scientific terms of art, may appear inaccessible to the layman, but must nonetheless be understood to prevent their misuse by adversarial parties in the courtroom. Fundamental to the difficulties encountered when introducing hydrologic models in the courtroom are law and science's conceptually different ideas of truth and the methods to be employed to arrive at that proof.[1] As a result, the law has at times been hesitant to adopt scientific knowledge, or conversely, been willing to make sound determinations in light of scientific uncertainty. Increasing scientific knowledge and modeling have helped minimize this disparity. An early example of the reconciliation of the gap between law and science was evidenced in *Wood v. Picillo*.[2] The Rhode Island Supreme Court overturned the prior decision of *Rose v. Socony-Vacuum*, by stating that as a "matter of scientific fact the course of subterranean waters are no longer obscure and mysterious"[3] and finding that negligence was no longer required in a nuisance case for pollution of waters.[4]

Aside from gaps between scientific and legal proof, critics note that contemporary law often remains blind to many hydrological realities.[5] In this era of increasing understanding of hydrology, the judicial system must necessarily employ the advantages of and, at the same time, recognize the limitations of hydrologic models.

1 William Goldfarb, Water Law 4 (Lewis Publishers, Inc., 2nd ed. 1988).
2 Wood v. Picillo, 443 A.2d 1244, 1249 (RI 1982).
3 Id. at 1249; Rose v. Socony-Vacuum, 173 A. 627 (RI 1934).
4 Goldfarb, supra note 1, at 4.
5 Eric Ryan Potyondy, Sustaining the Unsustainable: Development of the Denver Basin Aquifers, 9 U. Denv. Water L. Rev. 121 (2006).

Hydrologic modeling is a method by which to describe a water system's characteristics and behavior. It is also a means by which to predict future responses of the system to changing conditions.[6] The use of computer-based modeling has become standard in many types of water disputes and this benchbook summarizes several common areas of water law where models have been used. It also attempts to describe the major scientific and legal issues that arise in these cases. Specifically, this section briefly examines the following types of cases:

1. New appropriations — surface and groundwater
2. Quantification of existing rights
3. Federal land management decisions and NEPA
4. Water quality and pollution
5. Nuisance and flooding cases
6. Land use and its impact on water flows
7. Endangered Species Act water requirements
8. Tribal and federal reserved water rights quantification
9. Adjudications of Water Rights

2. OVERVIEW

Qui prior est tempore potior est jure — he who is prior in time is greater in right. It is axiomatic to western state water codes that senior water rights are protected against junior appropriators.[7] Likewise, juniors may not be injured by changes to existing senior uses or any new allocations of water. Hydrological models are used to analyze whether changes in water rights will affect existing rights. However, the acceptability of a hydrological model will be based upon the "number and strengths of confirming observations," and will always rest upon a subjective judgment as to the quality of the model in representing any particular hydrologic system.[8] By necessity, judges and juries, those tasked with the ultimate determination as to what constitutes a good model, must rely on the opinions of experts to make objective model evaluations. Section I of this book will provide some context and history of how hydrological models have been used to reduce scientific uncertainty, and ultimately, how they have affected water rights decisions.

3. SURFACE & GROUNDWATER APPROPRIATIONS

a. New Water Right Applications

A request for a new water right, the right to withdraw additional water from surface streams or tributary groundwater sources, must identify a particular location, use a precise means of diversion from a naturally occurring water course, specify a particular quantity of water, and must describe a explicit, recognized 'beneficial use.' The request also must typically be analyzed in terms of impacts upon other rights. Determination of these impacts often requires knowledge of local hydrology and will often benefit from the use of a hydrological model. From a procedural standpoint, new use requests are initially approved by a state water engineer if the request meets the "no injury" criterion in that it does not adversely affect any other user with a vested right or decreed right.

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6 Leonard Rice & Michael D. White, Engineering Aspects of Water Law 144 (John Wiley & Sons, Inc., 1987).

7 Seniority is based upon the date of the water right, either the date of application or perfection of the right if the use of the right preceded a formal application procedure.

8 Mariam J. Masid, Reforming the Culture of Partiality: Diffusing the Battle of the Experts in Western Water Wars 60 (2007) (unpublished Ph.D. dissertation, Colorado State University) (on file with Morgan Library).

i. The Role of Models in Appropriations

To determine whether an injury will occur to existing water users, the water engineer and courts must understand the hydrology of a watershed. Once causal connections are established between hydrological elements in a watershed, a computer model may be useful to show how connected, or possibly connected, aquifers behave under changed flow conditions. In the groundwater context, courts may require that a surface water right holder requesting a supplemental well downstream of an original point of diversion show that the well will tap a groundwater aquifer or a deeper, hydrologically unrelated aquifer.[9] A model often proves useful in demonstrating no harm to downstream wells.

A model may be particularly useful in coastal areas or island environments. Specifically, it may prevent irreparable harm to water resources by determining whether groundwater withdrawals will significantly impact the often delicate balance between saltwater, brackish waters, and a freshwater lens. As an example, on the Hawaiian island of Molokai, developers requested an additional use permit for groundwater withdrawals. In accordance with Hawaiian statutes, the Commission on Water Resource Management examined two models to evaluate the impact of proposed withdrawals. the "McNulty model" was offered by the water applicant and United States Geological Services (USGS) model was offered by the opponents. The Hawaiian Supreme Court noted that one model overestimated the level of groundwater loss because it failed to consider the presence of intrusive structures and their role in restricting the amount of water that would leave the aquifer. Accounting for this model failure, the court found that both models demonstrated that the proposed withdrawal would have a negligible impact upon the aquifer. The court approved the groundwater right subject to the Commission's requirement that continued monitoring be used to calibrate the models to ensure that withdrawn quantities would have the anticipated effects and continue to meet public interest requirements.[10]

Similarly, changes in locations of water rights may occur without losing priority if they can be made without detriment to or impairment of existing rights and meet any other state statutory requirements.[11] In Colorado, any change request would be adjudicated, while in all other states an administrative agency would determine whether the location change would prevent harm to existing water rights. To prove that no harm will result to competing rights, petitioners frequently use hydrological models. In *Montgomery v. Lomos Altos,* three hydrological models were competing for acceptance and demonstrated two distinct outputs.[12] A hearing examiner determined that the applicant's model and the State Engineer Water Rights Division model were more reliable than the protestant's model and should guide the outcome of the application.[13] Reviewing a challenge to the Engineer's decision, the New Mexico Supreme Court upheld the determination, but did not note in its opinion which factors were relevant in the hearing examiner's decision.[14] Change requests will be further discussed in a later section.

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9 See e.g. Herrington v. State of N.M. ex. rel. Office of State Engineer, 133 P.3d 258 (N.M. 2006).

10 See In re Waiola O Molokai, Inc., 83 P.3d 664 (HI 2004).

11 Montgomery v. Lomos Altos, Inc., 150 P.3d 971, 971 (N.M. 2006) (The Rio Grande is fully appropriated and as a result, no new appropriation is allowed. In this case Applicants sought to change location and use from surface water withdrawals to groundwater withdrawals. NM Supreme Court upheld the lower court's determination that the change from surface diversion to ground diversion was a transfer rather than a new appropriation).

12 Id.

13 Id.

14 Id.

ii. Perfecting a Water Right

Conditional, or provisional, water rights may be granted for a proposed, unrealized development project. Due diligence is required to perfect a provisional water right. Part of that diligence includes the gathering of data.[15] The Colorado Supreme Court has indicated that the "question of diligence must be determined in light of all factors present in a particular case, including the size and complexity of the project; the extent of the construction season; the availability of materials, labor, and equipment; the economic ability of the claimant; the intervention of outside delaying factors..."[16] While diligence is often measured by development of physical infrastructure related to a water project, modeling and proof of no harm may constitute a portion of these efforts.

b. No Injury

Western states require that new water rights applicants prove that unappropriated water remains available within a watershed and that a new diversion will cause no harm to existing rights or downstream users. For example, for water rights to be approved in Colorado, they must not "injuriously affect the owner of or persons entitled to use water under a vested water right or a decreed conditional water right."[17] Hydrological models are often helpful to prove no injury – the methods and standards of proving no injury will be discussed in the next section on change orders. The no injury rule is not limited to surface diversions. Indeed, as the science of hydrology has developed, the courts have come to recognize "the fact that many *underground waters* are *tributary to streams* and that withdrawal of water from wells can affect streamflow."[18] Where courts have been hesitant to recognize this, many states have equated non-confined aquifer waters and surface waters by statute.

c. Standing to Challenge a New Appropriation or Change Order

As a threshold matter, in order to challenge a water appropriation or change application, a plaintiff must show injury. As discussed, a model may be involved in establishing that a party has been or is likely to be injured by an order. Further complicating this notion is the concept of developed ('foreign') water, which is water that is brought into a system or derived from outside a hydrological system and would not otherwise be available. Developed water is also outside the traditional appropriation system and appropriators need not seek water rights for it. In *Town of Silver City v. Scartaccini*, a New Mexico appeals court upheld the notion that most water (pond water in this case) was public and assumed to be within the public domain, capable of appropriation (relying on a statute).[19] It noted that modeling improved the court's ability to judge the actual source and hydrological connection of a particular water body to streams and aquifers. Furthermore, it held that standing to challenge a change order request or new appropriation does not automatically arise merely because a water right holder is located within a hydrologic model boundary.[20] Actual injury and 'zone of interest' must be shown to bring a claim.[21]

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15 Rice & White, supra note 6, at 162.

16 Colorado River Water Conservation Dist. v. Twin Lakes Reservoir & Canal Co. 468 P.2d 853, 856 (Colo. 1970).

17 City of Thornton v. Bijou Irr. Co. 926 P.2d 1 (Colo. 1996); Colo. Rev. Stat. § 37-92-305(3) (1990); see also Mont. Code Ann. § 85-2-402(2)(a) (2007); Utah Code Ann. § 73-3-3 (2008) (regarding change orders); Utah Code Ann. § 73-3-8 (2008) (for new applications).

18 State, Dept. of Nat. Res., Div. of Water Res. v. Sw. Colorado Water Conservation Dist., 671 P.2d 1294, 1308 (Colo. 1983); Three Bells Ranch Assocs. v. Cache La Poudre Water Users Assoc., 758 P.2d 164, 170 (Colo. 1988) ("As knowledge of the science of hydrology has increased, it has become clear that natural streams are simply the surface manifestations of extensive tributary systems . . . .").

19 Town of Silver City v. Scartaccini, 126 P.3d 1177 (N.M. App. 2005),

20 Id. at 1185.

21 Id.

d. Changes to Existing Water Rights

Change applications are requests for an alteration in the time, purpose, or location of diversion for an existing water right. These applications ("change orders" in Colorado) must meet requirements similar to those for new water rights. A application will not compromise the seniority date of the existing right, but to be approved it has to meet the no injury rule. Any changes must be initially approved by a state engineer. In the case of Colorado, the application must then be approved by a water court. Change applications generally fall into one of three categories:

1. Change in type of use
2. Change in time of withdrawal
3. Change in location of withdrawal

Colorado recognizes a change in water rights as:

> A change in the type, place, or time of use, a change in the point of diversion, a change from a fixed point of diversion to alternate or supplemental points of diversion, a change from alternate or supplemental points of diversion to a fixed point, a change in the means of diversion, a change in the place of storage, a change from direct application to storage and subsequent application, a change from storage and subsequent application to direct application, a change from fixed place of storage to alternate places of storage, a change from alternate places of storage to a fixed place of storage or any combination of such changes. The term "change of water right" includes changes to conditional water rights as well as changes to established or perfected rights.[22]

Similar statutory language exists for other western states. It should be noted that diversion periods traditionally correspond to agricultural growing seasons or snowmelt runoff that allows for water storage and later use. Likewise, use is classified by type and includes broad categories of uses such as agricultural, industrial, domestic, or recreational use.[23]

Seniors also have obligations to their juniors. Those seeking a change in their water rights have a duty to ensure that any change in the timing, point, or use – which implicates return-flow timing and amounts – will retain historical flows to downstream juniors.[24] Since water rights are granted for a particular location, means of diversion, quantity, and type of use, change requests may require the use of a hydrological model. The New Mexico Supreme Court encountered such a case in *Montgomery v. Lomos Altos, Inc*. Conflicting hydrological models between an applicant requesting a change in the location of a diversion and juniors who produced a model indicating a greater impact to their rights provided the controversy. The court found that the state engineer's model and the applicant's model results were superior to the junior's model and determined that the engineer was reasonable in granting the change because the diminished flow would not impede the junior's rights.[25] Furthermore, the court reiterated a prior decision in which it stated "[T]he question of impairment of existing rights is one which must generally be decided upon the facts in each case, and...a definition of 'impairment of existing rights' is not only difficult but an 'attempt to define the same would lead to severe complications.'"[26] The use of models has begun to aid in this decisionmaking.

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22 Rice & White, supra note 6, at 155; 1969 Colorado Water Rights Determination and Administrative Act.

23 It should be noted that some states do allow, or even require, the designation of in-stream flows for the protection of riparian environments.

24 See e.g. Farmers High Line Canal and Reservoir Co. v. City of Golden, 975 P.2d 189 (Colo. 1999).

25 See Montgomery v. Lomos Altos, Inc., 150 P.3d 971 (NM 2006).

26 Id. at 978 (citing Mathers v. Texaco, 421 P.2d 771, 776 (1966).

e. Conflicts -- Uncertain Impacts of Groundwater Withdrawals on Surface Rights

In most Western states, except when defined as tributary surface waters, groundwater use is treated differently than surface waters. This benchbook will not examine the various groundwater legal regimes, but will examine the case of groundwater withdrawals interfering with existing surface rights. In some state legislatures have attempted to ameliorate conflicts among water users, especially surface and groundwater users, by mandating the use and development of specific computerized models. In Colorado's San Luis Valley, the state legislature required that the State Engineer develop an extensive computer model, which came to be known as the Rio Grande Decision Support System (RGDSS). One purpose of the model was to determine the impact of further withdrawals on artesian pressure in a confined aquifer system. In challenges to the State Engineer's rules on withdrawals and new wells in a confined aquifer based upon the RGDSS model, the Colorado Supreme Court upheld the model's sufficiency.[27] Here, the State Engineer developed the RGDSS model – discussed infra – and the court upheld rules that required any water applicant to challenge the State Engineer's model or present evidence that the withdrawal would not harm existing rights.[28]

f. Old Rights and New Understanding

Many senior water rights were granted and quantified when courts had only a rudimentary understanding of hydrology. As a result, courts may be hesitant to apply new understandings to modern water disputes or rights applications. The question of how to handle this new understanding applies to general adjudications and situations where water users seek changes to existing rights. Newer models are used to evaluate existing rights in several ways. In one case a water right was determined to be 'non-tributary' in 1953, prior to an accurate understanding of return flows.[29] The court determined that it could not later determine the right to be 'tributary' absent a request by the owner for such new status, under the theory of collateral estoppel.[30] Therefore, the application of newer, complex models may in fact harm some existing water rights, especially when senior rights that depend upon return flows seek to have hydrologically connected water users' rights reclassified or requantified.

g. Augmentation

A court approved augmentation plan allows juniors to appropriate water out of priority, but only if they adequately replace the water so as to prevent injury to seniors. Often, evaluation of an augmentation plan will involve a computer model. This was the case in *In the Matter of the Application for Water Rights of Park County Sportsmen's Ranch, et al. v. Colorado State Engineer*, where the court found the plan was fatally flawed because scientific evidence presented at trial was not sufficiently reliable to be admissible under Federal Rules of Evidence (FRE) 702.[31] This case is discussed in detail in Section VIII.

h. Choosing Boundaries for Adjudication of New and Existing Rights

Finally, hydrological models may be of relevance where a state agency is required by statute to determine administrative water jurisdictions. For example, the Model Water Code (a 2007 proposal of the American Society of Civil Engineers) requires a state agency to determine the boundaries in a general administrative adjudication area based upon sound hydrologic interconnections.[32] In addition, the model code allows for judicial review of state agency boundaries or revisions to the boundaries.[33]

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27 Simpson v. Cotton Creek Circles, LLC, 181 P.3d 252 (Colo. 2008).
28 Id.
29 City of Thornton v. Bijou Irr. Co., supra note 11, at 83.
30 Id.
31 Masid, supra note 8, at 70. (The model used usewd in the case was MODFLOW, a standard 3-dimensional finite difference groundwater flow model [see Appendix A], but its application in Sportsmen's Ranch was incorrect. The model users failed to do a sensitivity analysis and failed to properly calibrate the model (see Section IV) and the court did not accept the model.)
32 Joseph W. Dellapenna Ed., Appropriative Rights Model Water Code 208 (The American Society of Civil Engineers 2007).
33 Id. (Note: Comparable Statutes: Alaska Stat. §46.15.165(b); Ariz. Stat. Ann. § 45-256(A)(1); Cal. Water Code § 2500).

4. QUANTIFICATION OF EXISTING RIGHTS

These decisions involve the determination of historical consumptive use, which is the measure of a water right in terms of quantity and, to a lesser extend, quality. Consumptive use is defined as the measure of water diverted from a natural watercourse less any return flows into the watercourse.[34] Accurate quantification becomes important when water rights holders wish to change the time, place, or type of use of their rights.[35] The quantity of water used becomes relevant typically in regard to agricultural uses. As such, a court may need to determine the quantity of the right and in so doing must contemplate:

1) The *river flow* or amount that is available in the stream at the ditch headgate;

2) The amount *diverted for irrigation*, which is the amount of water pulled off the stream at the headgate, but not the amount of water which is actually delivered to the crops. (These quantities will differ by losses from *evaporation, seepage,* and *bypasses* and gains from *precipitation* and *inflow from surface runoff*.);

3) The *amount of river flow* that bypasses a head gate, but may be augmented between the point of *return flow* by *groundwater contributions, surface runoff from non-irrigated lands, industrial or municipal discharges,* and *natural inflow from tributaries*;

4) The water *applied to irrigation*, which includes losses due to crop *evapotranspiration*, or the amount of water lost from transpiration and growth of plant tissue and water lost to soil moisture evaporation;

5) The *irrigation return flow* which includes *canal seepage, bypasses,* and *deep percolation* of water beyond the root zone and returned to the source stream as subsurface flow and *tail water* or overland return flow.[36]

Determination of the amount and type of water that a party is entitled to take appears in a number of distinct types of cases, including: general stream adjudications, contract disputes, state compact disputes, some water quality disputes, or water takings cases.

a. General Stream Adjudications

A general stream adjudication is essentially an accounting. It is a judicial review and quantification of existing rights and a determination of abandoned water rights for a particular river or watershed. This process may occur on a specific river within a state's jurisdiction or in response to a conflict between states sharing a common watershed. In a state specific context it will include all existing and conditional water rights holders as parties. The result of a general stream adjudication is a decree which judicially defines all uses in the system.

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34 Rice & White, supra note 6, at 146.
35 Id. at 147.
36 Id. at 147–151.

b. Interstate Allocation of Water

Hydrological flows rarely adhere to political boundaries. Hence, a common dispute among states involves the quantity and quality of waters running into one state from upstream states. The Supreme Court has original and exclusive jurisdiction over state-state disputes under U.S. Const. art. III, § 2 and 28 U.S.C. § 1251 (2008). The interstate allocation of water is handled by Supreme Court decree (an equitable apportionment decree). In lieu of a decree, states may agree to a water compact. In water disputes, as with other technical matters, the Supreme Court appoints a Special Master to ensure that states are in compliance with prior decrees or to make recommendations on equitable apportionment. Most such decrees and compacts date from an era prior to the development of computer based hydrologic models. However, when these interstate allocation agreements are revisited by any of the parties, models invariably play a central role. For example, in *Kansas v. Nebraska and Colorado*, Kansas claimed that the Republican River Compact had been breached because Nebraska allowed the unimpeded development of wells that impacted surface flow. As a result of the settlement of the Kansas claims, the three states developed a comprehensive groundwater model to reflect the interaction of river flows and groundwater withdrawals (RRCA Model) as the basis for administering the settlement under the compact.[37] This case is discussed in greater detail in Section VIII.

Notwithstanding their widespread use, the sufficiency of model results or outputs is almost always a dispute in allocation cases. For example, in *Kansas v. Colorado*, concerning the Arkansas River Compact, the Supreme Court noted the inaccuracies of model outputs for a single year and upheld a Special Master's finding that, for purposes of assessing compact compliance, results should be averaged over a period of no less than ten years.[38] This case is also discussed in greater detail in Section VIII.

c. Contract Disputes

Disputes involving hydrological models may also arise within the contract realm. For example, in *Stockton East Water Dist. v. United States*, a water district sued the Bureau of Reclamation claiming that their management decisions and failure to adopt a more effective release schedule resulted in a denial of a full allocation to several water districts. The district argued that Reclamation failed to take all "reasonable means" to ensure full water deliveries. They supported this claim with expert testimony and a model performing mass-balance calculations of the Stanislaus River. The court found the model and report "enable[ed] a greater understanding of the potential for delivery of full contract amounts of water to the Contracting parties."[39] However, the court noted that the model and its results failed to incorporate real-time consideration of "operational factors" and was therefore merely speculative and historical. Further, it noted that the model did not take into account schedule requests that required greater or lesser releases at certain times during the year. In sum, the court concluded that "the inability of... [the] model to take into account operational decision-making precludes the court from finding liability for unreasonable operational decisions based on the expert testimony and model alone."[40]

d. Water Quality as a Vested Component of a Water Right

In many states, water rights holders are entitled to water of equal quality to that which they have historically enjoyed. As one court stated, "the owner of a water right has a vested right to the quality as well as the quantity which he has beneficially used."[41] Many water quality issues arise within the nuisance context and computer models are often helpful in demonstrating contamination levels.[42]

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37 Masid, supra note 8, at 80.
38 Kansas v. Colorado, 543 U.S. 86, 101 (2004).
39 Stockton E. Water Div. v. U.S., 75 Fed. Cl. 321, 367 (Fed. Cl. 2007).
40 Id. at 368.
41 Salt Lake City v. Boundary Springs Water Users Ass'n, 270 P.2d 453, 455 (Utah 1954).
42 See e.g. New Mexico v. General Electric, 335 F.Supp. 2d 1266 (D.N.M. 2004).

e. Water and Eminent Domain

Water rights are real property and it is likely that as the West continues to grow, state authorities may find it necessary to obtain water rights from private citizens under eminent domain authority for public purposes. If municipalities, water districts (with the authority), or state authorities do exert their eminent domain powers over water, it will fall upon the courts to determine the value of the water taken.[43] To do this properly, courts will need to evaluate the amount of the historical consumptive allocation and return flow patterns. Courts may choose to value a particular water right based upon the historical flow and the likelihood that a particular priority right will receive its full allocation over a period of years. Modeling will likely play an integral role in any such calculations.

5. FEDERAL LAND MANAGEMENT DECISIONS AND NEPA

Water modeling also frequently plays a role in another category of litigation – statutory challenges to federal and state agency decisionmaking. Legal challenges to final government actions under the National Environmental Policy Act (NEPA) have often involved hydrological models. Commonly, these model-related NEPA challenges involve the sufficiency of government actions to protect endangered species habitat under the Endangered Species Act (ESA) (which will be discussed in Section I.9). Another recent series of model-related challenges has been over the sufficiency or implementation of the U.S. Forest Service's (USFS) Land Use Plans. The federal Administrative Procedure Act is also implicated in many cases where parties challenge government action as "arbitrary and capricious" under the theory that agencies may have based decisions on incomplete or insufficient models.

Since the USFS mission includes the mandate to protect watershed health, it is not surprising that legal challenges to its activities have relied on hydrological models. For example, before authorizing a sale of timber, NEPA does not require that the Forest Service use a particular hydrological or impact model. In one challenge to a timber sale, the court noted that the Forest Service had developed and used a sediment model to analyze the cumulative impacts of logging on streams in a particular watershed. It indicated that the Forest Service had acted appropriately in relying on the model it had selected and, further, that it was not bound to quantify the cumulative impacts of logging projects in those cases where cause-and-effect relationships were poorly understood or underlying data were lacking.[44]

Environmental groups have challenged water management plans for a failure to adequately calibrate models and have alleged that manipulation of models was the basis for approving large scale flood control projects. In *Texas Committee on Natural Resources v. Van Winkle*, the court held that an agency need not explain variations between prior modeling and recent modeling in any detail, but under the APA, a reviewing court will only examine whether a methodology is consistent and rationally applied.[45]

6. WATER QUALITY AND POLLUTION

Pollution cases often appear in the civil tort and permit violation contexts. Hydrological modeling may be used to demonstrate causation in cases where pollution is thought to have migrated from one location to another. As will be discussed in Sections V-VI, a court must examine several threshold factors that a model should exhibit before it allows a model into evidence. A court must also carefully limit the scope to which an expert may testify concerning a hydrologic model.

43 See generally id. at 165.

44 Clinch Coal. v. Damon, 316 F.Supp. 2d 364, 386 (W.D. Vir. 2004) (citing to Hughes River Watershed Conservancy v. Johnson, 165 F.3d 283, 289 (4th Cir. 1999) for the proposition that NEPA allows an agency to "select their own methodology as long as that methodology is reasonable.").

45 Texas Comm. on Natural Res. v. Van Winkle, 197 F.Supp. 2d 586, 600 (N.D. Texas 2002).

Typical water pollution cases involve demonstrating causation between a polluter's conduct and measurable contamination in hydrologically connected ground or surface waters. In *Dura Automotive v. CTS Crop.,* plaintiffs sought to demonstrate the source of contamination in groundwater. Experts testified and offered opinions based upon hydrologic computer models. The court faced the difficulty of determining whether the offered expert was sufficiently knowledgeable to provide opinion testimony based upon a computer model. Similarly, in *W.R. Grace – Anderson, et al, v. Cryovac,*[46] a court examined whether a pollution source was contaminating groundwater and wrestled with the question of whether the science related to properly weighing the evidentiary value of a model was too complicated for the majority of people to understand.[47]

a. The Clean Water Act

The Clean Water Act was passed to prevent undue pollution of the nation's waters. The courts have struggled with defining which waters fall under and which are exempt from the Clean Water Act (CWA). In a series of decisions, the Supreme Court has attempted to define "waters of the United States" [Nation's Waters] which are subject to the CWA requirements. In doing so, it has determined that a mere hydrological connection of a stream, tributary or other water source is not sufficient for the Environmental Protection Agency (EPA) to exert jurisdiction over certain waters under the CWA.[48] Section 303(d) of the Clean Water Act makes it illegal for "anyone to discharge pollutants into the Nation's waters except pursuant to a permit."[49] In some cases a complicated hydrological model may not be required to determine whether the CWA should apply to particular waters, and a determination may be as simple as visual observation of surface waters flowing between two points. However, because a plaintiff is required to show a hydrological connection between a source of pollution and a discharge of pollutants at a particular point to trigger CWA protections a model may be useful. Courts have indicated that hydraulic conductivity and hydraulic gradient are important when creating a qualitative hydrologic model but these elements may be established by in-court expert testimony where pollution does not occur by migration, but rather through specific channels of transport, such as abandoned mine shafts between rock layers.[50] Because the Supreme Court's *Rapanos v. United States* decision has left ambiguity and frustration for both property owners, environmentalists, and the EPA as to what waters may be regulated under CWA, it is likely that hydrological modeling will play a role in the resolution of many future CWA disputes.

46 96 F.R.D. 431 (U.S. Dist. Court MA 1983)
47 Masid, supra note 8, at 76.
48 See Rapanos v. United States, 547 U.S. 715 (2006).
49 Mineral Policy Center v. El Paso Properties, Inc., (Not reported 2007 WL 1630710); see also Sierra Club v. El Paso Mines, Inc. 421 F.3d 1133 (10th Cir. 2005).
50 Id.; Mineral Policy Center, supra note 52, at 5.

b. Agency Decisions and Rulemaking

An agency's decisionmaking process may require permitees or permit applicants to use computer hydrologic modeling to show acceptable sedimentation control efforts and limitation on total sedimentation prior to issuing a permit.[51]

Furthermore, if a regulation is promulgated with supporting hydrologic models, a court will defer to an agency's– in many cases the EPA's – evaluation and weighing of a model. Use of such models and insertion of their results in an official record often provides sufficient evidence of statutorily mandated administrative consideration. Often, the mere use of a model will support any agency conclusions and agency actions for purposes of the Administrative Procedure Act (APA).[52]

Courts have found that the underlying data used in a model may be insufficient to warrant a particular regulation. For example, in *Waterkeeper Alliance, Inc. v. EPA*, the court found that an EPA regulation that equated CAFO (Confined Agricultural Feed Operations) facilities capable of containing a "100 year, 24-hour rainfall event" with a total prohibition on releases was not supported by a [sic] overflow water model using 25 year, 24-hour rainfall event" and the EPA's conclusion lacked sufficient evidentiary support in the record. As a result, the sufficiency of data used in a hydrological model may impact the validity of a government decision.[53] Similar cases will also be discussed under NEPA standards.

Hydrologic methodologies have also been an issue in the context of stormwater permits and whether permit evaluations have met statutory methodology requirements. In *Brown v. South Carolina Dept. of Health and Human Environmental Control*, the court ruled in a statutory interpretation that a hydrological analysis intended for small projects did not exclude its use on large projects as well.[54]

Finally, the Safe Drinking Water Act (SDWA) requires the EPA to approve withdrawals from certain aquifers, and approval may require hydrologic modeling and analysis.[55]

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51 See 40 C.F.R. § 434.82(b), Citizens Coal Council v. U.S. EPA, 447 F.3d 879, 887 (6th Cir. 2006) (where coal mining point dischargers must create a Sediment Control Model).
52 Id. at 901 (citing BP Exploration v. U.S. EPA, 66 F.3d 784 (6th Cir. 1995)).
53 Waterkeeper Alliance, Inc. v. U.S. EPA, 39 F.3d 486, 521 (2nd Cir. 2005).
54 Brown v. South Carolina Dept. of Health and Human Envt'l Control, 560 S.E. 2d 410 (S.C. 2002).
55 See e.g. Miami-Dade County v. U.S. EPA, 529 F.3d 1049 (11th Cir. 2008).

7. NUISANCE AND FLOODING CASES

a. Flooding

Injuries and damages that result from flooding thought to be caused by mining and timbering operations often involve computer models to prove causation. Specifically, computer models analyze the effects of land disturbance on stormwater flows and the effects of timber removal on sedimentation and watershed behavior. In *Coal River Watershed*, plaintiffs were able to present expert opinion based upon hydrological modeling to uphold a jury decision and fend off a motion to dismiss for lack of claim. The computer models used were of the type generally accepted and used within the engineering community.[56] The defendants attacked the data input for peak flows but did not provide an alternate computer model.

Hydrological models have been used in at least one private action against a railroad for flooding caused to a manufacturing plant when the railroad decided to leave several of its trains on tracks adjacent to the plant. In *Acker v. Burlington Northern and Sante Fe Railroad* Co., plaintiffs provided an expert who had constructed a hydrological model for floodwaters based upon data from historic flood level data.[57] The plaintiffs provided testimony that the modeling methodology and calibration conformed to generally accepted techniques. The defendants failed to refute the reliability of the model or provide sufficient evidence of the model's inaccuracy sufficient for the court to exclude either the model or an expert's testimony based upon the model. The court also noted that the model's reliability was likely, especially since the model was a slightly modified version of a model approved by the Army Corps of Engineers.[58]

Improper water management and resulting flood damage has also provided an opportunity for model use. For example, in *State ex. rel. Post v. Speck*, opposing models were offered to support and contest plaintiffs' claims that a government entity was responsible for flood damage.[59]

Modeling may also be relevant in federal or state flood planning and prevention efforts. As already mentioned, attacks on federal actions or on failures to act under NEPA and the APA may also involve hydrological models. For example, in *Sierra Club v. U.S. Army Corps of Engineers,* an environmental assessment was deemed inadequate where it failed to adequately model a river system or account for the cumulative impact of a proposed levee within a model so as to prevent flooding.[60]

b. Radioactive Waste and Other Contaminants

A failure to include correct or updated data into a model has also been grounds for attacking the validity of an agency decision in the radioactive waste context. In *Citizens for Alternatives to Radioactive Dumping v. U.S. Dept. of Energy*, a citizens group alleged that the Department of Energy (DOE) had failed to include transmissivity figures for how certain layers of underground formations may transmit radioactive wastes or were hydrologically contained or connected.[61] In this case, the court found that the DOE had not made "a 'clear error in judgment' in concluding that its site modeling was adequate," despite the failure to consider certain data.[62]

The decision on where to place a hazardous waste disposal site between alternate locations may also involve the use of hydrologic modeling.[63]

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56 See In re Flood Litigation, Coal River Watershed, 2008 WL 2523224, (W. Va. 2008).
57 Acker v. Burlington N. and Santa Fe Ry. Co., 347 F.Supp. 2d 1025 (D. Kan. 2004).
58 Id. at 1029 (noting that the model satisfied meeting the Kumho Tire Co. v. Carmichael, 526 U.S. 137 (1999) and Sawyer v. Southwest Airlines Co., 243 F.Supp. 2d 1257, 1266 (D.Kan. 2003) evidentiary requirements because it relied upon generally accepted techniques).
59 State ex. rel. Post v. Speck, 2006 WL 3477024 (Ohio Ct. App. 2006).
60 Sierra Club v. U.S. Army Corps of Engineers, 494 F.Supp. 2d 1090 (W.D. Mo. 2007).
61 Transmissivity is the volume of water flowing through a specified cross-sectional area in an aquifer under a specified head. It is a measure of the permeability of the aquifer.
62 Citizens for Alternatives to Radioactive Dumping v. U.S. Dept. of Energy, 485 F.3d 1091, 1100 (10th Cir. 2007).
63 See State of Wash. v. Bodman, 35 Envtl. L. Rep. 20 (E.D. Wash 2005).

Similarly, the use of models may arise in nuisance claims over the contamination of groundwater. In a case involving the impairment of New Mexico's interest in groundwater, an expert was consulted regarding a plume of contamination within a groundwater aquifer and the court opinion detailed particular steps involved in developing an accurate groundwater contamination model and acceptable data requirements.[64]

However, merely pointing out flaws in a methodology may not be sufficient to win in such cases. In the case where a plaintiff was attempting to prove hydrological connections and pollutant migration between a landfill and a well, a court found that an expert's allegations of methodological flaws were insufficient to rebut the hydrological conclusions of a plaintiff's expert witness.[65]

8. LAND USE AND ITS IMPACT ON WATER FLOW

a. Zoning and Special Use Permits

The connection between surface structures and groundwater often requires the use of sound modeling techniques to prevent development from unduly impacting water resources or flows. As understanding of hydrological connections has increased, parties have introduced modeling as an evidentiary tool in zoning cases. In *Greenwood v. Mayor and Tp. Committee of Tp. of Hopewell*, plaintiffs challenged a zoning decision to prevent development.[66] However, in response to the challenge, the regulators provided an expert witness who used two types of models to show that the recharge of aquifers depended upon the types and amount of surface development and that the planned building would minimally impact aquifer recharge. The plaintiffs did not rebut the expert hydrology testimony and suffered accordingly.

Modeling may also be presented as evidence when applicants seek either zoning changes or conditional use permits. For example, in *Wagner v. Miami City Board of Zoning Appeals*, the court determined that it was not unreasonable to deny a conditional permit even though a hydrologist's study concluded that no irreparable harm would result to surrounding groundwater wells if a stone quarry was allowed to operate.[67] Whether or not a party has satisfied the conditions of a permit may also involve hydrologic modeling. For example, in *Alaska Center,* a court was asked to review the sufficiency of an Army Corps of Engineers methodology it used to study anticipated environmental impacts. The court found that the Army Corps had satisified the condition that a proposed project demonstrate minimal environmental effects because the Corps' wetlands impact analysis accounted for hydrology, habitat, species occurrence and social function.[68]

Special use permit challenges also provide an opportunity for hydrological modeling in the courtroom. Special use permits are typically required for extractive industries, and certain activities may require proof of minimal hydrologic impact. In *Quality Rock Products, Inc. v. Thurston County*, a mining company sought to overturn a special use permit denial by county commissioners for a proposed gravel mine adjacent to a national wildlife refuge.[69] The mining company's expert hydrologist applied a model to address concerns about the effects that the proposed aggregate water extraction would have on ground and surface water levels. The court did not address the adequacy of the model because the county's hydrologist did not oppose the model's results.

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64 New Mexico, supra note 38, at 1278 (expert used historic single-year data to develop ground transport models to determine the movement of contaminated water over a period of time. The expert used MODFLOW 9See Appendix A), the USGS standard. Defendants attacked the modeling by comparing the actual observations with predicted values and ultimately the court rejected the introduction of evidence on relevance grounds despite a vigorous discussion of reliability under FRE 702).

65 MSOF Corp. v. Exxon Corp., 934 So. 2d 708, 720 (La. App. 1st Cir. 2005).

66 Greenwood v. Mayor and Tp. Comm. of Tp. of Hopewell, WL 3462431 (N.J. Super. A.D. 2008).

67 Wagner v. Miami City Board of Zoning Appeals, 2005 WL 678943 (Ohio Ct. App. 2005).

68 Alaska Center, 157 F.3d at 684-85; see also Wyoming Outdoor, 351 F.Supp.2d at 1254, n. 11 – taken from Sierra Club v. Army Corps, 464 F. Supp. 2d. 1171 (M.D. Fla. 2006).

69 Quality Rock Products, Inc. v. Thurston County, 159 P.3d 1, 1-4 (Wash. Ct. App. 2007)

Courts have found that where a political entity denies a permit for political reasons rather than on scientific principles (and the use of hydrologic models), the denial may result in a breach of a good faith obligation. For example, in one case a court was asked to determine if the State of Nebraska had breached its duties under a five-state compact when it denied a permit for a nuclear waste disposal project by dismissing results or cherry-picking scientific models to support its desired outcome. The court noted that three separate models were developed to determine a proposed waste facility's impact on groundwater, but that the State of Nebraska had based its decision to deny a project permit on the results of the least scientifically acceptable model. As a result, the court found Nebraska had willfully rendered incomplete performance under the Central Interstate Low-Level Radioactive Waste Compact by dismissing the results of the two superior models which showed no groundwater impacts.[70]

Finally, as will be discussed in Section VI, more than a facial challenge to the model is required if a party objects to modeling results. In one case, the sufficiency of a drainage model required for submission prior to approval by a Community Planning Commission for any new subdivisions was challenged. In responding to the model, the appellants merely stated that the "hydrologic model used to evaluate the effectiveness of detention basins is inadequate.. This argument was deemed insufficient to warrant a summary judgment in favor of defendants because the court was unable to identify any statutory language that required a particular modeling methodology to be used.[71]

b. Takings Claims

Modeling is also seen in eminent domain claims for flooded lands. Normally, the government's ability to flood land for the purpose of navigation under the navigable servitude is limited to the ordinary high water mark.[72] Aside from this power, however, government reclamation and flood control projects may be the cause of new flooding. Such a case occurred in *Alost v. United States*, where the court determined that a plaintiff's unscientifically substantiated claim was contradicted by a government expert hydrologist. In this case, the expert applied the HEC-RAS model to determine that the frequency and duration of flooding impacting the plaintiff was due to preexisting conditions and not a result of any government flood control projects. In light of the plaintiff's failure to provide expert testimony based on competent modeling, the court ruled for the government.

Furthermore, in a drainage district's claim that erosion and increased standing water was caused by the improper maintenance of a levee and channel system in the upper stretch of the Mississippi River, defendants employed an expert to show that excess water was creating crop loss and the impacts of the improper maintenance could have been reasonably ascertaine. prior to the running of the statute of limitations.[73] The expert used a computer model to determine the exact cause of excess wetness in farm fields. The court found that historic physical observations and the model showed that excessively wet conditions had existed in the district for an extensive time. Thus, the claim had accrued and the statute of limitations time began to run and subsequently expire well before the claim was brought.

70 Entergy Arkansas, Inc. v. Nebraska, 358 F.3d 528 (8th Cir. 2004).
71 Sanara Realty v. Hayden, 2004 WL 1485968, at 5 (Mass. Land Ct. 2004).
72 Alost v. United States, 73 Fed. Cl. 480 (Fed. Cl. 2006) (citing United States v. Kansas City Life Ins. Co., 339 U.S. 799 (1950)).
73 Henderson County Drainage Dist. No. 3 v. U.S., 60 Fed. Cl. 748 (Fed. Cl. 2004).

9. ENDANGERED SPECIES ACT (ESA) AND FEDERAL LAND MANAGEMENT

Over the last thirty years, increasing awareness of environmental concerns and the inherent value of riparian environments has lead to the passage of federal and state legislation that explicitly or implicitly requires minimum water quality or quantities to protect ecosystem resources and habitat. It is the responsibility of governmental agencies to ensure the amount and source of such water is protected from degradation or improper use. In part, judicial deference is generally given to agency decisions because a court lacks the expertise and/or background in fish biology, hydrology, hydraulic engineering, or water project management necessary to make an informed decision that will conform to legislative intent. Additionally, courts defer to agency expertise because Constitutionally mandated separation of powers requires that an agency be able to perform its legal, statutorily granted powers with minimal judicial interference.

a. Water Quantity

Many cases involving the ESA center on the fact that an agency issuing a biological opinion under the ESA must use the best available scientific information available and mus. "carefully examine the available scientific data and models and rationally chose the most reliable."[74] Even if a model withstands a facial challenge, many times the sufficiency of input data used in the model will be attacked. In *NRDC v. Kempthorne,* an operating plan and flow models used as a basis for agency decisions on operating and managing water in the Central Valley Project and California State Water Project were challenged in the context of the sufficiency of a Biological Opinion (BO). Here, the computer model CALSIM II was used to establish take limits for delta smelt in a variety of data conditions such as wet/dry years and under varying assumptions of future project operations.[75] The court found that the agency failed to use recent data suggesting that smelt levels were at record low levels. In addition, the court found that a failure to consider impact of climate change in models was arbitrary and capricious under the APA because the BO considered only historical flow data.

In some cases, hydrological models are also used to predict water quality and temperature and to ensure that habitat conditions are sufficient to meet ESA requirements for population health. Such was the case in *Pacific Coast Federation of Fisherman's Associations v. Gutierrez*, where plaintiffs sought temporary injunctive relief against water management plans by California's two largest water projects in order to prevent jeopardizing endangered and threatened salmon species or their habitat.[76]

Likewise, agricultural users dependent upon Central Valley Project water challenged Bureau of Reclamation water release plans that were meant to satisfy water users as well as improve wildlife and fish habitat in the Central Valley as required under the Central Valley Project Improvement Act.[77] Agricultural concerns focused on the high salinity content of releases and the court found that the model provided by the Bureau of Reclamation showed the potential for a credible threat of harm to the farmers.

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74 Natural Resources Defense Council v. Kempthorne, 506 F.Supp. 2d 322, 330 (E.D. Cal. 2007).
75 Id. at 370.
76 Pacific Coast Fed'n of Fisherman's Ass'n v. Gutierrez, 2008 WL 2851568 (E.D. Cal. 2008).
77 Central Delta Water Agency v. Bureau of Reclamation, 452 F.3d 1021 (9th Cir. 2006).

b. Water Quality

As mentioned previously, forest plans are also tied to hydrological models, and challenges to forest plans required by the National Forest Management Act (NFMA) can often involve the question of model sufficiency. Without a competing model to suggest that a federal agency has made incorrect calculations or conclusions, there will be little factual basis to challenge Forest Service plans. While modeling data must be sufficient to inform a model, it need only be reasonably current. One case examined whether forest plans needed to be backed up by on-site observations such as soil composition and drainage characteristics of individual locations within a watershed.[78] Reviewing courts determined that an agency has broad authority to choose a modeling methodology and that data input did not need to be extremely specific or detailed to support a Forest Service plan or decision.[79]

In *High Sierra Hiker's Ass'n v. Moore*, while the court did not specifically address hydrological modeling, it did require that forest plans prohibit the presence of pack animals during certain seasonal times where the Yosemite Toad was threatened by poor water quality resulting from the pack animals' presence.[80] In this case, visual observations of the pack animals' impact upon water quality was sufficient to inform an agency decision, although in future cases modeling may assist to demonstrate less apparent connections between an activity and water quality.

c. Water Management

Within the realm of water management decisionmaking, an agency may use a limited model with incomplete data in an attempt to prevent harm to an endangered species. The implementation of a water management plan and Congressionally authorized programs meant to balance a multitude of water-needs were found satisfactory even under these conditions. In *Miccosukee Tribe of Indians of Fla. v. United States*, the court found that the Army Corps of Engineers did not act arbitrarily or capriciously when it acted without extensive modeling data on a particular NEPA EIS alternative when a deferred decision would have likely posed "potential negative impacts on critical habitat" of an endangered sparrow.[81]

Recent concerns over depleting Chinook salmon runs and delta smelt in California have been a fertile legal ground for conflicting water models. In *Tulare Lake Basin Storage Dist. v. United States,* county water districts sued the federal government for reductions it imposed upon the California water system in order to meet ESA obligations.[82] The court was faced with determining the amount of water denied the plaintiffs as a result of the ESA requirements. Under existing contracts the counties and districts were entitled to a percentage of available waters, and the court examined conflicting models of available water absent the reduced releases for ESA purposes.

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78 Lands Council v. Powell, 395 F.3d 1019 (9th Cir. 2005).
79 See The Lands Council v. McNair, 2008 WL 2640001 (9th Cir. 2008).
80 High Sierra Hiker's Ass'n v. Moore, 2008 WL 2025012 (N.D.Cal. 2008).
81 Miccosukee Tribe of Indians of FL v. U.S., 420 F.Supp. 2d 1324, 1337 (S.D. Fl. 2006).
82 Tulare Lake Basin Storage Dist. v. U.S, 59 Fed. Cl. 246 (Fed. Cl. 2003) (liability for taking determined in Tulare Lake Basin Storage v. U.S., 49 Fed. Cl. 313 (Fed. Cl. 2001)).

10. TRIBAL AND FEDERAL RESERVED WATER RIGHTS

Congress has often reserved lands in the public domain for specific purposes, but the reservation of the water "expressly reserved... for use on these withdrawn lands"[83] is rarely identified or quantified. As a result, the quantification of these reserved water rights has become a significant source of litigation as competition increases over limited water supplies. The courts have long recognized Congress' ability to withdraw public land for use "as Indian reservations, forest reserves, national parks, and national monuments,"[84] and the related power to reserve the water rights necessary to achieve the purpose for which the lands were reserved. Where Congress has given the President the ability to reserve lands, it has also granted the power to reserve unappropriated water "to the extent needed to accomplish the purpose of the reservation."[85] Those water rights vest as of the date of the reservation.[86]

The quantification of federally reserved tribal water rights often leads to intense litigation because those rights tend to be characterized by early priority dates and relatively large amounts of water. In Winters v. United States, the seminal case for federal reserved tribal water, the Supreme Court made clear that the quantity of impliedly reserved water rights must be sufficient to accomplish the purposes of the reservation.[87] Models and supporting data sets used to quantify these historical water rights for specific purposes have given tribes a scientific basis for their claims.[88] Disputes over reserved tribal water rights claims are ongoing and affect a number of Western rivers. When specific quantities of water are adjudicated, state courts are often the arena in which the issues are played out, the federal courts having deferred to them in most instances.[89]

11. CONCLUSION

As the preceding sections have demonstrated, hydrological models play an important role in a variety of water disputes throughout federal and state jurisdictions: adjudications, change requests, challenges to government actions, nuisance actions, takings claims, pollution regulation, and others. The equitable resolution of these disputes may certainly benefit from hydrologic modeling evidence in the courtroom. Because of the increasing role and potential benefits of water models in litigation, the judicial community must be conversant in the benefits and limitations of existing hydrologic modeling. The next section describes what a hydrological model looks like and examines the basic characteristics every model should exhibit to adequately describe any hydrologic system.

83 Cappaert v. United States, 426 U.S. 128, 138 (1976).
84 United States v. New Mexico, 438 U.S. 696 (1978).
85 Cappaert, supra note 83, at 138.
86 Id.
87 Generally see Winters v. United States, 207 U.S. 564 (1908); Cappaert, supra note 83.
88 In Montana's Milk River drainage a complex database has been developed as part of a state-wide general stream adjudication to determine Fort Belknap reserved water quantities. Barbara Cosens, The Role of Hydrology in the Resolution of Water Disputes, 133 J. of Contemp. Water Research & Educ. 17, available at http://www.ucowr.siu.edu/updates/133/4.pdf.
89 Cappaert, supra note 83, at 146-47.

SECTION II
PROOF PROBLEMS IN LAWSUITS INVOLVING HYDROLOGY

1. SYSTEM DESCRIPTION

In order to make a legal claim that can be substantiated in the context of a hydrologic system, the system must be adequately described in terms of the components that comprise it, the relationships among the components, and the interactions among them in both space and time. We can easily grasp the nature of a simple system, e.g., pouring water from a pitcher into a glass. However, in a slightly more complex system we must resort to more advanced means to identify, describe, and interrelate the system's components.

Some straightforward examples illustrate this somewhat more challenging task. Figures II.1 and II.2 are systems that can be easily described – tanks connected by pipes – and whose interactions can also be easily described. In the case of the first figure (HS1), there are three components: Tank A, Tank B, and Pipe C. Tank A is located at an elevation above Tank B and the two tanks are connected by Pipe C. If water is poured into Tank A it will flow, by gravity, through Pipe C into Tank B. The rate at which water flows from A to B depends on: 1) the rate at which it is poured into A; and 2) on the size (diameter) of Pipe C. When no more water is being poured into Tank A, water will continue to flow to Tank B until Tank A empties. The amount of water in Tank B will depend on how much water has been poured into Tank A. If a volume of water less than the capacity of Tank B is poured, the tank will be partially full. If a volume equal to or greater than the capacity of Tank B is poured, then the tank will be full and in the latter case will have spilled. Given the arrangement of the tanks – Tank A above Tank B – water can never be made to flow, by gravity, from B to A. The system is at equilibrium when A is empty, B is either full or partly full, and no water is flowing in C.

In the case of Figure II.2 (HS2), the system is very similar to the first, i.e., two tanks connected by a pipe. The primary difference in this case is that the tanks are at the same elevation – one is not above the other. Note also that the pipe connecting the tanks is slightly above the bottom of the tanks and is not inclined from Tank A to Tank B. Nonetheless, there are circumstances under which water will flow from one tank to the other. If water is poured into Tank A, when enough water is in the tank to reach the level of the pipe, it will begin to flow until the surface elevation of water in Tank A is the same as it is in Tank B. Again, the rate at which water flows from A to B depends on: 1) the rate of pour into A; and 2) on the diameter of C. (The indication of water surface elevations in the figure with the label "Possible surface elevation difference before equilibrium" is meant to indicate a condition that can occur only when water is being poured into Tank A). But in this second case, the rate also depends on something else that was not a consideration in HS1, the difference in the surface elevation of the water in A and B. All other things being equal, the greater the elevation difference, the greater the rate of flow.

Water will stop flowing from A to B when the levels in the two tanks are the same (i.e., the equilibrium condition) and the amount of water that flows from A to B will depend not only on the amount of water poured into A, but also on the diameters of A and B. If the diameters are the same, half the water poured into A after the water in A reaches the bottom of the pipe will flow into B and half will remain in A. If B has a larger diameter, more than half the water will flow, because it will take more than half to maintain the same surface elevations in both tanks. Similarly, the opposite is true. If A has a larger diameter than B, less than half the water will pass into B. Unlike the first example, A will never be empty unless B is empty.[90] Also unlike HS1, water can be made to flow from B into A either by pouring water into B or by pumping water from A. The system is at equilibrium when water levels in A and B are the same.

HS1 and HS2, with only three components (A, B, and C), can be described in detail with a few pieces of data and relatively simple mathematical expressions. All the components can be identified, their relationships understood, and the reaction to "inputs" (i.e., management actions, pouring or pumping water) described and accurately predicted. In short, they can be modeled.

FIGURES II.1 AND II.2

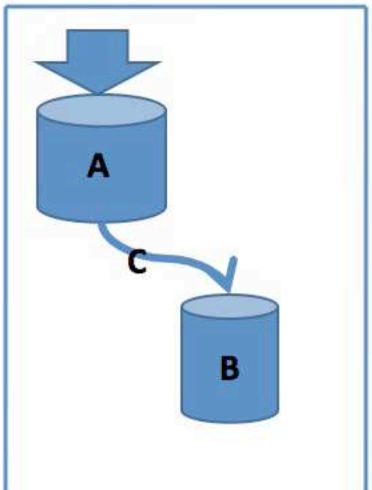


Figure II.1. Hydrologic System One (HS1)

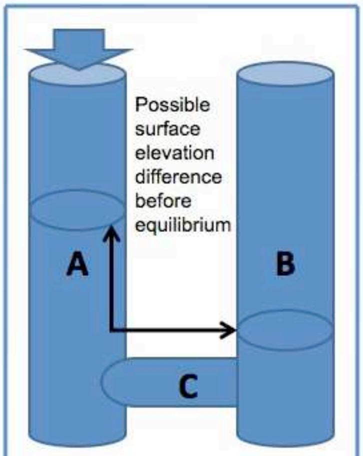


Figure II.2. Hydrologic System Two (HS2)

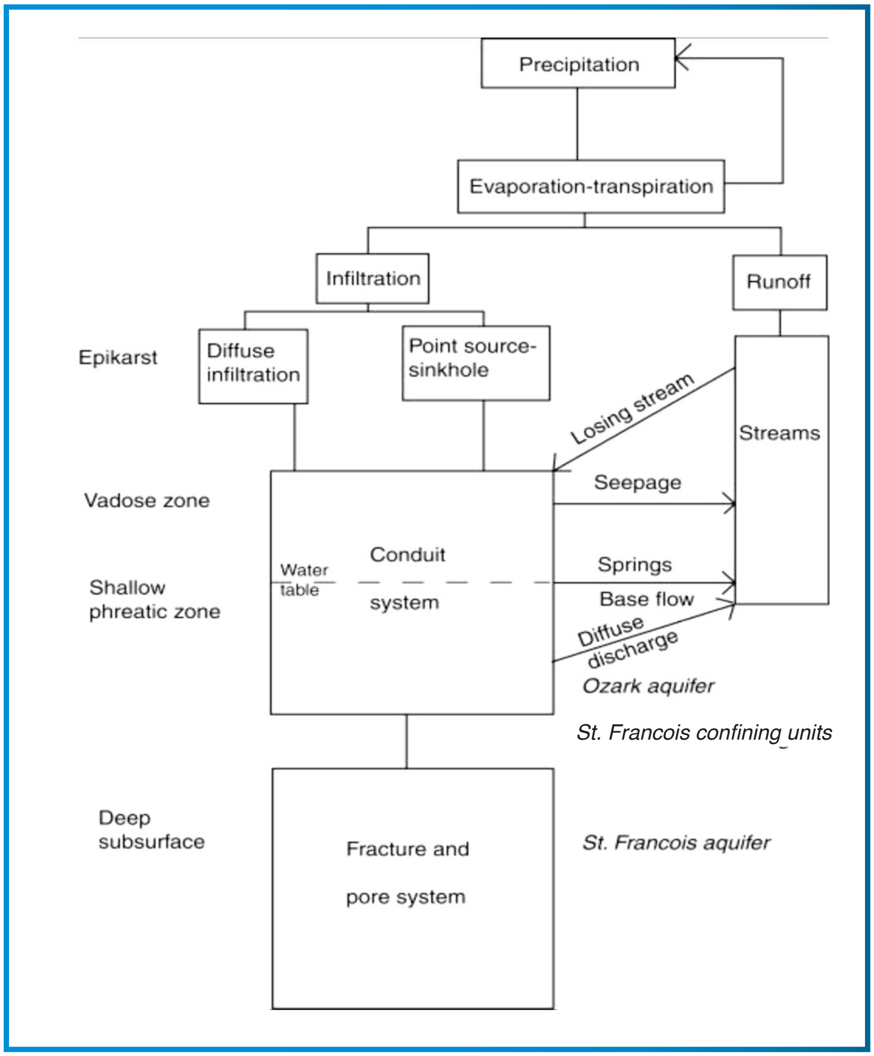
As systems become more complex, descriptive and analytic challenges increase. The mere process of identifying essential components can be very difficult and the process of moving from identification to system description and ultimately to the quantification of interactions and the prediction of changes becomes significantly more daunting.

In practice, natural hydrologic systems are inherently complex. An example of such a complex system that contains both surface and groundwater components that interact with each other and that are affected and influenced by the hydrologic cycle (precipitation and evaporation) is shown in Figure II.3. Systems like this can rarely be described in simple terms, nor can their behavior be predicted with anything less than a computer-based hydrologic simulation model (see Section IV. Model Development).

90 There are some exceptions to this rule that depend on the elevation of Pipe C.

In complex hydrologic systems the task of attempting to establish the behavior features of the system is rarely performed without a simulation model. Furthermore, the complexity of the system is magnified by the fact that in almost all circumstances, certain "inputs" to the system[91] like river flows and precipitation are not predictable with any certainty and must be treated probabilistically (discussed in more detail in Section III). The following parts of this section will outline ways to establish causal links, quantify effects, and estimate the timing of these effects (i.e., forecasting).

FIGURES II.3. Example of a Complex Hydrologic System (from USGS)



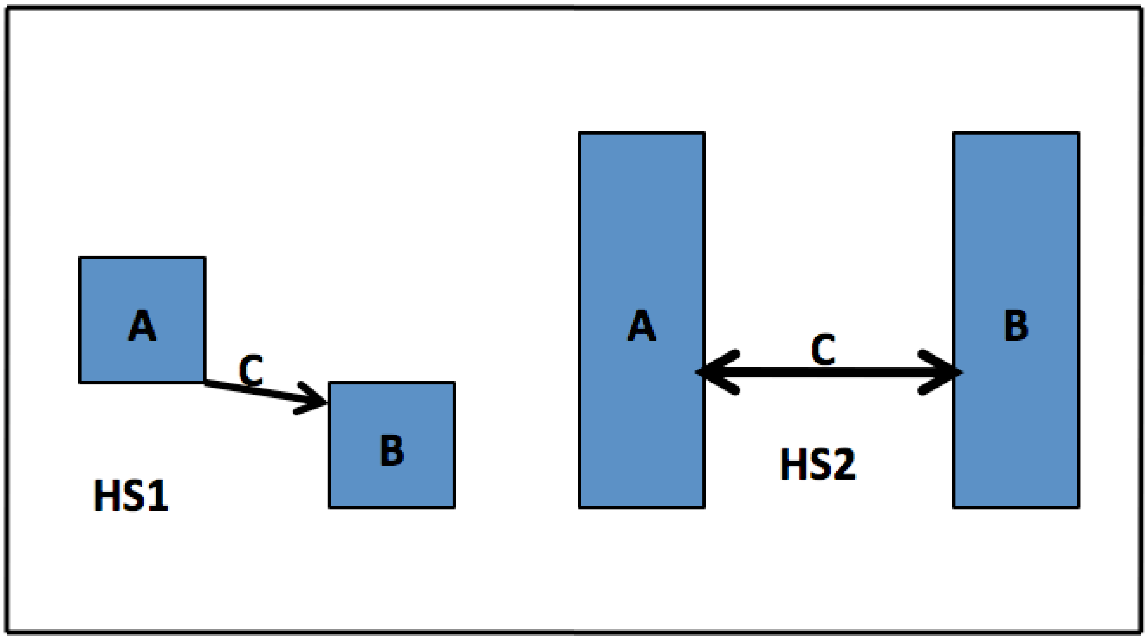
2. ESTABLISHING THE CAUSAL CONNECTIONS (OR LINKS) AMONG SYSTEM COMPONENTS

Once the system's components have been identified and described, the next step in establishing causal connections among components (i.e., the paths or links by which components interact with each other) involves describing the relationships among these components. For example in Figure II.3, the arrows labeled "Diffuse discharge," "Springs Base flow," "Seepage," and "Losing stream" are links between the shallow aquifer (the box labeled "Conduit system") and the surface water streams (labeled "Streams"). These links illustrate, in a conceptual way, how the shallow aquifer and the surface water streams interact. In other words, water flows via certain paths and mechanisms from the aquifer to the stream (or streams) and conversely through alternative paths and mechanisms from the stream (or streams) to the aquifer.

91 "Inputs" to a hydrologic system can be natural phenomena like flows and precipitation or management actions like dam releases, well pumping, and water diversions.

This step (or stage) in the process (discussed in detail in Section IV) is merely conceptual and descriptive. System links are identified and their functions (e.g., linking elements by means of the flow of water) illustrated in a very elementary way. To refer back to the simple systems (HS1 and HS2), in both instances Tank A is linked to Tank B by means of Pipe C (a link that carries water between the tanks). However, if we were to draw elementary schematic figures of the two systems, we would do it in such way that we illustrated the nature of the relationship between the tanks in each system and the function of the link. As Figure II.4 below illustrates, in HS1 Tank A is above Tank B and the link between the two, Pipe C, can carry water in only one direction, whereas in HS2, Tanks A and B are on the same level and Pipe C can carry water in either direction.

FIGURE II.4. **HS1 and HS2 Schematics**



This very simple example obscures the complications that a real hydrologic system presents (e.g., Figure II.3). In practice, a substantial amount of data may be necessary to advance even to this modest level. The identification of components and the description of causal connections are not trivial steps.

3. QUANTIFICATION OF SYSTEM BEHAVIOR AND THE EFFECTS THAT COMPONENTS AND CONNECTIONS HAVE ON EACH OTHER

The measurements, physical features, and mathematically described behavior of the system components and connections, their initial states, and boundary conditions are the essential elements for calculating the quantification of behavior and effects. This quantification process involves both the specification, in explicit quantitative terms, of the components of the system and of the links among them. It requires describing dimensions, boundaries, and physical features of the components (e.g., size of Tank A, dimensions of an aquifer, length and cross-sectional area of a river, location and size of a reservoir) and additional features that may affect behavior (e.g., aquifer material [sand, clay, gravel], river gradient and roughness).

The same must be done for the connections in the system – a complete description of physical features and characteristics that affect their performance (e.g., the diameter, length, roughness, and slope of Pipe C, nature of soils through which precipitation infiltrates to an aquifer) and the mathematical rendering of their behavior.
Once a system and its features are defined and described, the initial conditions (i.e., the state in which the system starts)

and boundary conditions (i.e., the situation at the periphery of the system) must be specified in quantitative terms. For example, the initial condition for Tank A in HS1 must be that it is empty, because any water in A will immediately flow to B. In HS2, Tank A may have an initial condition at any surface water level (e.g., it might contain one gallon of water and is half full), but at whatever initial level defines it initial condition, the same surface water elevation condition must be defined for Tank B. A boundary condition for Tank A might be that it does not leak – no water escapes though its walls. In an actual hydrologic system, some initial and boundary conditions may be easily specified (e.g., volume of water in a reservoir, the geographic limits of a watershed). Others may be very difficult to precisely quantify or specify exactly (e.g., volume of water in an aquifer and the limits of the aquifer), requiring certain simplifying assumptions about these conditions.

The quantitative and physical description of components and the mathematical specification of system connections, initial states of components and connections, and boundary conditions are the basis for the quantification of behavior and effects. These activities are a necessary precursor to describing quantitatively what occurs when a complex hydrologic system is subjected to some natural or manmade input, perturbation or disturbance. As mentioned above, inputs might be such things as pouring water into Tank A, precipitation in the system in Figure II.3, the release of water from a reservoir, or pumping a well in an aquifer. The modeling process is the calculation of the magnitude and timing of effects caused by inputs or disturbances.

4. MAGNITUDE AND TIMING OF EFFECTS (PREDICTION AND FORECASTING)

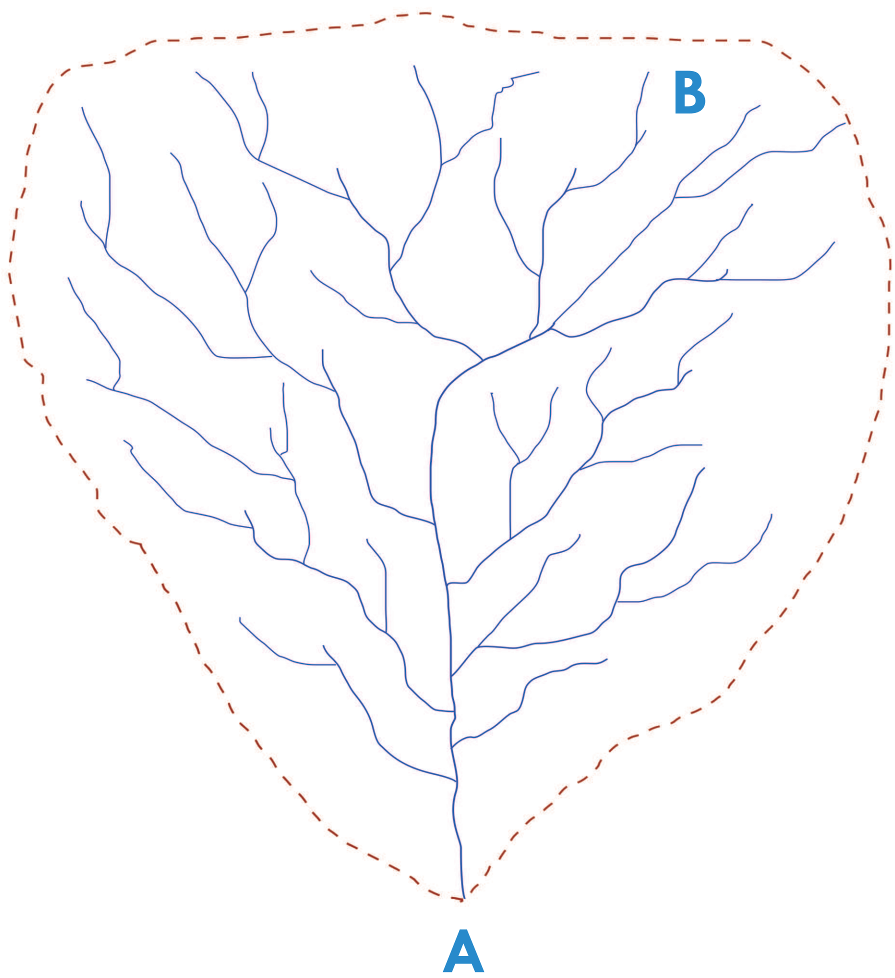
Calculating the magnitude and predicting the timing of the effects of a natural or manmade disturbance to a hydrologic system is the ultimate step in the process of constructing a computer based model, i.e., the core for specifying the dynamics of the system and establishing how a system behaves. For example, in HS1, it is possible to predict the rate at which Tank B will fill by knowing: 1) the physical dimensions of Tank A and specifying the initial condition that Tank A always starts empty; 2) the diameter and length of Pipe C; 3) the dimensions of Tank B; and 4) the rate at which water is poured into Tank A.

As a less abstract example, consider the schematic of a watershed depicted in Figure II.5. It has the appearance of a typical drainage system, i.e., it looks like the branches of a tree as the smaller streams at high elevations in the basin merge with larger streams and ultimately converge to a trunk, the largest stream in the basin. If the physical features of the watershed in are adequately defined, the processes linking points A and B are quantified, and rate of precipitation at Point B is given, the magnitude and timing of flow at Point A can be predicted. To modify the example slightly, suppose that rather than precipitation at Point B, there is a reservoir at the location. In that case, the effects of releases from the reservoir on flows at Point A can be calculated and predicted. The example can be taken a step further by considering a case in which there is precipitation over the entire basin and/or several reservoirs in the drainage. The combination of the effects of the precipitation and reservoir operations can be modeled and impacts predicted. This latter example would be very much like a flood routing operation.

To return briefly to the more complicated example depicted in Figure II.3 (the surface and groundwater example), with a complete description of elements of the system and the delineation of their connections and interactions, the effects of precipitation on the aquifers and on stream flow could be calculated and the timing of these outcomes predicted. Without a computer-based hydrologic model this task could not be accomplished.

As we have seen, the fundamentals to understanding a complex hydrologic system include: 1) describing the elements of the system; 2) establishing causal connections; and 3) quantifying system behavior and the effects of components and connections on each other. With these building blocks in place, we have the foundation for calculating the magnitude and predicting the timing of impacts on a hydrologic system that occur as a consequence of a natural or manmade stimulus.

FIGURE II.5. **Example of a Schematic Drawing of a Watershed**



From the text: *This figure has the appearance of a typical drainage system, i.e., it looks like the branches of a tree as the smaller streams at high elevations in the basin merge with larger streams and ultimately converge to a trunk, the largest stream in the basin. If the physical features of the watershed in are adequately defined, the processes linking points A and B are quantified, and rate of precipitation at Point B is given, the magnitude and timing of flow at Point A can be predicted. To modify the example slightly, suppose that rather than precipitation at Point B, there is a reservoir at the location. In that case, the effects of releases from the reservoir on flows at Point A can be calculated and predicted. The example can be taken a step further by considering a case in which there is precipitation over the entire basin and/or several reservoirs in the drainage. The combination of the effects of the precipitation and reservoir operations can be modeled and impacts predicted. This latter example would be very much like a flood routing operation.*

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SECTION III
NECESSITY OF MODELS TO EXPLAIN WATER SYSTEMS AND THEIR BEHAVIOR

Computer-based hydrological models have proven helpful, in fact essential, in a variety of water disputes. Complex hydrologic systems (like Figure II.3 in the previous section) require models to describe physical features and their interactions. Furthermore, illuminating and understanding the behavior and interaction of components (i.e., physical features) are rarely accomplished without models. Models also make it possible to account for natural meteorologic and hydrologic variability by "operating" systems over long periods of time, based either on the existing historic record or on synthetically generated hydrologic data[92], and thereby introducing the unpredictability of wet and dry periods (floods and droughts) into the descriptions and analyses of systems.

Models also can be used to recreate (or reconstruct) historic conditions (or pseudo-historic conditions, i.e., conditions that might have prevailed if certain intervening actions had not been taken) to examine the relationship between past management actions, hydrology, and present conditions. Models may also make it possible to project the consequences of future management actions, based on the assumption that forecasts of hydrologic conditions can be made using the historic record or by generating synthetic flow sequences that build in assumptions about past and future hydrologic conditions. Finally, computer-based models make it possible to compare the consequences of a variety of management actions and hydrologic assumptions on a complex hydrologic system.

92 Synthetically generated hydrologic data are hydrologic record entries created by mathematical routines that incorporate the statistics of actual flows (e.g., means, variances, temporal and spatial correlations, and so on) combined with a random input factor (often called a random number generator) to construct flow sequences that are statistically similar to, though usually longer or more complete than, the historic record. (The history and development of synthetic hydrology is described in some detail in A. Maass et al., Design of Water-Resource Systems: New Techniques for Relating Economic Objectives, Engineering Analysis, and Government Policy (1962). A variation on the standard synthetic record would involve modifying the statistics of an actual record (e.g., reducing means) to create a synthetic record that would allow a model to estimate the consequences of a specific hypothesis about changes in future flow patterns. Another variation uses tree-ring data in conjunction with flow gage data to construct a statistical relationship (usually a linear regression model) between tree-rings and measured flows. A long historic flow record can then be constructed using tree-ring chronologies to estimate past flows. (See, e.g., David Meko and Donald A. Graybill, Tree-ring reconstruction of Upper Gila River discharge, 31 Water Res. Bull. 4, 605-616 (1995)).

The following paragraphs describe first some of the complexities of natural systems, the behavior of these systems, and hydrologic variability. The remainder of the section then discusses the roles of models in recreating the past and in predictive/comparative analyses of possible future management actions.

1. COMPLEXITY OF PHYSICAL FEATURES OF HYDROLOGIC SYSTEMS

Descriptions of complex physical systems are rarely sufficient without models. The USGS example (from Section II and reproduced below as Figure III.1) graphically illustrates the kind of challenges presented in portraying complex hydrologic systems. The nature of this challenge was perhaps best summarized by the special master in the Kansas suit against Colorado (*Kansas v. Colorado*, the case is discussed in Section VIII below). He found that:

> *Modeling the Arkansas River Basin in Colorado is extraordinarily difficult... The modeling effort must represent highly variable river flows over 150 miles... the intervention of a major federal reservoir; storage and releases from numerous large private storage reservoirs; transmountain flows... surface diversions... operating under a priority system... the reuse of all surface flows; ungaged tributary inflows and torrential summer thunder storms; consumptive use of various crops as well as phreatophytes along the river... pumping by upwards of 1000 wells...* [93]

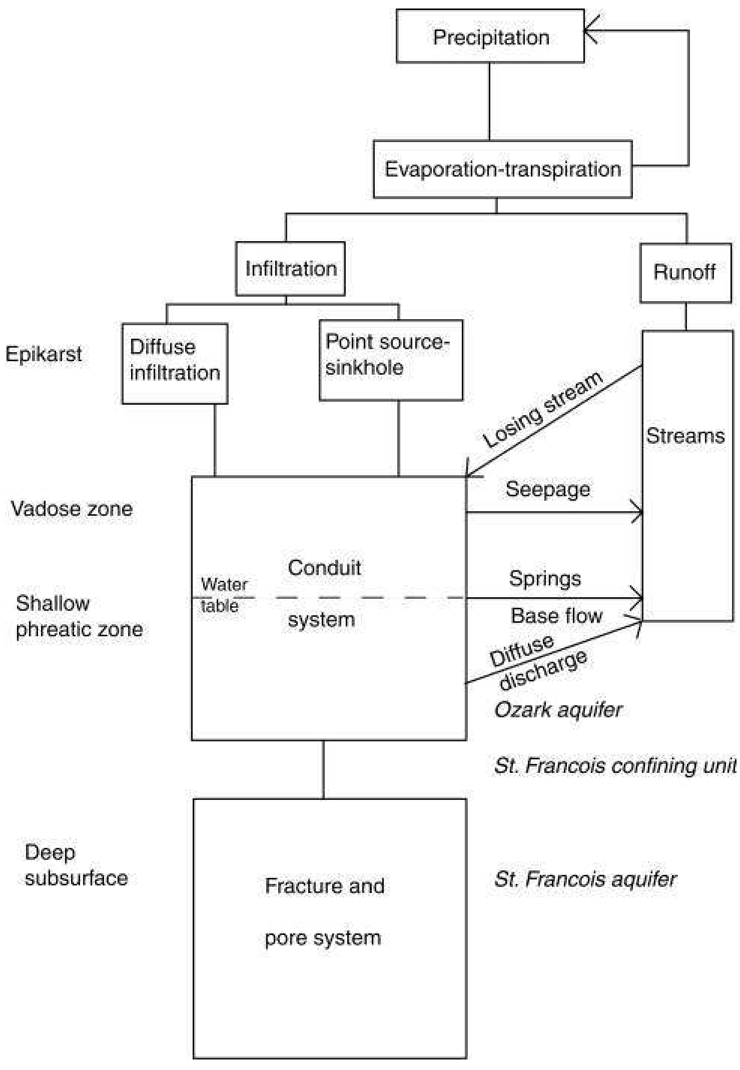
Successful modeling is indispensible to the proper understanding of a system as complex as the Arkansas River. The mere description of the river, its many components (river reaches, reservoirs and diversions), and its connection to the basin's aquifer could not be accomplished without reliance on a computer based hydrologic model.

93 A.L. Littleworth, Fourth Report of the Special Master in Kansas v. Colorado (2003).

2. SYSTEMS COMPLEXITIES

The complexity of hydrologic systems first requires the identification and naming of all related physical components. The USGS example (Figure III.1) exemplifies what is required to describe complex system behavior. In the figure a surface drainage system ("Streams," the large rectangular block on the right side of the figure), a two-part connected groundwater system ("Conduit system" and "Fracture and pore system," the large squares in the middle of the figure), the formation that separates the two ("St. Francois confining unit"), pathways in which the upper groundwater system is connected to the drainage system ("Losing stream," "Seepage," "Springs Base flow," and "Diffuse discharge"), and the water source ("Precipitation" minus "Evaporation-transpiration") are all physical components that require description. Beyond the components themselves the processes linking them together add another layer of complexity. For example, the water source delivers water directly to the "Streams" via runoff and to the upper groundwater system by means of "Infiltration," both "Diffuse infiltration" and "Point source-sinkhole."

FIGURE III.1. USGS Example from Section II



Even without a precipitation event to set things in motion there is probably a more-or-less steady flow of water (likely to be a very small volume varying by season) between and among components. For “Streams” water enters this model component from the upper groundwater system by means of “Seepage,” “Spring Base flow,” and “Diffuse discharge” and water is lost from “Streams” to the upper groundwater system by “Losing stream.. There is also likely to be some movement of water from the upper to the lower groundwater systems. In other words, some parts of the surface drainage system flow with water that, at least in part, comes from the aquifer and some parts of the surface system recharge the aquifer.

Precipitation events initiate even more complex phenomena that engage all of the system components and their linkages and that also involve time, flow variability, and component lag times (e.g., surface flows tend to be at a much higher velocity than subsurface flows). The “no precipitation state” can be thought of as one of equilibrium (or semi-equilibrium); but with the introduction of a precipitation driver, this equilibrium is disturbed and descriptions of system behavior become noticeably more difficult. A proper understanding and description can hardly be achieved without a computer-based hydrological model.

Human intervention with the hydrologic system further complicates matters. For example, if wells were drilled in the upper or lower groundwater basins describing the effects of pumping would introduce complexities that would be difficult, if not impossible, to analyze absent a computer-based model.

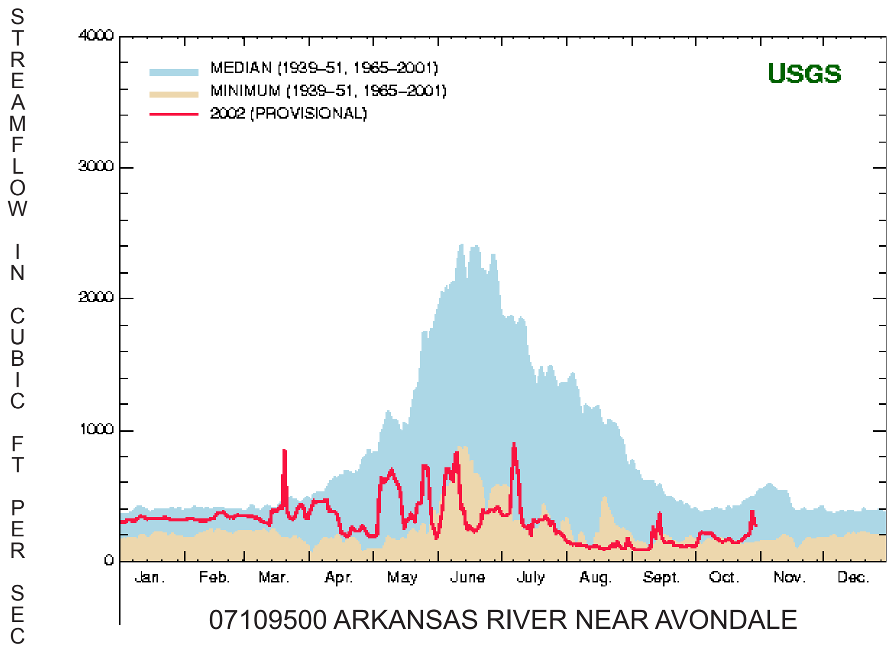
3. NATURAL VARIABILITY OF HYDROLOGY

River flow volumes exhibit substantial swings over time and groundwater systems that are hydraulically linked to surface water sources can vary, too. The primary driving forces for both surface and groundwater hydrologic systems include both direct precipitation and, in most parts of the West, snowmelt in the spring and early summer. Capturing the variability and unpredictability of annual, seasonal, daily, and sometimes even hourly flows is essential to a proper behavioral description.

Natural variability is perhaps best described by the figure below (Figure III.2), a set of hydrographs for a gage on the Arkansas River at Avondale, Colorado.[94] The figure illustrates the typical behavior of a river in the western United States, i.e., low flows from the fall to early spring and moderately high to high flows from mid-spring to late summer.

94 A hydrograph is a graph showing flow, or some characteristic of flow, with respect to time.

FIGURE III.2. **Example of Flow Variability both Within-Year and Between-Year for a USGS Gage on the Arkansas River**



To appreciate what the figure represents and what hydrologic variability means, it is necessary to understand some of the hydrographs' details. The blue shaded hydrograph denotes median flows based on average daily flow measurements expressed in cubic feet per second (cfs) for the years 1939 to 1951 and 1965 to 2001. In other words, on any given date in the combined record of 50 years of data (e.g., the 50 February 1sts in the record) half the average daily flows would have been above 400 cfs and half below 400 cfs. The median maximum average daily flow occurred in earl. June and was approximately 2,400 cfs (six times the average daily flow in February).

The tan hydrograph illustrates minimum average daily flows (also in cfs) for the same years, 1939 to 1951 and 1965 to 2001. The minimum flow hydrograph was constructed by selecting the minimum average daily flow for any given date. Looking at February 1st again, the minimum flow for the 50 year period was approximately 200 cfs. According to the hydrograph, the highest minimum average daily flow occurred in mid-June and was between 800 cfs and 900 cfs.

The red hydrograph plots the average daily flow measurements for the year 2002, a dry year. As the 2002 hydrograph shows, average daily flows in the first half of the year were about half way between the median and the minimum. In the second half of the year the flows were typically less than or near the minimum flows. The composite picture of Arkansas River flows is one of extreme seasonal and year-to-year variability and often unusual event-specific behavior in one given year (e.g., the flow spike in mid-March of 2002).

Note that Figure III.2, by using mean daily flows, ignores the within-day variation in flows which may be substantial at certain times of the year and important in the context of certain water cases and, in using medians and means, does not reflect the full range of flows. Nonetheless, it does demonstrate a range of variability and unpredictability and suggests that capturing this variability and unpredictability is yet another reason that computer-based models are often essential in water cases. The way in which this hydrologic variability is most often depicted is by using, as data inputs to the model, long periods of hydrologic records or by generating hydrologic records that are statistically similar to, but often much longer than, the historic record.

4. RECREATION OF HISTORIC CONDITIONS

There are times when historic conditions may have to be recreated or reconstructed. Instances may arise in which water allocation agreements or rulings are revisited, flow-water quality relationships must be reestablished, or undisturbed aquifer conditions estimated. The reconstruction may require estimating flows on previously ungaged streams or the establishment of water table levels in an aquifer at a time prior to well drilling or groundwater investigations. A more likely case is one in which pseudo-historic conditions (defined above) must be recreated. In the Arkansas Compact case the special master noted that "all of the experts from both states [Kansas and Colorado] have testified that the use of a computer model is the only way to estimate what the river flows would have been in the absence of postcompact pumping."[95] In the Arkansas, estimating "what river flows would have been" was essential to establishing and quantifying Kansas' claim that Colorado's wells violated the compact.

Either case – historic conditions or pseudo-historic conditions – would require the use of a model, the one major difference being that the former would include system modifications (e.g., diversions, dams, wells), operational features (e.g., pumping, transbasin imports), and any other changes (e.g., growth of demand centers like cities or irrigation districts) made between the present and the earlier period of interest. One of the particular challenges in this kind of case is determining when the results are reasonable (e.g., a standard based on professional judgment), since there are no actual data against which to compare computations made by the model. Often little more than a "reasonableness" criterion can be used, i.e., do the recreated "data" fall within an acceptable or believable range.

5. PREDICTION OF FUTURE IMPACTS OF DECISIONS AND MANAGEMENT ACTIONS

Estimating the impacts of future decisions and proposed management actions is the mirror image of recreating historic conditions. Rather than removing system components, operational features, and water use patterns, the model is augmented in such a way that the overall effects of contemplated changes can be estimated. However, before a model is run with changes in place it is usually run in a "base case" (or existing conditions mode, another label for which would be "control conditions") to provide a standard against which to compare the likely impacts of the changes being modeled. This first step is performed because future hydrologic and meteorologic conditions cannot be predicted with any level of detailed certainty, so hydrologic variability and patterns are captured using historic data, generated data, or fabricated data based on a specific underlying assumption (e.g., warming will reduce runoff by X%).

The modified model is then run with the same input data set used in the base case and the differences between the base case and change case are calculated. It is these differences rather than the absolute values that are assumed to offer a reasonable measure of the impacts of future actions. The fundamental working assumption in this kind of comparative analysis is that the hydrologic data (and other input data that are used in the two models) are realistic representations of what might be expected. If this is so, then the differences in the output of the model in its two modes (base case and future conditions case) represent the impacts on the system of contemplated future decisions and management actions.

Figure III.3 below, illustrates this "differences" analysis.[96] Streamflows in the central Platte River in Nebraska, developed by a Platte River computer model, are shown for a base case condition (Present Condition, blue hydrograph) and for a set of proposed management actions (Governance Committee, red hydrograph) placed over a set of targets specified by the U.S. Fish and Wildlife Service (FWS, Average Species and Annual Pulse Flow Targets, black bar hydrograph). The FWS targets were not generated by the computer model, but are included in the figure as a reference to show what future management actions are trying to accomplish or achieve, i.e., getting flows closer to targets than existing conditions.

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95 Littleworth, supra note 93, at 109.

96 U.S. Dept. of Interior, Platte River Recovery Implementation Program: Final Environmental Impact Statement (April 2006) (the figure comes from an environmental impact study of the central Platte River in Nebraska).

FIGURE III.3. **Target Flows & Computer Generated Hydrographs for the Platte River**

In this model, a 48-year hydrologic record from 1947 to 1994 was used for both the Present Condition and the Governance Committee alternatives. River modeling of the two alternatives also required the inclusion of a large number of dams, diversions, return flows, and groundwater recharge activities spanning areas of Wyoming, Colorado, and Nebraska. The base case modeled the system as it currently exists and the future management actions case incorporated planned groundwater recharge projects, a major dam modification, the creation of an environmental storage account in another dam, and a host of smaller projects and management actions.

Note the differences between the Present Condition and Governance Committee hydrographs and how those differences may help decide which alternative will meet modeling goals. The primary question is whether the differences between the alternatives favor the Governance Committee or Present Condition if the objective is to meet the FWS target. The differences between the two are clear in the figure and demonstrate that while the Governance Committee actions do not achieve the targets, they are an improvement over the Present Condition.

6. TIMELY COMPARISON OF ALTERNATIVE ACTIONS AND DECISIONS

Comparison of alternative actions is really an extension of the predictive power of models. Here the hydrologic model is expanded to incorporate more options and operational features and to allow the analyses of a large number of alternatives. The important point to make is that all assessments are done on a comparative basis, with either one alternative compared directly against another or with all alternatives measured against a base case. Of course, when using hydrologic models to examine future actions, absolute values are invariably suspect.

SECTION IV
MODEL DEVELOPMENT

This section will elaborate on some general model features, discuss their construction and data needs, and explain their potential uses that were briefly mentioned in Sections II and III. It will describe: 1) the general features of several kinds of models; 2) the types of errors encountered in modeling and approaches designed to control them; 3) model calibration, verification, and validation/assessment; 4) examples of calibration processes; and 5) sensitivity and uncertainty analysis. The section will conclude with a discussion of opinions on calibration, verification, validation, and model assessment.

1. GENERAL FEATURES OF MODELS

In the context of hydrology, a model is an approximate or simplified representation of a real water system and its behavior. As has been pointed out in earlier sections, computer based models are almost invariably our most effective means for representing complex systems and for estimating the impacts of the interplay of management actions and natural variability on these systems. One the other hand, one important caution is that hydrologic models are fundamentally representations of open environmental systems (i.e., systems that exchange energy and materials with their surroundings) and, as such, are inherently uncertain.

A model is built on an underlying concept of the system being represented. It typically consists of a system “architecture” (e.g., aquifer cells in a groundwater system or nodes and links in the case of a surface water system), equations that reflect the “physical system” (e.g., rainfall-runoff relationship), and/or logical constraints and conditions (and sometimes equations) that delineate the operational (or management) features of the system (e.g., reservoir operating rules, water rights, etc.). One of the most general distinctions between model types is that some represent purely physical systems and others represent system management relationships (more common in surface water systems that simulate the operation of reservoirs). The latter are often called operational, administrative, or institutional models. In practice, most models are hybrids of the two, containing both physical and operational features. Groundwater models are commonly hybrids and are usually referred to as groundwater management models.

A second distinction made between models is the level of detail with which they depict a system. There are basically two types, lumped parameter (a parameter being a constant term in an equation that reflects a relationship) models and distributed parameter models.[97] The former, more popular before the widespread use of digital computers, represents the modeled system with few parameters and functional relationships. The latter represent the system with many discrete, but usually connected, units, each with its own parameter set.

A third type of distinction is often made between "analytic models" and "numerical models."[98] Analytic models incorporate exact solutions to equations that describe the physics of flow and are relatively easy to apply; applications of analytical models are subject to many limiting assumptions such as simple geometry, limited dimensionality, and homogeneity or uniformity of the structure of the system being modeled. Numerical models are approximate solutions to the equations that use the discrete units already described in the paragraph above. These models are not restrictive with respect to geometry, dimensionality, or homogeneity, but can be complicated and expensive to construct. In this benchbook we will be referring almost exclusively to these latter, distributed parameter numerical models.

The performance of a model is best tested against historical data and knowledge to determine if it is a reasonable depiction of the system being simulated. In other words, a model's ability to capture the features and behavior of a system is assessed first on the basis of its capacity to replicate the past. When it is then operated in a predictive or forecasting mode, there will be some uncertainty in the results. The degree of uncertainty is almost always proportional (to some degree) to the number of new conditions and stresses being modeled. These factors dictate that model predictions will have varying degrees of uncertainty. This section will attempt to clarify the import of properly detailing these uncertainties, to suggest appropriate levels of model transparency, and to properly weigh these uncertainties in the context of judicial consideration.

2. MODEL ERRORS AND APPROACHES TO MODEL BUILDING DESIGNED TO CONTROL THEM

Several distinct kinds of errors can be contained within a model. Four of the most important, and the only ones we will refer to here, are coding, specification, discretization, and data. Coding errors (e.g., incorrect units, erroneous logic) persist when a numerical model has not been verified adequately (fully tested against analytical solutions and other established models). A specification error is the incorrect description, usually at the conceptual modeling stage (described below), of the actual physical system to be modeled. In other words, the conceptual model does not adequately correspond the system being modeled). Discretization errors are associated with incorrect compartmentalization of physical systems in time and space during efforts to create model cells or units. As a result, missed or distorted essential features of a real system, e.g., river reaches, aquifer units, or time steps (hours, days, etc.) may lead to inaccuracies in final model outputs. Data error, to the extent that data are used to estimate model parameters, leads to poorly estimated parameters and structural errors in the model's architecture, imprecision in the features of the model itself. Errors in the data that are inputs to the running of the model (e.g., flows, water table elevations in aquifers) amount to operational errors in the modeling. The raw data, such as water levels or flow values, may contain errors or the data, while they may be accurate, might not represent corresponding values in the model well. For example, the water level measured in a well might not be a good representation of the water level in a model cell. The remainder of this section will describe the model building process and several steps designed to reduce three kinds of error – specification, discretization, and data (and parameter estimation).

97 Lumped parameters models are a simplification in mathematical models of relatively homgeneous physical systems where variables and parameters that are spatially distributed fields are represented as single scalars instead. Distributed parameter models are models in which variables and parameters are associated with subdivisions of the model (e.g., grid points, cells, or links and nodes).

98 This can arise in a legal setting because calculations of stream flow depletion from groundwater pumping are sometimes done with analytical models, and regional simulation of groundwater flow is done with numerical models.

A number of authors have suggested model building approaches or modeling protocols.[99] Any modeling method requires translation of the conceptual model into an actual numerical model. This process involves dividing space and time into discrete units (i.e., "discretizing"), assigning boundaries and hydrologic properties, and representing sources of water, paths of movement, and destinations or sinks. Following this process, the model is calibrated to field observations (discussed below) and then used to make predictions. Various authors and professional associations have described this process. For example, the American Society of Testing and Materials (ASTM) has developed guiding standards for groundwater models. One particular ASTM standard uses a flow chart that outlines a sensible sequence of steps and tests for model construction and which is intended to limit errors in the modeling process.[100] This sequence, with modifications, is laid out in Figure IV.1. At the conceptual level, it is a reasonable approach for both groundwater and surface water model development.

The standard ASTM diagram has been modified for purposes of this benchbook to include the addition of "Parameter Estimation" in the box labeled **Model Construction** and "Analysis" in the box labeled **Calibration & Sensitivity** and the insertion of a feedback arrow (shaded) to the **Model Construction** box – an important feature of the calibration process discussed below. The steps in Figure IV.1 from Data Collection through Model Construction, while not necessarily straightforward or inexpensive (especially Data Collection), are reasonably clear and unproblematic. In the literature on model evaluation relatively little time is devoted to them. Rather, it is the interaction of Parameter Estimation and Calibration, and Sensitivity Analysis, that occupies the greatest share of attention. Substantial effort is put into trying to make the model "behave" by comparing its results with data sets and defining or quantifying uncertainty in the model results. Voluminous literature exists on manual and automated methods of accomplishing appropriate adjustments to models. This benchbook will further describe and examine all of the steps in the modeling process depicted in the figure.

3. DATA COLLECTION AND DATA REQUIREMENTS MODEL DEVELOPMENT (BOX A)

Data are a fundamental building block of model development. It can be fairly said that, all other things being equal, data quality and quantity will determine the ability of any computer-based model to simulation, replicate, and represent, in a reasonable way, a physical system. Data collection is the first step in the model building process (See Figure IV.1).

Modeling an aquifer, for example, will require quantitative data on groundwater levels, well locations, pumping measurements, pump test results, aquifer characteristics, geophysical characteristics, and water budget components (inputs like infiltration and recharge and withdrawals like pumping for municipal and agricultural uses, evapotranspiration from native plants, and seepage into surface water systems) of the groundwater system.

Likewise, modeling a surface water system depends on stream flow data, drainage characteristics (e.g., river reach lengths), losses to aquifers and evapotranspiration, reservoirs data (size and operational features), and information on other system management features like points of diversion and return flows. Water budget component data are also needed. In cases where agriculture uses play a large role in a river basin, data on the major ditches in the basin and their use characteristics shoul. be gathered. Data on cropping patterns and overall consumptive use rates should also be included.

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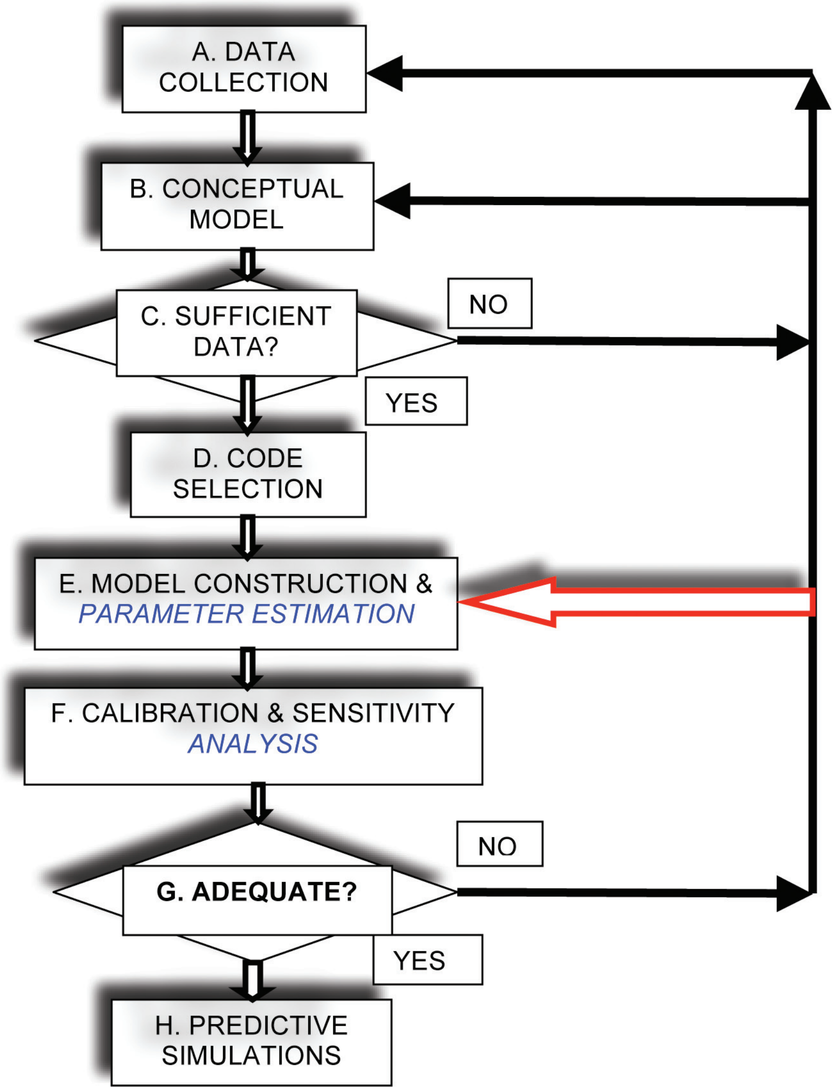
99 See, e.g., Mary P. Anderson & William W. Woessner, Applied Groundwater Modeling – Simulation of Flow and Advective Transport (1992); Thomas.E. Reilly & Arlen. W. Harbaugh, USGS Guidelines for Evaluating Ground-Water Flow Models, Scientific Investigations Report (2004).

100 American Society for Testing and Materials (ASTM), Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem (D 5447-93) [hereinafter ASTM]. The American Society of Civil Engineers (ASCE) also discussed modeling criteria and evaluation. See ASCE Task Committee on Definition of Criteria for Evaluation of Watershed Models, Criteria for Evaluation of Watershed Models, 119 J. Irrig. and Drain. Engr. 429 (1993).

FIGURE IV.1. Flow Chart of Modeling Process from ASTM

A similar, but more elaborate flow chart is presented in Mary P. Anderson and William W. Woessner, Applied Groundwater Modeling, Simulation of Flow and Advective Transport., Eds. Academic Press, Inc. (1992).



Models that seek to mimic the interaction between aquifer and surface water system components additionally require quantitative data on the points and nature of interaction between an aquifer and surface water.

Certain types of model data needs to be updated regularly, other types do not. Data that do not change over time, like that pertaining to aquifer characteristics, geophysical data, and reservoir features, can be prepared from existing databases and current information. Other data that vary over time – generally the hydrologic data pertaining to stream flows and groundwater levels and data associated with changing use patterns – would have to be available for a fairly long period of time (30 years would be close to the lower limit for a relativity simple case and for complex and large basins nothing less than 50 years would be reasonably acceptable).

In complex cases a data management system that allows the model to "communicate" with auxiliary databases may also be necessary. For example, the use of a geographic information systems (GIS) database may be essential to spatially locate and portray data. GIS data might include such things as roads, counties, water districts, hydrologic boundaries, stream gages, climate stations, ditches, canals, wells, and drains.

The United States Geological Survey (USGS) is often an important source of water-related information in the United States. The USGS collects data on stream flows, surface and groundwater quality, and groundwater levels. It publishes data on aquifer characteristics, geophysical properties, and river basin features. Useful publications include water resources investigation reports, open-file reports, water resources bulletins, professional papers, and hydrologic investigations atlases. Reports on particular watershed or system components are also available by state and water year. State engineers offices, state departments of water resources, water utilities, irrigation districts, and special water districts are also reliable sources, as are the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, National Weather Service, National Oceanic and Atmospheric Administration, and the U.S. Environmental Protection Agency. Despite these extensive sources of information developed over the last century, there are many occasions, particularly in the case of aquifers and groundwater systems, when sufficient data are not available and new data must be collected, always a very expensive enterprise.

4. CONCEPTUAL MODEL (BOX B)

There is no one single definition of a conceptual hydrologic model, but it is best thought of as a representation, in abstract and simplified form, of the real world events to be simulated by a computer model. The ASTM describes a conceptual model as "an interpretation or working description of the characteristics and dynamics of the … system."[101] A good conceptual model describes the components of a real system, the general functional relationship among components, the essential features of important hydrologic phenomena, and the principal processes taking place among the system components.

The formulation of a conceptual model creates the basis for simulating surface water and groundwater processes in a basin. At its essence, a conceptual model is a simplified description of the physical components and interactions of surface water and groundwater systems. The purpose of constructing a conceptual model is to simplify the layout and behavior of the system to be modeled and to organize the available data so that the system can be analyzed in a reasonable way. Simplification is necessary because a complete system accounting is impossible because it would require unreasonable expenditures on computing capacity and data collection. The raw data and the conceptual model of a system are the precursors to and the foundation of any effort to develop of a fully formed numerical model.

101 ASTM, supra note 100, at 1.

To be complete, a conceptual model needs to provide:

- A definition of the phenomenon in terms of features recognizable by observations and analysis
- A statement of the controlling physical processes which, in turn, enables the understanding of the proximate factors affecting the mode and rate of change of the phenomena
- Specification of the key hydrologic features that impact the system's dominant hydrologic processes
- Guidance for predicting system behavior

Finally, a conceptual model makes it possible to assess the adequacy of the available data and determine, early in the process, whether further data gathering efforts will be necessary. Developing the conceptual model usually makes it clear whether the data are sufficient to turn the conceptual model into a mathematical computer model (i.e., a fully formed model). If the answer is no or perhaps not (see Box C, the diamond shaped box, in Figure IV.1), then a new round of data collection may be required.

5. CODE SELECTION AND SIMULATION MODEL CONSTRUCTION (BOXES D AND E)

Code selection and model construction, though presented as separate steps in Figure IV.1, have become closely linked activities, thanks largely to the availability of generalized programming packages that have been developed for hydrologic simulations.[102] These programs eliminate the need to develop computer code from the ground up and allow model developers to merely customize existing code. In the last 15 years, federal agencies like the U.S. Bureau of Reclamation (Reclamation), U.S. Army Corps of Engineers, and USGS, either alone or in cooperation with universities or other agencies, have constructed such modeling frameworks. State agencies, universities, and private firms have also been a source of modeling frameworks.[103] Finally, large regional and municipal water utilities have their own models. (Appendix A describes several examples, with at least one from each of the categories mention in this paragraph.)

Existing computer models are distinguished by their principal purpose. Some of the models are primarily quantitative surface water models (e.g., Reclamation's RiverWare model), some are groundwater models (e.g., USGS's MODFLOW model), some are capable of dealing with both surface water and groundwater to some extent (e.g., Hydrosphere's CRAM), and some incorporate features for modeling both water quantity and water quality (e.g., USGS's HSPF). Other models are river basin specific (e.g., Colorado Department of Natural Resources' CRDSS) and some are use or system specific (e.g., Denver Water's PACSIM).

All of these computer models have graphical capabilities that make them user friendly (usually called a graphic user interface or GUI) and that make specific model construction, data and parameter input, and simulation of output relatively easy. However, ready-made code and user-friendly features do not eliminate the fundamental challenges of constructing a model that replicates or simulates an actual hydrologic system to a reasonable degree. These "plug and play" options do not negate the need for the careful model calibration and sensitivity analysis described below.

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102 At one time almost all hydrologic computer models were setting (i.e., a given river basin) and use (i.e., water supply, hydropower, and flood control) specific.

103 Examples of state agencies that have developed modeling frameworks include the California Department of Water Resources (DWR) and the Colorado Department of Natural Resources (DNR) with its series of decision support systems for specific river basins.

6. MODEL CALIBRATION, VERIFICATION, AND VALIDATION/ASSESSMENT (BOX F)

Model calibration is the process of estimating (and adjusting) specific values for parameters (constants) in the model's mathematical equations and algorithms. When applied to hydrologic models, "calibration" is generally defined as the specification and fine-tuning of parameter values within known ranges to simulate a measured state of the flow system, where a measured state is one for which there are actual field data.[104] In general terms, the process of calibration is one of adjusting parameters in such a way that the model results match as closely as possible actually observed historic data ("measured state") for the hydrologic system being modeled.[105]

Once a model is calibrated, it is sometimes rerun using a different field data set (again, actual field data, but usually over a different time period) to test its ability to reasonably represent a system. The modeling literature often uses two terms, "verifications" and "validations," for this phase of model development. This additional history matching step adds credibility to the calibrated model's representation of modeled conditions.[106] In this benchbook we define verification as the process by which a numerical model is tested to insure that it is correctly solving or simulating a given situation. Comparison of model output with the results of analytical solutions and other established numerical models for ranges of parameters likely to be used are important components of model verification.

The second term, validation, often implies a certification that the model can be successfully applied over a defined range of conditions. Rigorous model validation (i.e., simulating a significantly different set of conditions from those used in calibration, without further parameter adjustment) is a crucial and yet often overlooked procedure. Model validation in effect defines the degree of expected confidence that one should have in applying a model to new, untested situations. Model calibration, by its nature, can obfuscate various sources of model error (i.e., two wrongs can make for a right answer). Model validation can be, therefore, an important procedure for establishing model credibility. Model validation can be very challenging, if not impossible, with models that are unavoidably based on incomplete data, and it is sometimes better to view this second process as additional model calibration. (We will discuss this issue in more detail below in the section on Opinions on Calibration, Verification, Validation, and Model Assessment.)

The desired test result in the validation phase is proof of the model's ability to produce results that are close to those of the second set of field measurements. The calibration process, as a whole, might be thought of as a combination of the model teaching phase, the first calibration educating the model about the process it is simulating and the examination phase, verification/validation, testing the model to see what it has learned.

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104 ASTM, Standard Guide for Calibrating a Ground-Water Flow Model Application (D 5981-96), 1, (1996).

105 A very simple example would be a single reservoir model relating inflow, storage, and residence time to outflow where parameters to be estimated and adjusted might include net evaporation per unit surface area and a bank storage factor (that could be positive or negative) related to storage per unit of time. After estimates of the parameters are made, the model based on a mass balance equation (Change is Storage = Inflow – Outflow – Evaporation +/- Bank Storage) is run using historic inflow data. Model results are compared with historic data and, based on the comparison, the parameters are adjusted. Several iterations of this parameter adjustment process may be needed in order to consider calibration complete.

106 The verification/validation phase of model testing depends on having a second data set for the hydrologic system different from the data used in calibrating the model.

a. Examples of Calibration Processes

At this point we will take a moment to summarize a few examples from the extensive literature on methods for model calibration that were mentioned above.[107] The first and most intuitive method is visual comparison of model output data with observed data, plotting both and comparing them. Obvious examples are the plot of a simulated hydrograph against measured streamflows or a comparative map of simulated pumping on aquifer drawdown with actual, physically observed drawdown with pumping. Though useful, complex models may limit the value of this approach and in many instances modelers resort to the use of statistical measures of error.[108] Table IV.1 contains a list of the kinds of criteria (the criteria appear with their mathematical formulae in Appendix B) that are often used or recommended to summarize and assess modeling errors (the difference between observed values and simulated values in the calibration processes).

TABLE IV.1. Examples of Modeling Error Estimates Used in Calibration

Type of Error Measure
Root Mean Square Error
Mean Absolute Error
Maximum Absolute Error
Nash-Sutcliffe Measure
Bias (Mean Error)
Autocorrelation of Error

Examples of representative criteria include mean absolute error, mean error, bias, and correlation among errors. All are designed to give the model builder information on which to base adjustments to parameters.[109] Needless to say, the use of different error measures in the calibration process lead to different parameter estimates.

One further refinement in the calibration process involves the automation of error assessments, parameter adjustment, and further calibration. Mathematical optimization routines have been applied to the operation of parameter adjustment that identify the best combination of parameter adjustments to provide the greatest error reduction in model output (as measured by one of the formulae like those appearing in Table B.1 found in Appendix B).[110]

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107 A helpful summary can be found in C.M. Brendecke, Review of the Kansas Analysis of Colorado Compliance with the Arkansas River Compact 1997-1999 and Prospective Compliance, (April 2002) (on file with author) [herinafter Brendecke].

108 The Republican River Compact case discussed below is a counter example of this. In that instance, the model builders argued that because the model was so complex, the only reasonable means of calibrating it was through the use of visual comparisons of model output against field data.

109 Not discussed here, but a common feature of model construction and calibration, are parameters or conditions that may not have specific physical or operational meaning (sometimes referred to as J-factors or Jesus-factors), but that are made part of the model to improve its operational behavior. See, for example, Brendecke, supra note 107, at 16–18. This issue is discussed below in the context of the Arkansas River.

110 Appendix B contains examples of the calibration process and an explanation of a “mathematical routine” for calibration.

7. SENSITIVITY AND UNCERTAINTY ANALYSIS (BOX F)

As Figure IV.1 makes clear, the model building process is iterative (regularly looping back and making adjustments or corrections). The same technique is applied to the sensitivity analysis phase or the determination of how reactive model output is to changes in parameter values) that is performed in conjunction with calibration. While calibration is the procedure of parameter adjustment to reduce model output error, sensitivity analysis is the process of determining how model results are affected by deliberate and systematic variation in selected parameter values, input data, and other model features.[111] The objective of this analysis is often to determine which parameters, input data, or model features require more attention (data gathering, more careful specification, etc.) to improve model performance.

For example, the sensitivity analysis of a reservoir model might reveal that model output is very responsive to changes in a parameter like net evaporative loss (e.g., a 20 percent change in the parameter results in a comparable or greater percentage changes in output values), but virtually indifferent to changes in bank storage factor estimates. Or as another example, an alluvial groundwater model might be very sensitive to estimates of hydraulic conductivity (a parameter that specifies the ease with which water can more through pore spaces) and very insensitive to surface water infiltration rates. In such cases, this sensitivity analysis information would strongly suggest that more data are needed to improve estimates of net evaporation, in the case of the surface water model, and hydraulic conductivity, in the case of the groundwater model.

The next phase, uncertainty analysis, attempts to compute the expected distribution of output(s) based upon the variability of input parameters and the sensitivity of model output(s) to these input parameters. Uncertainty analysis is more complicated than sensitivity analysis, but is required to ascertain a realistic idea of the expected confidence associated with simulation outcomes.[112] An optimal modeling result (i.e., greatest confidence in simulation outcomes, or minimum output uncertainty) may not involve the most complicated or complex model. Highly complex models often require more complete understandings of system variables. If data are limited in either quantity (i.e., number of points) or quality (i.e., measurement error), then a more complex model may well generate results with greater uncertainty than a simplistic model that uses an average value which can be better defined.[113] Beyond considering only water quantity, the same conceptual tradeoffs exist for water quality modeling.[114]

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111 ASTM, Standard Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application (D 5611-94) (1994).

112 There is no one definition of uncertainty analysis, but in general terms it is an analysis designed to assess the extent to which the variability in an outcome variable is caused by uncertainty at the time of estimating the input parameters of the study.

113 See, for example, D.P. Boyle et al., Towards Improved Streamflow Forecasts; The Value of Semi-Distributed Modeling, 37 Water Res. Research 2749 (2001).

114 See, e.g., John J. Warwick, Interplay between Parameter Uncertainty and Model Aggregation Error, 25 Water Res. Bull. 275 (1989).

8. OPINIONS ON CALIBRATION, VERIFICATION, VALIDATION, AND MODEL ASSESSMENT

Successful calibration, sensitivity analysis, and validation[115] are designed to lead to a model that performs acceptably predictive simulations. The calibration, sensitivity analysis, and validation steps are also fertile ground for disagreement, and arguments over a model's quality often begin right here.[116] In a 1993 paper in **Ground Water**, Bredehoeft and Konikow maintained that the very words calibrate and validate are misleading because they imply veracity (finding the truth?).[117] Their view is that any test of a model can only be used to invalidate it. In their opinion, the most that any modeler can claim is that his or her model can track or match history. In a subsequent editorial in the same journal, Bair counters by using an actual courtroom example. He argues that efforts by one party to the proceeding he cites " [to] provoke a sense of uncertainty about the reliability of all ground water models" was unsuccessful with the jurors because of the "…enormous amount of site-specific data, the skill with which the…expert [for the other party] modeled the flow system, and the recognition that no data were presented that ***invalidated*** [emphasis added] the…model."[118]

The same year of Bredehoeft and Konikow's paper, Oreskes and her colleagues published a paper in **Science** which took a slightly different approach to the question by looking at three model-related concepts – verification, validation, and confirmation.[119] Citing a number of reports and papers, they define the term "verification" as meaning that the *truth* of a model has been demonstrated, something that is only possible in closed systems, systems that do not exchange energy and materials with their surroundings. This definition of "verification" is fundamentally different from that defined above. They then argue that this closed condition can never be met for models of natural systems for a host of reasons, among them the fact that parameters are incompletely known, non-additive properties are scaled up, the measurement of both independent and dependent variables are burdened with inferences and assumptions, and model results are always non-unique. A given set of model results can be produced with more than one formulation of the model and its parameter settings.

Thus, they conclude that the term "verification" cannot be used in association with models of natural systems. They go on to examine the concepts of "confirmation" and "validation" and argue that while models can be partially, but never completely, confirmed (the model results tracking real data) they can never be validated, either in the sense of replicating real world data or as a "good representation of the actual processes occurring in a real system."[120] Their final verdict is that modeling results are only useful in relative terms and that the primary value of models themselves is merely heuristic, useful teaching aids that can be employed to further the understanding of natural systems.

In 1996, after reviewing related literature, including that mentioned above, Woessner and Anderson offered additional insights into inherent modeling uncertainty and the ability of models to produce the truth.[121] They concluded that there is no way to avoid uncertainty. They suggest a very practical approach – evaluating models based on confirming observations, comparisons of field data and alternative hypotheses with simulated results, and a phased review in which field data are used to confirm or reject the modeler's choices and approach. They argue that any judgment on a model's acceptability, ultimately, is a subjective assessment made within the context of the model's stated purpose. The next section looks at their advice in the context of other more formal processes and standards for judging the adequacy of models.

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115 We use the term "validation" in the discussion as the commonly used label for testing a calibrated model against field data, but this use is not meant to imply more than that about model performance.

116 This issue will be discussed in specific terms below in the context of the Arkansas River Compact dispute between Kansas and Colorado.

117 John D. Bredehoeft and Leonard F. Konikow, Editorial, Model Validation, 31 Ground Water 178 (1993).

118 E.Scott Bair, Editorial, Model (In)Validation – A View From The Courtroom, 32 Ground Water 530, 531 (1994).

119 Naomi Oreskes et al., Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences, Science, Feb. 4, 1994, at 641.

120 Id.

121 William W. Woessner & Mary P. Anderson, Good Model-Bad Model, Understanding the Flow Modeling Process, in Subsurface Fluid Flow (Ground-Water and Vadose Zone) Modeling, 1288, Ritchey & Rumbaugh eds. (1996).

SECTION V
JUDGING THE ADEQUACY OF MODELS

The first question at this point is whether we can improve on the pragmatic advice of Woessner and Anderson that argues for a careful review grounded in field data and tempered with a certain amount of professional judgment (i.e. an amount of subjectivity guided by training and experience). With their practical advice in mind, it is appropriate to review at least some of the professional criteria offered as the basis for judging the adequacy of models or assessing a model's ability to produce results that meet its stated purpose. We will limit this to three: 1) ASTM Standard Guides; 2) Daubert Criteria; and 3) Federal Judicial Center Reference Manual on Scientific Evidence (and other material on expert testimony). As we do this, we will keep in mind the observation of a courtroom hardened hydrologic expert, who reminds us that, "[T]oday… methods used to calibrate the model would probably be evaluated by the trial judge under the *Daubert* ruling and… would be highly scrutinized under cross-examination."[122]

1. AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM)

In 1993, the ASTM began issuing guidelines for model construction, calibration, and sensitivity analysis (some of which have been cited above). In fact, between 1993 and 1996, ASTM developed an extensive set of guides that, in addition to dealing with items like the modeling process flowchart described above, covered defining boundary conditions, initial conditions, model documentation, and subsurface flow.[123] (See the ASTM reference list in the Bibliography). Each guide goes into substantial detail defining terms, establishing procedures, setting criteria, and outlining reporting requirements. Perhaps the single most comprehensive guide is the one dealing with model documentation.[124] The thoroughness of documentation that supports a model might even serve as a threshold criterion for the admission of a model into evidence. For this reason several types of documentation are described below.

122 E.S. Bair, Models in the Courtroom, in MODEL VALIDATION: PERSPECTIVES IN HYDROLOGICAL SCIENCES (M.G. Anderson & P.D. Bates eds., 2001).
123 The guides are specifically designed for groundwater models, but they have broader application and are very appropriately applied to surface water models as well.
124 ASTM, STANDARD GUIDE FOR DOCUMENTING A GROUND-WATER FLOW MODEL APPLICATION (D 5718-95) (1995).

In the simplest terms, model documentation should include written descriptions and graphical presentations of the model's assumptions, the model's objectives, the conceptual model, the computer code, the model construction, the model calibration process, the predictive simulation process, and expert conclusions. These several elements translate into a detailed list of desired documentation that is represented in Table V.1 (on the next page). Providing this level of detail on a model, its construction, operation, and data, while not ensuring that a particular model reasonably approximates a given system (and ought to be accepted into evidence), would at least create transparency and establish a reasonably firm foundation for understanding the model and its attendant features and limitations. Moreover, in the case of competing models, documentation would assist the judge in evaluating the model's merits.

TABLE V.1. ASTM Model Documentation Elements

Model Function	Describe model use to meet purpose & goals of study
General Setting	Relevant information on region, hydrology, & land
Conceptual Model	Site-specific (data based) on region & system dynamics
Hydrologic System	**Interpretation of geologic & hydrologic characteristics**
Hydrologic Boundaries	*Discuss hydrologic boundaries*
Hydraulic Properties	*Present known hydraulic properties & spatial variation*
Sources & Sinks	*Present detail on sources and sinks*
Water Budget	*Interpret how water is entering & leaving system*
Computer Code Description	Describe code & criteria used for its selection
Assumptions	**Describe & justify assumptions built into code**
Limitations	*Describe limitations of code*
Solution Techniques	*Describe solution technique used in code*
Effects on Model	*Describe how assumptions & limitations affect model*
Model Construction	Define model domain, all conditions, & assumptions
Model Domain	**Present model domain, map, grid spacing, element size**
Hydraulic Parameters	*Present hydraulic parameters & spatial variation*
Sources & Sinks	*Present sources & sinks & describe model incorporation*
Boundary Conditions	*Present location & types of boundary conditions*
Calibration Targets	*Present calibration targets & justify their selection*
Numerical Parameters	*Present parameters (if any) used in solution technique*
Calibration	Present and discuss model calibration procedure
Qual/Quant Analysis	**Describe types of calibration procedures used**
Sensitivity Analysis	*Present goals & results of sensitivity analysis*
Model Verification	*Present verification results including residuals*
Predictive Simulation	Describe any predictive simulation conducted
Summary & Conclusions	Summarize results & draw conclusions
References	Complete references for data, codes & procedures

The documentation process recommended under ASTM guidelines is one in which the model builder is asked to describe the function of the model, the physical and operational features of the system to be modeled, and then, in some detail, the code construction, model testing, predictive simulations, and results and conclusions. The objective is to provide a framework for model transparency that might not otherwise be achieved.[125]

125 In fact, they have been used as a standard against which to measure admissibility. See Jonathan W. Hays, Order Dismissing Application (C.R.C.P. Rule 41(b)(1) Concerning the Application for Water Rights of the Park County Sportsmen's Ranch (2001), discussed below.

2. USGS GUIDELINE FOR EVALUATION GROUNDWATER MODELS

The USGS adds a feature to the ASTM guidelines that can be used to assess the adequacy of a hydrologic model. The approach offers a road map relating hydrologic problem types to reasons for undertaking model development and the appropriate approach to model selection based on the problem type and the study's objectives.[126] Table V.2 lays out the map in a step-wise fashion. The guidelines reinforce all of the features of the ASTM guidelines, but place stronger and more consistent emphasis on the idea that the objectives of model building must be clearly specified to allow the adequacy of the model to be evaluated.

3. EVIDENTIARY GUIDELINES FOR ADMISSIBILITY

The legal tests for model admissibility are *Frye*, *Daubert*, and FRE 702 or its state-court equivalent.[127] (The criteria for judging scientific evidence used by most western states are summarized in Table V.3.. The *Frye* test includes "general acceptance in the relevant scientific community.. Such acceptance can be established through the testimony of experts familiar with the degree to which a given model is accepted as valid. Evidence of general acceptance may also be found in journals and other publications that address the science and practice of hydrology and hydrologic model development and use. The *Daubert* factors expand upon the *Fry* test to include, among other things, whether the techniques have a known error rate, are subject to standards governing their application and, enjoy widespread acceptance. Issues associated with the acceptability of scientific evidence are also discussed in the Federal Judicial Center's Reference Manual on Scientific Evidence.

a. *Daubert* Criteria

In *Daubert v. Merrell Dow Pharmaceutical, Inc.*[128] the Supreme Court resolved an earlier conflict on the admissibility of scientific evidence in favor of the Federal Rules of Evidence[129] and essentially made the judge the gatekeeper on expert scientific testimony.[130] While the court did emphasize the need for flexibility, it also listed several factors that it thought would be pertinent to evaluating any scientific evidence:

1. Whether the theories and techniques employed by the scientific expert have been *tested*
2. Whether scientific evidence has been subjected to *peer review* and *publication*
3. Whether the techniques employed by the expert have a *known error rate*[131]
4. Whether they are subject to *standards* governing their application
5. Whether the theories and techniques enjoy widespread acceptance

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126 Reilly, supra note 99.

127 Jonathan W. Hays, Sr. Dist. Judge Water Div. No. 1, Comments on Draft Hydrologic Modeling Paper (2003) (The comments are attached as Appendix C.).

128 Daubert v. Merrell Dow Pharm. Inc., 509 U.S. 579 (1993).

129 John J. Gibbons, Tenth Anniversary of the Supreme Court Decision in Daubert v. Merrell Dow Pharmaceutical, Inc: The Respective Roles of Trial Appellate Courts in Daubert-Kumho Rulings, 34 Seton Hall L. Rev., 127, 127 (2003).

130 See Daubert, supra note 128.

131 The Arkansas River Special Master has pointed out that "known error rate" may be inappropriate for complex models like the Arkansas because important parts of the model output, flow depletion estimates, cannot be assessed against field data because those estimates do not exist. A.L. Littleworth, personal communication with author, June 2004 (on file with author).

TABLE V.2. Types of Problems and Associated Groundwater Flow Models

Problem Type	Reason for Study	Approach to Model
Basic Understanding of Groundwater System	Investigation of hydrologic processes	• *Hypothetical system model* • *Superposition* • *Particle tracking*
	Determination of Effective Data Collection Network	• *Calibrated model* • *Hypothetical system model* • *Superposition* • *Sensitivity analysis*
	Preliminary model to determine current level of understanding	• *Calibrated model* • *Hypothetical system model* • *Superposition* • *Sensitivity analysis*
Estimation of Aquifer Properties	Aquifer test analysis	• *Calibrated model* • *Superposition*
	Determination of aquifer properties	• *Calibrated model*
Understanding the Past	Understanding historic development of an aquifer system	• *Calibrated model*
	Estimation of predevelopment conditions	• *Calibrated model*
Understanding the Present	Determination of effect of groundwater pumpage on surface water bodies	• *Calibrated model* • *Superposition* • *Particle tracking*
	Determination of sources of water to wells	• *Calibrated model* • *Particle tracking*
	Determination of responsible parties causing impacts on system	• *Calibrated model* • *Particle tracking*
Forecasting the Future	Management of the System	• *Calibrated model* • *Superposition* • *Particle tracking*

By way of offering further guidance, the Court emphasized that the admissibility inquiry must focus "solely" on the expert's "principles and methodology," and "not on the conclusions that they generate."[132] Not surprisingly, professional engineering and scientific associations and review panels have, in general, supported the decision and the implementation of *Daubert* criteria.[133]

TABLE V.3. **Western States Criteria for Evaluating Scientific Evidence (from Jonathan W. Hays, 2003; Summarized from 90 ALR 5th 453.)**

Western States that have adopted the Daubert or similar test	
CO	Schreck v. People, 22 P.3d 68 (Colo.2001); CRE 702.
ID	Kolln v. Saint's Luke's Regional Medical Center, 940 p.2d 1142 (Idaho 1997); Kolln also ruled that Idaho R. Evid. 702 applies to all types of expert testimony.
NE	(For trials commencing on or after October 1, 2001).
NM	State v. Alberico, 861 P.2d 192 (N.M. 1993).
OK	12 Okla. St. Ann. §§ 2702-2705. Christian v. Gray, 65 P.3d 591 (Okla. 2003).
OR	State v. Futch. 924 P.2d 832 (1996). (Analysis of admissibility under Or. Evid. Code 401, 403, 702 is consistent with the holding in Daubert)
TX	E.I. du Pont de Nemours and Co., Inc. v. Robinson, 923 S.W.2d 549 (1995).
Western States that continue to apply the Frye test or a hybrid	
AZ	Logerquist v. McVey, 1 P.3d 113 (Ariz. 2000).
CA	People v. Kelly, 549 P.2d 1240 (Cal. 1976).
KS	State v. McIntosh, 58 P.3d 716 (Kan. 2002).
NV	Nevada has not rejected the Frye test in toto but applies the Daubert factors. Dow Chemical Co. v. Mahlum, 970 P.2d 98 (Nev. 1998) , reh'g denied, 973 P.2d 842 (Nev. 1999).
UT	The state of Utah has developed its own test for the admissibility of scientific and other expert testimony. State v. Crosby, 927 P.2d 638 (Utah 1996). The trial court must determine whether the underlying scientific principles and techniques are "inherently reliable," and whether principles involved were properly applied by qualified experts. The court weighs the prejudicial effect of the evidence against its probative value.
WA	State v. Copeland, 922 P.2d 1304 (Wash. 1996).

The obvious question is whether these criteria, either alone or in conjunction with the ASTM documentation criteria described above, establish an adequate screen or threshold necessary to admit the models into evidence. One way of asking this question slightly differently is to look at a model, not as an approximate or simplified representation of a real system and its behavior, but rather as a multi-part theory of a hydrologic system (aquifer, river, or both). The model is a specific theory about a given system, and its construction, calibration, and validation serve collectively as a test of that theory.

132 Kenneth J. Chesbro, Taking Daubert's "Focus" Seriously: the Methodology/Conclusions Distinction, 15 Cardozo Law Review, 6-7, 1745, (1994).

133 See, e.g., National Academy of Engineers, Amicus Curiae Brief to the Supreme Court in Kumho Tire Co. v. Carmichael,(October 1998).

There are benefits and potential limitations to adhering only to the ASTM guidelines or *Daubert* factors as the unique criteria for determining whether hydrologic models should be admitted into evidence. For example, the *Daubert* test asks whether a model (hypothesis) has been peer reviewed. But it is unclear whether peer review is always important in determining whether it should be a prerequisite to entering scientific opinion, in the form of a specific hydrologic model, into evidence. What may be more important is that a model has been properly documented.

A similar question exists on the importance of error rates. Parties may present the errors associated with validation, but against what error rate are they to be compared. (This question is discussed in the context of the Arkansas River below). Furthermore, hydrologic models are not subject to rigid standards; only to general guidelines, which provides difficulties for any party seeking to get models admitted into evidence. A final example emerges in the use of an ASTM documented model, where the hypotheses and techniques underlying the model enjoy widespread acceptance among professionals. However, popularity may not be a very good guide to reliability. Perhaps a starting point can be established in applying both the *Daubert* check list and ASTM documentation criteria to create an effective threshold for models (ASTM/*Daubert*).

Such a threshold test does not solve all the problems, however. In an adversarial setting, particularly a complex and high stakes case, it is very likely that each side will be able to assemble an expert group that can produce a model that meets the ASTM/*Daubert* standards.

a. *Frye* Test

To meet a court's *Frye* standard, scientific evidence presented to the court must be deemed as "generally accepted" by a meaningful segment of the associated scientific community. This applies to procedures, principles or techniques that may be presented in the proceedings of a court case.

A significant weakness of the *Frye* rule is that it does not address situations involving new, unique or novel scientific evidence. Unless the scientific principle that the expert's testimony is based upon is sufficiently established in the scientific community, the expert testimony must be rejected under *Frye*.

A question left largely unanswered by the *Frye* rule is exactly what level of acceptance within the scientific community is required to be deemed "generally accepted." The decision provides little guidance and creates as many questions as it answers. Should "general acceptance" be the conclusion of a particular expert witness, the methodology used to arrive at the conclusion or the mode of reasoning and application of the scientific principles involved. What should be the effect of applying a generally accepted scientific principle in an unaccepted way. Even if an expert's methodology is generally accepted, how is that methodology being used in the particular case – is it a novel use. It was not until the 1990s that many of these questions were considered by the courts, and the then-existing Federal Rules of Evidence offered little help. In particular the state of the law begged the question of how the *Frye* rule should apply specifically to the evaluation of a hydrologic simulation model.

a. Rule 702 of Federal Rules of Evidence (FRE 702 or state equivalent)

Under FRE 702, if "[S]cientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case."[134]

134 Fed. R. Evid. 702 (2009).

In a review of FRE 702, David Bernstein concludes that the implicit rationale for the reliability test is designed to preserve the perceived advantages of the adversarial system, while mitigating the harms to the courts' truth-seeking function by the inevitable strong biases that accompany adversarial expert testimony.[135] These biases include the conscious/intentional biases of "hired guns," the unconscious biases of other paid experts, and the selection biases that inevitably result from attorneys "shopping" for experts that will support their theory of the case from among a large pool of qualified individuals.

Bernstein goes on to say that while Rule 702 attempts to serve a worthy goal, it falls short of achieving it in an efficient manner. When applied correctly, it has the benefit of barring junk science and improper causation evidence. However, it does so at the expense of excluding in some cases where data may be limited, speculative causation evidence from the courtroom, even though the evidence of causation has wide support among experts in a particular scientific field. From Bernstein's point of view, while Rule 702 is greatly preferable to the prior overly permissive regime, it tends to go too far in insisting on a strict reliability test. That test keeps causation evidence which is widely accepted within the scientific community itself out of the courtroom.

d. Federal Judicial Center Reference Manual on Scientific Evidence and Other Material on Expert Testimony

The majority of reference and guide material on scientific evidence and expert testimony revolves around *Daubert*. Issues involving admissibility, the qualifications of experts, the scientific method, and the use of court appointed experts dominate discussions on the use of scientific evidence or models in the courtroom.[136] While some commentators go beyond these issues to offer specific advice on such topics as multiple regression analysis, economics (and the calculation of losses), epidemiology, and DNA evidence, *Daubert* remains the touchstone for all scientific evidence admission discussions. Even the literature's discussion of engineering practice, a topic that might be relevant in the context of model building and assessment, is limited almost exclusively to design criteria and the proper use of safety factors in construction, a topic not really appropriate in the context of hydrologic model building.

A perspective that may be helpful in sorting through the issue of model acceptability is found in the Federal Judicial Center's Manual in a chapter discussing language in the context of scientific evidence in the courtroom.[137] The author analyzes several words – *evidence, theory, law, error,* and *mistake* – that have very different meanings in law and science. For example, he argues that in the law *error* and *mistake* are almost synonymous and, if found to contaminate a judicial opinion, can be the basis for overturning such an opinion. In science, on other hand, *error* and *mistake* have very different meanings. *Mistakes* are certainly made (e.g., in a laboratory procedure) and the scientist's only obligation is to go back and correct them or clean up the procedure. *Error*, however, is inherent in any measurement, and a scientist is obliged to provide a careful analysis of errors in his (or her) work and report them along with all other results. Combining these very different meanings with the differing objects of law (i.e., *justice* or *equity*) and science (i.e., *truth* or *knowledge*) and the differing time scales on which the two operate, the former with time limits and the latter with none, the author suggests that the two disciplines have the potential of operating at cross purposes. The implication is that the court must serve as a vigilant gatekeeper to ensure science in the courtroom is reasonably right and that it may do so by requiring well-defined and acceptable error levels of the science.

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135 David E. Bernstein, Expert Witnesses, Adversarial Bias, and the (Partial) Failure of the Daubert Revolution, 93 Iowa L. Rev. 451 (2008).

136 See, e.g., Federal Judicial Center, Reference Manual on Scientific Evidence (Second) (2000) [herinafter Scientific Evidence]; National Academy of Sciences, The Age of Expert Testimony; Science in the Court Room, Report of Workshop, (2002).

137 See David Goodstein, How Science Works, in Scientific Evidence, supra note 134, at 67–82.

SECTION VI.
MODELS AND THE STANDARD METHODS OF EVIDENTIARY PRESENTATION

1. BURDEN OF PROOF AND OF PRODUCING EVIDENCE

As discussed in Section I, an applicant for a new water right or change order faces the burden of producing evidence sufficient to show no harm will arise from any new water diversion or use. In some cases a model will be introduced as evidence.[138] Typically, a preponderance of the evidence standard is used for a new application or change order.

In Utah, however, a slightly lower standard known as the "reason to believe" standard, applies to initiate a change order. Under this standard the applicant need only "show 'reason to believe' that no impairment will result from application approval."[139]

In the context of the quantity of water requested under an application, a rebuttable presumption may arise based upon an agency decision. This is especially relevant to the developing law of recreational water rights. For example, under Colorado water law, an applicant may request an in-stream, recreational diversion water right. However, any conditional grant is perfected based upon recommendations of the Colorado Water Conservation Board (CWCB) as to the minimum amount needed to satisfy the proposed recreational use.[140] Colorado courts have chosen to treat the CWCB's findings of fact as a rebuttable presumption, under which an applicant may provide additional facts if he believes the amount recommended by the CWCB to be inadequate.[141]

In the context of abandonment cases, a long period of non-use may establish a presumption of abandonment in some states and shifts the burden of proof to the holder of a right to show that he or she had recently used the water right under dispute.[142]

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138 See ex. Bd. of County Comm'r of Park County v. Park County Sportsmen's Ranch, LLP, 45 P.3d 693, 697 (Colo. 2002).
139 Searle v. Milburn Irr. Co., 133 P.3d 382, 390 (Utah 2006).
140 2001 Colo. Sess. Laws 1187 (codified at Colo. Rev. Stat. §§ 37-92-102(5), -103(4), (7), (10.3), -305(13)-(16) (2004)).
141 Colo. Water Conservation Bd. v. Gunnison River Water Conservancy Dist., 109 P.3d 585, 589-90 (Colo. 2005).
142 State ex. rel. Reynolds v. South Springs Co., 452 P.2d 478, 483 (N.M. 1969) for a discussion of abandonment and burdens of proof.

Colorado courts have placed the burden upon the water rights applicant to show that an aquifer "is capable of being utilized for the recharge and storage of the applicant's water without impairment to the decreed water rights of senior surface or ground water users who depend upon the aquifer for supply."[143]

The burden of production to rebut legal presumptions, however, is separate from the burden of proof required in a case.[144] At least in abandonment cases, the production of more concrete evidence than mere subjective declarations of intent not to abandon could involve the use of a model.[145] To demonstrate water usage or groundwater drawdown over prior periods model could be used to in order rebut to claims of non-use.

Expert testimony may be used to satisfy evidentiary burdens. However, the introduction of expert witnesses and opinion creates a separate evidentiary requirement. As a preliminary matter, a party offering an expert also has the burden of showing the expert is "qualified to testify competently regarding the matters he intend[ed] to address; the methodology by which the expert reach[ed] his conclusions is sufficiently reliable; and the testimony assists the trier of fact."[146]

2. STANDARD OF PROOF

a. Preponderance of the Evidence

Generally speaking, the burden of proof in any civil action "shall be by the preponderance of the evidence."[147] Unless a statute expressly requires another standard to be used, courts have held that the preponderance standard applies to those applying for water rights or change orders. An applicant that can demonstrate no injury by a preponderance of the evidence will be able to perfect a water right.[148]

As mentioned above, with Utah's change orders, the preponderance standard is not required for a water application to be approved by a state engineer, but only for the water right to stand up to a river adjudication and challenge in courts.[149] Regardless of case law, numerous states clarify the issue by implementing statutes which expressly lay out a preponderance standard for a new application.[150]

b. Clear and Convincing Evidence

The most notable use of the clear and convincing proof standard applies to interstate conflicts. States seeking an equitable apportionment of an interstate stream "must present clear and convincing proof of some real and substantial injury or damage."[151] It also applies where a state seeks a modification of a decree.[152] However, this standard does not apply when a state merely wishes to enforce an existing Supreme Court degree.[153]

As mentioned previously, the court in *Colorado Water Conservation Board v. Upper Gunnison* rejected the appellant's argument that rebutting a CWCB recommendation requires clear and convincing evidence and upheld the preponderance standard.[154]

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143 Park County, supra note 138, at 705.
144 Colo. Water Conservation Bd. v. Gunnison River Water Conservancy Dist., 109 P.3d 585, 597 (Colo. 2008).
145 See generally Haystack Ranch, LLC v. Fazzio, 997 P.2d 548, 552 (Colo. 2000).
146 McCorvey v. Baxter Healthcare Corp., 298 F.3d 1253, 1257 (11th Cir. 2002) (citing Maiz v. Virani, 253 F.3d 641, 664 (11th Cir. 2001)).
147 Colo. Water Conservation Bd. v. Gunnison River Water Conservancy Dist., 109 P.3d 585, 597 (Colo. 2005); Colo. Rev. Stat. § 13-25-127(1) (2008).
148 See e.g., Confederated Salish and Kootenai Tribes v. Clinch, 158 P.3d 377, 320 (Mont. 2007).
149 Searle v. Milburn Irr. Co., 133 P.3d 382. (Utah 2006).
150 Mont. Code Ann. § 85-2-402(2) (2007).
151 Idaho ex rel. Evans v. Oregon, 462 U.S. 1017, 1027 (1983); see also Kansas v. Colorado, 1994 WL 16189353;
152 Nebraska v. Wyoming, 507 U.S. 584, 592 (1993); Kansas v. Colorado, 1994 WL 16189353 at 29.
153 Nebraska v. Wyoming, 507 U.S. 584, 591-92 (1993).
154 Colo. Water Conservation Bd. v. Gunnison River Water Conservancy Dist., 109 P.3d 585, 590 (Colo. 2005).

Clear and convincing evidence may be required in abandonment cases, but is unlikely to implicate any modeling issues. In Colorado, a party asserting abandonment "has the burden of proving non-use and the intent to abandon by clear and convincing evidence."[155] Here, the demonstration of water abandonment is made "[upon] a showing that there has been an unreasonable period of nonuse, a prima facia case of abandonment is made, which in turn, shifts the burden going forward to the water rights' owner who may then introduce evidence sufficient to rebut the presumption."[156]

Furthermore, clear and convincing evidence may be required where a junior appropriator challenges a senior user's injunction against the junior use. Colorado courts have stated "[w]here a senior seeks to enjoin a junior appropriator of water from diverting" to his detriment and the junior wishes to defend his use as not injuring the senior "such a defense ought to be established by clear and satisfactory evidence."[157]

3. PRESUMPTIONS AND INFERENCE

When evaluating whether testimony is reliable and worthy of introduction into evidence for jury consideration a court must "consider whether the testimony is based upon an assertion or inference derived from scientific methodology."[158]

An inference may also arise where a party fails to produce a witness that has knowledge of material facts relevant to the case. Such an inference is known as an adverse inference and "the court may drawn the inference that the testimony of the witness concerning those facts would have been unfavorable to the party."[159]

Parties to water disputes may also move for summary judgments. In these cases, courts must assume that all evidence of the non-movant is to be believed and "all justifiable inferences are to be drawn in its favor."[160]

155 Means v. Pratt 331 P.2d 805, 807 (Colo. 1958) (citing to Cline v. McDowell 284 P.2d 1056, 1059 (Colo. 1955)); for discussion of abandonment generally see Beaver Park Water, Inc. v. City of Victor, 649 P.2d 300 (Colo. 1982).

156 Id. at 302.

157 Alamosa Creek Canal Co. v. Nelson, 93 P. 1112, 1115 (Colo. 1908).

158 Wilt v. Buracker, 443 S.E. 2d 196, 23 (W. Va. 1993).

159 Stockton East Water Dist. v. U.S., 76 Fed. Cl. 497, 505 (Fed. Cl. 2007).

160 Central Valley Water Agency v. U.S., 327 F.Supp. 1180, 1199 (E.D. Cali. 2004) (citing Anderson v. Liberty Lobby, Inc., 477 U.S. 242, 255 (1986)).

4. EXPERT WITNESSES ON MODELING

The presence of experts is nearly ubiquitous with use of computer models in water litigation. As such, courts need to ensure that expert testimony substantiates the models and that expert opinion about and founded on the models can be properly framed and evaluated by the finder of fact. As Section V discussed, FRE 702 allows expert testimony in the form of opinion if it is reliable and relevant.[161] The burden falls upon "trial courts [to] act as 'gatekeepers' to ensure that speculative, unreliable expert testimony does not reach the jury."[162] At the same time, courts have interpreted the FREs as having a "strong and undeniable preference for admitting any evidence which has the potential for assisting the trier of fact."[163]

a. Qualifications

Generally speaking, the qualifications for an expert on modeling will require the same judicial discretion as the certification of any other type of expert. FRE 702 allows certification as an expert if a witness is qualified "by knowledge, skill, experience, training, or education." Typically, certified engineers, professional hydrologists, and academic professionals will be accepted by the courts in water-related disputes.[164]

However, when examining the admissibility of an expert opinion, the court needs to distinguish between an expert hydrologist and a modeling expert intimately familiar with the coding of a particular model. As is discussed below, the court must understand and distinguish between the levels of expertise in the hydrological computer modeling context.

b. Permissible Testimony

Simply because a hydrologist is certified as an expert does not give him or her unlimited scope of opinion testimony. Rather, the court must qualify and define the scope of the expertise. Courts have conceded that an expert need not understand all of the intricacies of particular procedures or the disciplines encompassed by a team or researchers "in order to testify to the team's conclusions."[165] However, in cases where an expert relies upon a research team or members of his or her staff to perform certain duties, the court may need to take a closer look at admissibility of opinion. An expert may only testify as to the veracity of the immediate subject matter, and may not vouch for the truth of statements of other experts in tangential areas upon which he or she relied.[166] In short, "[a] scientist, however, well-credentialed he may be, is not permitted to become the mouthpiece of a scientist in a different specialty."[167]

Within the context of hydrological modeling, a hydrologist may be an expert in many aspects of geology and water movement, but should be distinguished from a computer modeling expert. In short, if he or she lacks particular modeling expertise, the expert may only testify as to the role that a computer modeler's opinion helped form his or her own opinion on the acceptability of a particular model.

161 Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, 592 (1993). It should be noted that the standards by which to consider opinion relevant or reliable are outlined in Daubert, and enumerated supra Chpt. V. However. the court has broad discretion in the application of those factors and the overall analysis should remain flexible. Kumho Tire Co. v. Carmichael, 526 U.S. 137, 152 (1999).

162 McCorvey v. Baxter Healthcare Corp., 298 F.3d 1253, 1256 (11th Cir. 2002).

163 Kannankeril v. Terminix Intern., Inc., 128 F.3d 802, 806 (3rd Cir. 1997) (citing to Holbrook v. Lykes Bros. S.S. Co., 80 F.3d 777, 780 (3rd Cir. 1996).

164 See e.g., City of Austin v. Leggett, 257 S.W. 3d 456, 464 (expert was professional engineer and hydrologist), Yamagiwa v. City of Half Moon Bay, 523 F. Supp. 2d 1036, 1042 (N.D. Cal. 2007) (Ph.D. expert); New Mexico v. Gen. Elec. Co., 335 F. Supp. 2d 1266, 1281 (court upholding research professor as expert).

165 Dura Auto. Sys. of Ind. v. CTS Corp., 285 F.3d 609, 614 (7th Cir. 2002) (citing to Walker v. Soo Line R.R., 208 F.3d 581, 589 (7th Cir. 2000)).

166 Id.

167 Id.; see also Goodwin & Proctor, LLP, Admissibility of Expert Opinion Based on Computer Modeling – What Does Daubert Require, Environmental Law Advisory, June 2003, available at http://www.goodwinprocter.com/~/media/EA1675B56719466BAFB6764F8BA261F0.ashx.

If the opinion testimony upon the ultimate issue of the case is formed without consideration of material facts that bear upon the ultimate issue, that opinion "cannot be helpful to the trier of fact" and therefore must be excluded.[168]

c. Hypothetical Scenarios Offered As Proof

Providing a mere allegation or laying out a hypothetical possibility of harm in the future is insufficient to show injury. In *Central Valley Water Agency v. United States,* the court noted that plaintiffs must show through tangible evidence or expert testimony that they would suffer imminent harm. Hypothetical "possibilities of what may happen in the future" are insufficient.[169]

Despite the speculative or hypothetical nature of any expert's testimony it is up to the trier of fact to determine the credibility and weight of any testimony.[170]

d. Nature of Modeling Results

The sufficiency of data supporting a model result implicates issues of admissibility for the courts. Courts, however, seem to lack a coherent standard on whether a failure to include variables in a model should be a considered under the rubric of either admissibility or probative value. In *Quiet Technology DC-8, Inc. v. Hurel-Dubois UK Ltd.,* the court noted that the failure to include certain variables does not affect a computer model's admissibility, since a model's results are "empirically testable" and "susceptible to effective cross-examination."[171]

Erroneous interpretations of modeling are sufficient to exclude modeling evidence. For example, in C*entral Valley Water*, model results were eliminated due to rounding errors in modeling studies.[172] Finally, if data underlying a computer model are flawed then any expert opinion based upon that data may be sufficiently unreliable to admit into evidence.[173]

168 New Mexico v. General Elec. Co, 335 F.Supp. 2d 1266, 1273 (D.N.M. 2004) (citing Kieffer v. Weston Land, Inc., 90 F.3d 1496, 1499 (10th Cir. 1996)).
169 Central Valley Water Agency v. U.S., 327 F.Supp. 2d 1180. (E.D.Cali. 2004)
170 See e.g., Associated Underwriters v. Wood, 98 P.3d 572, 597 (Ariz. Ct. App. 2004).
171 Quiet Tech. DC-8, Inc. v. Hurel-Dubois UK Ltd., 326 F.3d 1333, 1345 (11th Cir. 2003); see also Goodwin & Proctor, supra note 25, at 4.
172 Central Valley Water, supra note 168, at 1210.
173 Tarrant Regional Water Dist. v. Gragg, 43 S.W. 3d 609, 615 (Tex. App. 2001).

SECTION VII
CASE MANAGEMENT IN LITIGATION INVOLVING HYDROLOGIC MODELS

1. INTRODUCTION

Water issue litigation in which hydrologic models play a central role is usually complex and can quickly overwhelm an unprepared court. There are a myriad of issues, parties, and testimony to consider. Adding to the confusion is the inherent complexity of the models themselves. In such instances the best guide to managing these cases is the Federal Judicial Center's *Manual for Complex Litigation* ("the manual"), especially Parts I and II. While the manual is organized around rules that apply to the federal court, its case management advice is derived from and applicable to all courts.

This section of the benchbook relates specific challenges associated with hydrologic models to relevant suggestions in the manual and is based on the premise that courts have moved well beyond "…the classic model of the adversarial process, [in which] judges remain passive until the lawyers request their assistance."[174] It assumes, like the manual, that in complex cases an active judge working in collaboration with counsel should "…develop and carry out a comprehensive plan for the conduct of pretrial and trial proceedings."[175]

This section proceeds from the manual's admonition that "The *sine qua non* of managing complex litigation is defining the issues. The materiality of facts and the scope of discovery (and the trial) cannot be determined without identification and definition of the controverted issues."[176] The remainder of the section will relate this caution first to some general characteristics of judicial management and then to the specifics of how to manage both the introduction of hydrologic models as scientific evidence and the testimony of experts as the vehicle for introducing this evidence.

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174 Francis E. McGovern, Toward a Functional Approach for Managing Complex Litigation, 53 The University of Chicago Law Review 440, 442 (1986).
175 Manual for Complex Litigation (Fourth) § 10.0 (2004). [hereafter Manual].
176 Id. at § 10.31.

2. GENERAL CHARACTERISTICS OF CASE MANAGEMENT

Effective case management is generally a careful exercise in judicial involvement that is: 1) active; 2) substantive; 3) timely; 4) continuing; and 5) firm, but fair. Effective management of a complex case will allow a judge to make informed rulings on issue definition, issue narrowing, and on related matters, such as scheduling and discovery control. Proper management will also allow the judge to anticipate problems before they arise rather than waiting for counsel to raise objections or point out problems. To do so, the efficient judge seeks to become familiar, at an early stage, with the substantive issues of the case. The judge must also decide disputes promptly and correctly, particularly those that may substantially affect the course or scope of the subsequent proceedings and the court's ultimate decision. As the manual points out "…parties may prefer that a ruling be timely rather than perfect."[177]

But merely setting the stage with early judicial involvement is not sufficient. Proper case management must include periodically monitoring the litigation's progress, and judges should require interim reporting for the parties to ensure that schedules are being followed. The efficient judge should also impose time limits and not be hesitant to employ other controls, but should not do so arbitrarily or without considering the views of counsel. Once established, schedules should be adhered to and sanctions imposed as necessary to ensure party compliance.[178] A cardinal rule of effective case management is that the judge issue, early in the case process, a scheduling order including a firm trial date. This should occur after consultation with counsel. Complex cases should always have a firm setting for the next court event to avoid letting the case lay dormant and escaping necessary judicial oversight.

3. SCHEDULING THE INITIAL CONFERENCE

The court's very first step in managing a case should be to promptly schedule and hold an initial conference with counsel before parties file motions and discovery requests or engage in any other adversarial activity. Counsel should be given sufficient time to prepare, but this organizational step should occur as early as practicable. Depending on whether the case is a statutory adjudication or one initiated by complaint, the hearing may need to be set prior to the joinder of all parties.

Most courts will have their lists of subjects for consideration at such a conference, but the manual suggests the following additions, if not already on a particular court's list:

- *Suspending all discovery and motion activity pending further order;*
- *Specifying that responses to the order will not be treated as admissions or otherwise bind the parties;*
- *Listing specific topics that the court intends to address at the conference;*
- *Inviting suggestions from counsel for additional topics;*
- *Requiring counsel in advance to discuss claims and defenses, a plan for disclosure and discovery, and possible settlement;*
- *Directing counsel to submit a tentative statement, joint if possible, identifying disputed issues as specifically as possible;*
- *Directing counsel to submit a proposed schedule for the conduct of the litigation, including a discovery plan;*
- *Calling on counsel to submit brief factual statements to assist the court in understanding the background, setting, and likely dimensions of the litigation;*
- *Discussing with counsel the need and advisability of the court acquiring assistance on the technical aspects of computer modeling, if applicable;*
- *Setting the next hearing date (a cardinal rule of case management!)*[179]

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177 Id. at § 10.13.

178 Part I of the manual discusses on appropriate sanctions (Part I § 10.15). Sanctions, as part of case management, will not be further discussed here.

179 See Manual, supra note 175, at § 11.11. (Part I also suggests that counsel identify related litigation pending in other courts, an issue that may not be of concern in most water cases); see also author communication with Sr. Judge Dan Hurlbutt (5th Judicial Dist., Idaho), March 18, 2009 (notes on file with author).

4. DISCOVERY PLANS AND PREDISCOVERY DISCLOSURE

A discovery plan should be crafted for each case and be a collaborative effort between the court and counsel. It should facilitate the orderly and cost-effective acquisition of relevant information and materials and, in theory, enable the prompt resolution of any discovery disputes. The manual recommends that "[T]he judge should ask the lawyers initially to propose a plan, but should not accept joint recommendations uncritically."[180] The judge must retain responsibility for control of discovery, to oversee the plan, and to provide guidance and control. To prevent manipulation of the discovery process by the parties as an adversarial tactic, a judge should not hesitate to ask why particular discovery is needed and whether information can be obtained more efficiently and economically by other means.

Regarding a computer model or competing computer models, and their input data and results, a court may wish to help structure discovery in such a way that the information sharing process helps satisfy the scientific evidence admissibility criterion (e.g., *Daubert*) or a more specific set of modeling requirements like the ASTM documentation elements (see Table V.1). Regardless of the structure of any given case's discovery process, periodic conferences including the parties and the court will enable the judge to monitor the progress of the plan and to ensure its fair and effective operation.

Many courts require parties to exchange certain core information within a specified number of days after their initial discovery planning conference without the necessity of a separate discovery request. The manual cautions that in complex litigation, this requirement may need modification or suspension. It points out that "[T]he scope of disputed issues and relevant facts in a complex case may not be sufficiently clear from the pleadings to enable parties to make the requisite disclosure."[181] In circumstances like this, the judge's most important initial function as case manager may be to press the parties to identify, define, and narrow the issues sufficiently to enable an economical discovery process.

5. DISCOVERY OF COMPUTERIZED DATA[182]

The goal of sharing computer-based data is to maximize potential advantages while minimizing the potential problems of incompatibility among various computer systems, programs, or models. By having counsel agree on a common data set early in the discovery process, the court will minimize problems with intrusiveness (a party's access to proprietary or irrelevant information) and data integrity (protecting against compromise of data in search and retrieval).[183] In seeking a balance between advantages and problems a number of general features may be relevant.

Form of production: Computer data must be provided in a reasonably usable and accessible form. As this issue relates to experts' disclosures and computer models, a recent rule change made by the Colorado Supreme Court is an example of such a provision:

> *"An executable electronic version of any computational model, including all input and output files, relied upon by the expert in forming his or her opinions."*[184]

In other words, a common formatted data set, along with the model itself, should be made available to all parties if such a model will be used in litigation.

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180 Id. at § 11.42.
181 Id. at § 11.13.
182 Part I of the manual (§ 11.446) includes a discussion of discovery and computerized data that is very broad in reach. While computer models are not mentioned in the discussion, some of the general points may be relevant to models and their data and outputs.
183 Models' outputs are a result of: 1) the models' inherent structure (as a function of numerous components interacting in a defined way); and 2) the underlying data sets. A common data set upon which all parties agree (or can at least come close to agreement) may reduce the variability of model outputs and make it more likely that each model can be evaluated on its merits and its outputs understood in that contex. Further if the parties can agree to reduce or eliminate variability, the issues can be narrowed.
184 2009(04) Rule Change to the Colorado Rules of Civil Procedure for Courts of Records in Colorado, Chapter 10, General Provisions ([Hereinafter COLORADO RULES]; COLORADO RULES in Appendix G.)

Access to parties' computers: Allowing requesting parties access to the responding parties' computer systems to conduct their own searches should not be allowed as it would compromise legally recognized privileges, trade secrets, and often the personal privacy of employees and customers.

Data requests, format, and need: Requests for production of data in a specified nonstandard format should be conditioned upon a showing of need or, in the alternative, a sharing of expenses.

Search, retrieval, and privilege: Production of computer-stored data may require broad database searches. Protecting against the production of confidential and irrelevant information that may create a loss of privilege can be costly and time consuming. In such instances, judges often encourage counsel to stipulate at the outset of discovery to a "nonwaiver" agreement that a party does not waive privilege through the inadvertent disclosure of confidential and irrelevant information. Such an agreement may be incorporated into case-management order.

Use at trial: Computerized data may be vulnerable to a number of factors that could affect their accuracy – incomplete data entry, mistakes in output instructions, programming errors, damage and contamination of storage media, power outages, and equipment malfunctions. The data may also be compromised in the course of discovery by search and retrieval techniques, data conversion, or mishandling. Regardless, the proponent of computerized evidence has the burden of laying a proper foundation for its accuracy. The judge should bear in mind these issues of accuracy and reliability, ensuring that they are managed in discovery during pretrial proceedings, so that first challenges to the computer-based evidence are not made at trial.[185]

Computer experts: As the technology for the management of computerized materials becomes ever more complex, the judge may find it appropriate to seek the assistance of a special master or neutral expert, or call on the parties to provide the court with briefings or some other form of expert assistance on the relevant technological issues. The judge should explore this need with the parties at the initial conference.

6. DISCLOSURE, DISCOVERY, AND MANAGEMENT OF EXPERT OPINIONS

As with document discovery, effective case management requires reasonable judicial control over the use of experts. At a minimum, the judge should be involved in determining whether the proposed testimony will be necessary and appropriate, in establishing limits on the number of expert witnesses and the scope of their admissible subject matter expertise, and in managing the disclosure and discovery of experts' opinions. Timely involvement in these areas can facilitate rulings on the admissibility of expert evidence and can also avoid surprise at trial. In the name of accomplishing this and with the objective of narrowing issues to the maximum extent possible, the manual recommends that the judge "[A]t the initial conference, establish a timetable for expert disclosure and procedures to implement it."[186]

The manual distinguishes the functions and responsibilities of trial experts, consulting (but nontestifying) experts, and court-appointed experts. It pays specific attention to their reporting and disclosure requirements and to the limits, in each case, of prediscovery disclosure.[187] It also emphasizes the importance, when the court appoints an expert, that the judge "…establish the terms on which the expert serves and the nature and functions the expert is to perform."[188]

185 Concerning managing errors in large data sets, the manual suggests that "[W]hen the data are voluminous, verification and correction of all items may not be feasible. In such cases, verification may be made of a sample of the data. Instead of correcting the errors detected in the sample—which might lead to the erroneous representation that the compilation is free from error—evidence may be offered (or stipulations made), by way of extrapolation from the sample, of the effect of the observed errors on the entire compilation." Manual, supra note 175, at §11.446.

186 Id. at § 11.481.

187 Id. at § 11.491. See also Id. at §§ 11.48, 11.50.

188 Id. at §11.483.

One of the most challenging management issues related to experts is dealing with significantly divergent opinions. Such opinions can substantially and perhaps unnecessarily broaden the issues before the court. Although experts often appear to be at loggerheads, early disclosure that reveals the assumptions and the underlying data on which the experts have relied can sometimes uncover the bases for their differences and may make it possible to narrow the issues appreciably. Early disclosure can also facilitate early rulings on objections to expert qualifications and the relevance and reliability of data and opinions. This process will avoid duplicative efforts if more suitable experts or new data sets need to be introduced late in the litigation. To narrow the grounds for disagreement, judges can ask the experts to explain the reasons for their differences. An alternative has been incorporated in Colorado rules:

> "*The expert witness(es) for the applicant and the opposer(s) shall meet within 45 days after the applicant's initial expert disclosures are made…The purpose of the meeting is for the experts to discuss the matters of fact and expert opinion that are the subject of the expert(s) disclosures and with respect to such disclosures: to identify undisputed matters of fact and expert opinion, to attempt to resolve disputed matters of fact and expert opinion, and to identify the remaining matters of fact and expert opinion in dispute.*"[189]

7. CONSIDERATIONS IN ASSESSING HYDROLOGIC COMPUTER MODELS – ADMISSIBILITY AND WEIGHT

a. Admissibility

The manual goes to great lengths in its discussion of *Kumho Tire*, *Daubert*, and the gatekeeping responsibilities of the court with regard to scientific and technical information.[190] However, as Jonathan Hays, a former water court judge in Colorado and a participant in Dividing the Waters, discusses in Appendix C of this document[191], the application of *Daubert* to the admissibility of a hydrologic computer model is not necessarily straightforward. He argues that "a known error rate" is difficult to apply to a computer model and is a vague term in its own right. On the other hand, he does see a trend in the use of computer-based models as being "subject to standards governing their application" and certainly "enjoy[ing] widespread acceptance."[192] Regarding the former, he points to the ASTM guidelines as the example of guiding standards that he successfully employed in *Park County Sportsmen's Ranch*.[193]

Certain hydrologic models have become generally used and accepted in a variety of disciplines and professions. Particular models have matured so that they may be employed to describe nearly any physical location with customization (i.e., parameter estimation and calibration). The models' legitimacy is further supported by an enormous body of scientific literature which analyzes their construction and use and has led to model improvement over time. In sum, the development of these models has reached the state, that, as described in Appendix A, many government organizations, universities, and private entities rely on certain general model architectures and codes that are adapted to specific modeling tasks.

Hays' conclusion is that "…modeling evidence will be regularly received in evidence at trials in both State and Federal courts, because the model and its results will meet the threshold for admissibility."[194] He also sees at least one very practical reason that models will be built well enough to pass a reasonable admissibility screen — "…research and preparation in developing a model and generating results is too costly for a litigant to risk its outright exclusion at trial."[195] Notwithstanding his conclusions, however, a reasonable check list to employ as a threshold admissibility test is the ASTM Model Documentation Elements mentioned earlier in this section and described in some detail in **Judging the Adequacy of Models**, *supra Section* V (Table V.1).

189 Colorado Rules, supra note 184, at 13.
190 See Manual, supra note 175, at §23.
191 Hays, supra note 125.
192 Id.
193 For a discussion of the ASTM standards see Section V.
194 See Appendix C, infra at 14.
195 Id. at 14.

a. Weight

Once a model is deemed sufficient under the prevailing standard of admissibility to be considered as evidence, it is also necessary to identify to the trier of fact several potential problems before evaluating the model. If a hydrologic computer model is thought of as a complex hypothesis for the behavior of a natural hydrologic system, then giving substantial weight to the model's results can be thought of as "accepting" the hypothesis. On the other hand, giving little or no weight to the results is a "rejection" of the hypothesis. Generally, an acceptance/rejection decision is seen as having two possible outcomes – either right or wrong. In fact, there are four possibilities. A hypothesis can accepted and it can be "true," a correct decision, or accepted when it is "false," or incorrect decision. Conversely, a hypothesis can be rejected when it is "true," again incorrect, or rejected when it is "false," a correct decision. In other words, there are two right answers and two wrong answers, conditioned by the reasonableness and adequacy of the model. The two kinds of errors in outcomes are known as Type I error (rejection of a hypothesis when it's true) and Type II error (accepting a hypothesis when it's false).[196]

Contending with inherent modeling uncertainty is inescapable in water cases. As Woessner and Anderson make clear in their review of model construction summarized in Section IV, there is no way to avoid uncertainty, and the judgment on a model's acceptability is, ultimately, a subjective assessment made in the context of the model's stated purpose. The risk of accepting a particular model's output as proof is further magnified under a "preponderance of the evidence" standard, a standard which only requires that an outcome is considered legally true if there is a greater than fifty percent chance that the proposition is true. Woessner and Anderson's admonition rings particularly strongly when the limitations of the preponderance standard are combined with the two error type pitfalls.[197]

Although unavoidable, the problems of uncertainty and the risk of error can first be reduced by employing a simple checklist like the ASTM documentation elements to determine admissibility. Secondly, as the manual suggests throughout Parts I and II, the problems may be addressed by narrowing the issues via management of discovery and sound rulemaking in the pretrial proceedings. The manual also cautions that "…the selection of criteria appropriate to judge the reliability of a particular type of expert testimony will be a coordinated effort between the judge and the parties."[198]

8. SUMMARY AND CONCLUSIONS

The fundamental goal of case management in complex litigation is to rapidly define the issues in controversy and, to the extent possible, to narrow the range of disagreement. Successful issue definition and narrowing depends on early and continuing judicial involvement. A sequential checklist to accomplish this appears in Table VII.1.

196 Acceptance/rejection decisionmaking and the risk of error is discussed and illustrated in Appendix D.

197 A standard of clear and convincing evidence (i.e., that it is substantially more likely than not that a hypothesis or proposition is in fact true) is not discussed here. However, in those cases where it is the applicable standard, it would not necessarily reduce uncertainty, but would change Type I and Type II error rates.

198 MANUAL, supra note 175, at §23.31.

TABLE VII.1. Recommended Steps for Management of Complex Litigation Involving Hydrologic Modeling

	Action	Goal
1.	Initial conference	Set a conference with counsel prior to motions or other filings, within 30 – 60 days of receiving the complaint. Communicate likely sources of dispute in water modeling cases and prepare counsel to address these problems. Set next hearing date.
2.	Discovery plan	Craft discovery plan/schedule with input of parties.
3.	Minimize discovery efforts	Actively question parties requesting discovery to ensure particular data is truly needed and not being used as an attempt to disadvantage the other party with costs, etc.
4.	Share information	Enable information sharing by ordering access to each party's underlying computer based data sets by the other party. Order parties to provide data in easily understandable and usable formats.
5.	Expert disclosure	Require parties to clearly define the types and scope of expertise of each expert likely to be offered, and the evidentiary function each expert is to perform at trial.
6.	Expert conference	Set up early 'expert only' conferences to identify areas of agreement and matters remaining in dispute. If possible, reach agreement on an acceptable common data sets.
7.	Resolve technical disputes	Consider appointing a special master to oversee and resolve complex technical (computer or technology) disagreements between the parties
8.	Narrow issues	Require the parties, through the discovery and pretrial requirements to identify and define issues.
9.	Timely rule on threshold issues	Quickly rule on discovery disputes and admissibility/evidentiary matters.
10.	Sanctions	Administer sanctions as appropriate to ensure timely resolution and advancement of the case.
11.	Admit acceptable models into evidence	Using ASTM checklist, or other standard criteria, ensure the model meets a minimum 'trustworthiness' standard by accounting for common modeling problems and having certain 'good model' attributes.
12.	Properly inform those judging the reliability of models	Ensure that the criteria by which the reliability of the models are to be judged are properly laid out in early case management rulings.

Toward this goal, the court must properly handle expert testimony and the scientific models upon which it is based. The place to start is the initial pretrial conference, in which the court may advise counsel to prepare responses to predictable inquiries into the nature of the claims and defenses in the case. The court should also put the parties on notice of likely lines of questioning into underlying assumptions, the nature of expert evidence expected to be offered, and if known, into the areas of disagreement among experts. These recommended steps are especially important with complex evidence like computer models for both judicial efficiency and the conservation of both party's resources. Reserving consideration of the reliability of expert testimony until trial carries more disadvantages than advantages. Failure to address predictable issues and problems early on can lead to serious management challenges in the handling of hydrological models and expert evidence.

SECTION VIII.
CASE EXAMPLES OF THE USE OF MODELS IN COMPLEX ADVERSARIAL PROCEEDINGS

We have selected the Arkansas River and Republican River cases because they deal with complicated physical and operational systems that would be very difficult, if not impossible, to organize and analyze in the absence of models. They also offer very different examples of model development and use. In our opinion, they highlight some of the modeling issues we are most concerned with in this benchbook. We have not selected them because we think one necessarily led to a model that more closely represented the physical and operational features of one or the other river basin, but because they point out some features of different paths in model development.

We have also selected *Application of Park County Sportsmen's Ranch (Colorado)* and *Confined Aquifer New Use Rules (Colorado)* because *Park County* illustrates the misuse of a standard model (MODFLOW), while *New Use Rules* demonstrates the proper use of a model in a complex groundwater case involving the headwaters of the Rio Grande.

1. ARKANSAS RIVER COMPACT: *KANSAS V. COLORADO*[199]

In 1985 Kansas filed suit against Colorado under the Arkansas River Compact, claiming that Colorado allowed well development in the Arkansas Valley east of the City of Pueblo that violated the compact. When Kansas initiated litigation, its analysis of compact violations was based in part on the results of a computer simulation it had developed specifically for the Arkansas River Valley (the so-called Hydrologic-Institutional Model, the H-I Model [H-IM]). One of the primary purposes of the H-IM was the estimating depletions in Arkansas River flows caused by Colorado's alluvial wells in the lower Arkansas River valley. Colorado responded with its own model, though the battle over which model was better was avoided when Colorado agreed to the use of H-IM because its estimates of compact deficits tended to be lower than those calculated with the Colorado model. This agreement, however, did not by any means put to rest modeling questions. At the same time, it was clear that both sides agreed that modeling was the only way to estimate depletions.[200]

199 The summary of issues and the trial phase below is derived primarily from Littleworth, supra note 4.
200 A.L. Littleworth, personal communications with author, June 2004 (on file with author).

Following the issuance of the Special Master's First Report in *Kansas v. Colorado*[201] the U.S. Supreme Court found, in May 1995, that Colorado had violated the Arkansas River Compact by allowing well development in the Arkansas Valley after the compact was signed in 1948.[202] In the wake of this decision, the states stipulated that depletions between 1950 and 1985 amounted to 328,505 acre-feet. Subsequently, the Special Master found that additional depletions of 91,565 acre-feet had accumulated between 1986 and 1994.

Succeeding phases of the trial included two additional Special Master's reports after which the states agreed that depletions in the two years of 1995-96 were 7,935 acre-feet and either agreed to or disputed a number of issues associated with remedies, interest on damages, and compact compliance rules. The Supreme Court, in a June 11, 2002 opinion, affirmed all of the Special Master's findings and recommendations except for the date from which prejudgment interest on damages should be calculated.[203]

At this point, the states sought a stay in the proceedings in order to mediate the remaining issues. After this effort failed, the Special Master initiated a trial phase dealing with Compact compliance that was a direct outgrowth of his earlier findings. In this trial segment the essential questions were:

- Colorado's use rules (including replacement water supplies) and Compact compliance
- Measurement of Colorado's well pumping
- Colorado's 1998 irrigated acreage study (and its verification)
- Crop consumptive use values in the H-IM
- Colorado's changes to the H-IM
- Contested dry-up credits
- Prospective compact compliance modeling with the H-IM
- Measuring compact compliance
- Continuing jurisdiction

Like virtually all earlier trial phases, questions associated with computer modeling were central to the proceedings. The Special Master discusses some aspects of the model in each of his reports. We will summarize a few of the issues here.

H-IM is a hybrid distributed parameter model (see *supra* Part IV for a discussion) that simulates the physical and operational features of the Arkansas River and its alluvial aquifer. Although Kansas and Colorado both adopted the model, they independently adjusted and modified it over the years of the trial. The Fourth Special Master's Report makes reference to at least three different versions that were being run as late as 2002.[204] Moreover, Colorado experts pointed out many deficiencies in the initial model.[205] The model was not documented; it improperly specified both physical and operational relationships; and it operated with a mix of daily, monthly, and annual data. Further, it incorporated unrealistically simplified assumptions such as specifying that daily inflows are instantaneously available throughout the basin despite clear evidence to the contrary. Perhaps most problematic are the structural and specification errors like the inclusion of "diversion reduction factors" that limited some canal diversions, but had no real physical meaning and monthly demand factors or "want factors". These factors were used as calibration parameters that were internally inconsistent with assumptions used elsewhere in the model. Kansas experts had their own concerns about revisions that Colorado had made to the model.[206]

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201 A.L. Littleworth, First Report of the Special Master in Kansas v. Colorado (Volumes I & II) (1994).

202 This compact between the States of Colorado and Kansas, with the consent of the United States Congress, provides operating criteria for the John Martin Reservoir constructed by the Corps of Engineers in 1943. During the summer storage season (April 1 – October 31), Colorado may demand releases of water equivalent to the river flow up to 500 cubic feet per second. Kansas may demand releases of water equivalent to the portion of the river flow between 500 and 750 cubic feet per second. During the summer storage season, water being held in storage may be released upon demand by both states concurrently or separately in amounts dependent upon the magnitude of the storage. With concurrent demand, Colorado is entitled to 60 percent of the release and Kansas 40 percent.

203 Littleworth, supra note 4.

204 Id.

205 Brendecke, supra note 107.

206 Spronk Water Engineers, Inc. & S.S. Papadopulos & Assoc., Kansas Analysis of Colorado Compliance with the Arkansas River Compact 1997-1999 and Prospective Compact Compliance (Apr. 2001, rev. Jan. 2002).

For his part, the Special Master found the model to be inadequate to the task of compact compliance assessment on an annual basis (Kansas' preference) and, instead, opted for Colorado's proposal that the model assess compliance based on a 10 year average.[207]

Most of the model's flaws were discovered in the course of the trial either through expert review, discovery, or expert cross-examination, and the Special Master has pointed out that "the experts for both states agreed that the model results only provided best estimates."[208] Nonetheless, there is no doubt that the model was improved substantially in the course of the litigation process, but as the Kansas expert stated, when asked by the Special Master about the accuracy of the model, "the term 'accurate' is a little difficult to deal with since it implies that we know what depletions are…[But] since we don't have measurements of depletions, we can only provide estimates."[209]

The Special Master made his view of the model and the modeling process very clear in his Fourth Report:

> Modeling the Arkansas River Basin in Colorado is extraordinarily difficult, and perhaps unprecedented. Yet all of the experts from both states have testified that the use of a computer model is the only way to estimate what the river flows would have been in the absence of postcompact pumping. The modeling effort must represent highly variable river flows over 150 miles to the Kansas state line; the intervention of a major federal reservoir; storage and releases from numerous large private storage reservoirs; transmountain flows brought through tunnels from the west slopes of the Rocky Mountains. surface diversions initially made by some 23 canals operating under a priority system that regulates diversions by the hour; the reuse of all surface flows; ungaged tributary inflows and torrential summer thunder storms; consumptive use of various crops as well as phreatophytes along the river, both on the surface and from groundwater; pumping by upwards of 1000 wells; and the fallowing of land to provide replacement water to offset the impacts of pumping. And the model is then asked to estimate what the usable Stateline flows in the river would have been at any point in time if there had been no postcompact well pumping.[210]

A reasonable question is whether both a screening process like the use of the ASTM/*Daubert* criteria might have avoided some of the problems that still challenge the Arkansas River modelers and whether, in the course of the trial or as an initial phase of the trial, an "expert" resolution review (or some other process to identify and narrow the issues and expert disagreements) might have more efficiently dealt with many of these modeling issues in an equitable fashion.

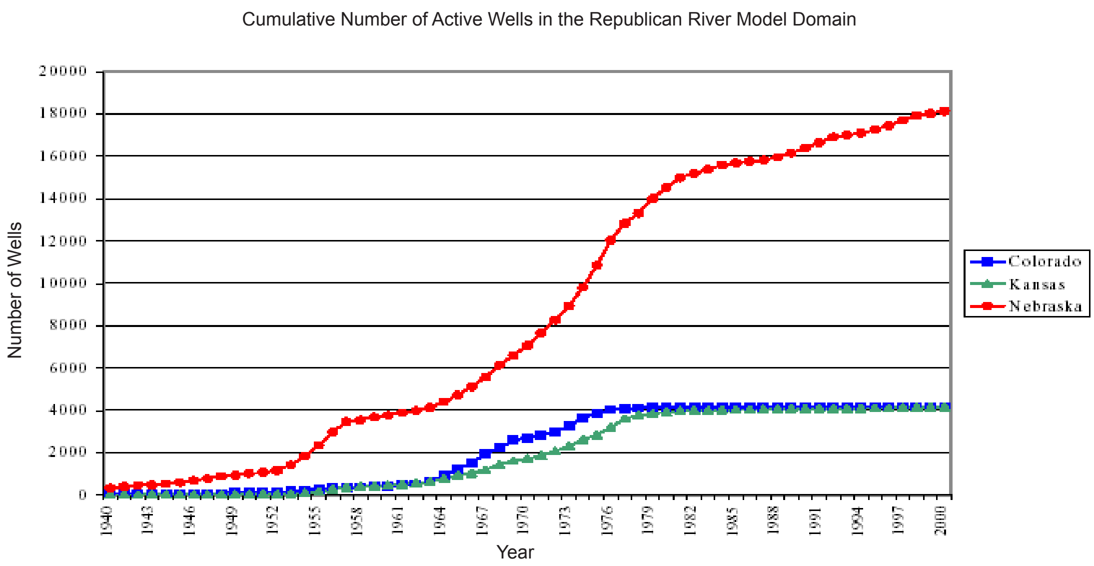
2. REPUBLICAN RIVER COMPACT: *KANSAS V. NEBRASKA AND COLORADO*[211]

The initial action in *Kansas v. Nebraska and Colorado* was brought by Kansas against Nebraska for violation of the 1943 Republican River Compact. On May 26, 1998, the State of Kansas filed a complaint in the United States Supreme Court that claimed the State of Nebraska had violated the Republican River Compact by allowing the unimpeded development of thousands of wells in an aquifer hydraulically connected to the Republican River and its tributaries. Kansas further alleged that Nebraska was using more water than its allocation under the Compact and was depriving Kansas of its full entitlement. (Kansas' concern with well development in Nebraska is reflected in Figure VIII.1). The United States joined as *amicus curiae* in January 1999. Colorado was joined in the lawsuit because the headwaters of the Republican River rise within that state and because it is a party to the Republican River Compact.[212]

207 Littleworth, supra note 4.
208 Littleworth, personal communications with author, June 2004 (on file with author).
209 Id.
210 Littleworth, supra note 4.
211 The summary of the case is taken primarily from Colorado Division of Water Resources, The Republican River Compact, http://water.state.co.us/wateradmin/RepublicanRiver.asp (2009).
212 The Republican River Compact allocates beneficial consumptive use of the Republican River, a small basin in northeastern Colorado, western Kansas and Nebraska, based on an estimate, contained in the compact, of virgin flows in the basin. Making allowances for changes if virgin flows vary by more than plus-or-minus 10 percent, Colorado is entitled to 54,100 acre-feet of beneficial consumptive use, Kansas to 190,300 acre-feet, and Nebraska to 234,500 acre-feet.

Nebraska denied Kansas' allegations and filed a Motion to Dismiss the case on the premise that the compact did not specifically mention groundwater, therefore groundwater could not be restricted or included in the allocation of consumptive use computations. Kansas argued the opposite and asserted that all forms of groundwater should be included within the computation of virgin water supply and consumptive use. Colorado offered an intermediate position and claimed the Compact and historic practice of the Republican River Compact Authority (RRCA) justified the inclusion of alluvial groundwater in computations, but not wells located on the tablelands that pump from the Ogallala aquifer.

FIGURE VIII.1. Well Development over Time in the Republican River Basin



After a hearing and review of party briefs and other supportive documentation, the Special Master issued a ruling in January 2000 that denied Nebraska's motion and concluded that groundwater was to be included within the allocation and consumptive use computations in the compact.[213]

The decision that all sources of groundwater were to be included in the allocation system in the compact was followed by two further procedural processes, the first a series of issues dealing with underlying or preliminary legal issues raised by the pleadings and the second an extensive discovery process needed by the construction of a hydrologic model. The completion of the first and the near completion of the second prompted the three states to request a stay in the trial to direct their efforts toward mediation.[214] The stay was granted and the states reached a tentative agreement on the major issues in April 2002. With additional time from the Special Master, they reached a final agreement in December 2002. The Final Settlement Stipulation, approved by the Supreme Court in May 2003, contained the waiver of claims, a moratorium on new wells, compact administration mechanisms, and a dispute resolution system, among other features. Perhaps most importantly, it also contained provisions for the cooperative development of a groundwater model to determine the amount, timing, and location of depletions from groundwater pumping that accrue to the Republican River and its tributaries.[215] The settlement's mandated model was intended to serve as the basis for future compact administration.

213 V.L. McKusick, First Report of the Special Master (Subject: Nebraska's Motion to Dismiss) (January 28, 2000).
214 McKusick, V.L., Presentation to Dividing the Waters, Seattle, Washington, October 8, 2004.
215 Following completion of the model in July 2003, the Supreme Court accepted the recommendation and Final Report of the Special Master, including final dismissal of the case with prejudice on October 20, 2003. Following completion of the model in July 2003, the Supreme Court accepted the recommendation and Final Report of the Special Master, including final dismissal of the case with prejudice on October 20, 2003. On May 3, 2010, Kansas filed suit in the U.S. Supreme Court to enforce the final settlement stipulation. According to Kansas, Nebraska has violated the compact and failed to take action necessary to avoid future violations, especially in the inevitable dry periods to come. Kansas urges the high court to hold Nebraska in contempt for disregarding the 2003 order adopting the final settlement stipulation and seeks damages.

Overall, model development in the Republican River Compact suit has been very different from that in the Arkansas. The model, a cooperative effort of the states with the active involvement of the US Geological Survey, is a hybrid distributed parameter model, but unlike H-IM is not of the one-of-a-kind, built-from-scratch variety, but is based on a modified version of an existing model code, MODFLOW 2000 (version1.10).[216] With additional modeling modules ("add-ons"), it calculates stream depletions from groundwater pumping and accretions from imported water supplies by using a finite-difference method to solve the groundwater flow equation, *Darcy's Law*. In developing the model the parties came to agreements on the conceptual model, model architecture, simulation period, discretization (spatial units and time steps), boundary and initial conditions, water balance, aquifer parameters, and pumping rates (or stress estimates). They also agreed on reservoir operations and evapotranspiration estimates. Finally, they agreed on the approach to calibrating the model, i.e., the purpose and goal of calibration, calibration targets (outputs to compare with field data), calibration standards (graphical rather than statistical comparison), and parameters to adjust in calibration. (The model is called the Republican River Compact Authority Model or the RRCA Model.)

The states established as their calibration objective achieving "…an acceptable level of correspondence between model inputs, results, and historical physical observations of the groundwater flow system in the Republican River Basin."[217] They also agreed to use a five-year period for averaging. The primary calibration targets were groundwater levels (in the non-irrigation season) and base flows (in the streams). The principal parameters adjusted in the calibration process were hydraulic conductivity (a measure of a soil's ability to transmit water when the soil is saturated or flow through an aquifer) and precipitation recharge (portion of precipitation that infiltrates the soil and reaches the groundwater table). In the calibration assessment experts applied "professional judgment" to compare model output in hydrograph format with hydrographs constructed from historic data.[218] (Note: There is no specific mention of sensitivity analysis in the model's description).

It would appear that all of the modeling issues have been resolved in the case of the Republican. The model has been built and accepted by all parties, it has passed their calibration assessment criteria, and it is stipulated to have achieved a reasonable level of correspondence between model output and historic data. It now serves as the primary Compact compliance monitoring tool for the basin.[219]

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216 The model is described in some detail in V.L. McKusick, Final Report of the Special Master with Certification of the Adoption of RRCA Groundwater Model in Kansas v. Nebraska and Colorado (Sept.17, 2003).

217 Id. at 43.

218 Id. at 46. The states specifically rejected the use of statistical assessments like those described above arguing that the model was too large and complex for the use of such methods.

219 While the Republican River Model is still accepted by all parties, a challenge has been raised by Nebraska as to how the model output is to be used in the compact compliance accounting process. Transcript of the Special Meeting of the Republican River Compact Commission at Kansas City, MO, March 11, 2008, at 96.

3. COMPARING THE RRCA MODEL WITH THE H-IM

A reasonable question to ask at this point, before discussing Park County Sportsmen's Ranch and the San Luis Valley, is whether the RRCA Model is a "better model" than the H-IM of the Arkansas (does it achieve a higher level of fidelity to the physical system?) or is it only a less controversial model. Another question is whether the approach taken in modeling the Republican is one to emulate in other adversarial settings.

The first question might be subdivided into more specific questions like the model's conformance to professional association criteria, transparency to other parties, and documentation. In all of these areas, the RRCA Model fares much better than HIM. The RRCA comes close to meeting both the ASTM guidelines and *Daubert* checklists. The H-IM appears to fail in this respect. Because the RRCA Model was developed as a cooperative effort between the parties, it is relatively transparent. The H-IM is more transparent now than it was at the commencement of litigation because it has been reviewed exhaustively by Colorado and by the Special Master, but it is still "understood" by a rather small number of individuals. Although the RRCA Model is fairly well documented, it still does not achieve the ASTM guidelines level. The documentation of HIM remains, for all practical purposes, an open question. While both states (Kansas and Colorado) recognize the need to use the model for future compliance issues, there is not agreement on whether the model itself is fully documented.

With regard to whether the Republican approach is one to emulate, there is general consensus among hydrologists and the legal community that the common enterprise approach or mediated model development is preferable. The superiority of the approach rests on the facts that data and expertise are pooled, a common understanding of the model develops, criteria for model performance are shared, there is a mutual interest in "getting it right," and the model is transparent to those who must use it and who will be judged by its results.

On the other hand, lest we suggest the Republican approach is without flaw, the RRCA calibration objective was not all that rigorous, i.e., achieving "…an acceptable level of correspondence between model inputs, results, and historical physical observations of the groundwater flow system in the Republican River Basin."[220] Furthermore, one of the important issues that was central to the Arkansas case was the question of damages. Damage calculations were not a part of the Republican dispute and it remains uncertain whether the RRCA would be an effective tool in damage calculations.

220 McKusick, supra note 216, at 43.

4. APPLICATION OF PARK COUNTY SPORTSMEN'S RANCH

In 1996, Park County Sportsmen's Ranch (PCSR) proposed a project in a high mountain valley (South Park) at the headwaters of Colorado's South Platte River and asserted that it could create a groundwater storage basin by withdrawing 140,000 acre-feet (AF) of water from the South Park Formation, a saturated aquifer approximately 25 miles long, and 5 miles wide at its extremes. (The formation consists primarily of sandstone and is 6000' thick at its extreme.. The cone of depression (depleted volume) that would be created by PCSR's pumping was to constitute a "storage vessel.. The withdrawn water would be discharged into the South Platte River stream system for delivery to the City of Aurora under an existing contract between the City of Aurora and PCSR.

PCSR proposed to store water, during times that the South Platte River system was under no priority call, by diverting excess stream flow into recharge reservoirs and ditch fields that would be located upon the upper surface of the South Park Formation. The water thus diverted and stored would percolate into the underlying aquifer, recharging it and reducing the volume of the depletion cone that would result from PCSR's pumping. PCSR claimed the amount of this recharge as the actual volume of the water it would store.

The South Park Formation is hydrologically connected ("tributary," in the words of Colorado water law) to the South Platte River system. PCSR had no water rights in the system, other than the 1996 rights that it sought in the application; hence, its pumping from the aquifer constituted an out-of-priority diversion that would eventually result in depletions to the stream system. At times of no water in the surface reservoirs, PCSR intended to augment these depletions by pumping additional water from the aquifer for direct discharge to the stream. PCSR proposed to determine the quantity and timing of depletions by use of the MODFLOW computer model to determine aquifer characteristics that govern the timing and amount of recharge, the fluctuation in the size of the depletion cone, and the timing, location and amount of stream depletions that would result under the proposal.

The depletion cone would exist beyond the life of the project until eliminated by recharge from natural sources, and would fluctuate in size based upon its correlation to precipitation patterns. Any quantification and timing of recharge, like quantification and timing of stream depletions, depended directly on the validity and reliability of PCSR's MODFLOW computer model.

In Colorado, the admission of scientific evidence and expert opinion is controlled by C.R.E. Rule 702. *People v. Schreck*, 22 P.2d 68 (Colo. 2001). (*Schreck* held that Rule 702, rather than the *Frye* test[221], represents the appropriate standard for determining the admissibility of scientific evidence, i.e., that the scientific principles upon which the evidence is based is reliable, and that the resulting evidence/opinion is relevant). In this case, the focus of Rule 702 was upon the reliability of the MODFLOW model output and the expert opinion based upon the model output. The relevance of such output and opinion turns on the usefulness of such evidence in resolving the controversies presented to the court.

The court found that the model itself is widely used to model aquifer parameters, among other uses, and that it is capable of producing reliable, relevant results. However, the court concluded that, in order for computer modeling results to be reliable, and hence relevant, the model must be operated in a manner that is consistent with accepted modeling techniques. The court held that the techniques applicable to the operation of a ground-water flow model such as MODFLOW are set forth in the American Society For Testing And Materials (ASTM) *Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem* (ASTM Guide D-5447), and *Calibrating a Ground-Water Flow Model Problem* (ASTM Guide D-5981). If the model were to be operated by some other method or standards, there would have to be sufficient evidence to establish that such other method or standards produce valid and reliable results.

221 Frye v. U.S., 293 F. 1013 (D.C. Cir. 1923)

Specifically, the court found that, as applied in this case, the model generated information that was not sufficiently reliable to support the experts' opinion or the court's reliance on modeling results, principally because.

1. The model was not calibrated in accordance with accepted standards.
2. No sensitivity analysis was conducted on the model.
3. The model produced anomalous results that PCSR's experts were unable to explain, specifically that repeated model runs based upon identical data produced different outcomes. For example, the residual error in water level prediction, in two successive runs on each of 12 wells, ranged between 6 feet and 198 feet.
4. The residual error between observed and model-predicted levels for 15 of 33 flowing springs exceeded 1 foot, and ranged between +46 feet and –26 feet. The absolute residual mean was 14 feet.
5. PCSR's expert and model designer recognized and reported the need for:
    a) Additional data
    b) Additional model calibration
    c) Explanation of the anomalous results
    d) Further evaluation of the model target data, before he could defend the admissibility of the model results at trial
6. An independent peer review was begun, but not completed.[222]

Subsequent to the case, in comments made on "Hydrologic Models in the Courtroom: Working Paper" (Dividing the Waters Model Assessment Committee), the presiding judge wrote that he did not think that it made much difference to the results whether one applied the *Frye, Daubert/Schreck,* or Rule 702 standards for admissibility of scientific evidence (see Appendix C). Under any of these tests, the proponent must show that the correct protocol was followed in conducting the test at issue.

The judge also thought that groundwater modeling evidence was likely to be regularly received into evidence at future trials in both state and federal courts, because parties would be unlikely to present a model and its results which would fail to meet established thresholds for admissibility. He further noted that the research and preparation in developing a model and generating results is too costly for a litigant to risk its outright exclusion at trial. Hence, in the majority of cases the outcome will depend upon the weight given to the modeling results by the trier of fact. In PCSR, the opposing parties were so confident of their ability to undermine PCSR's model that they did not offer a model of their own, and declined PCSR's offer to run the model using the opposition's data. The opposition made these decisions after PCSR had provided them with their model and modeling results.

The judge also observed that if his assumption about the general admissibility of modeling evidence was correct, then the primary issue in the future will be the appropriate weight the trier of fact should give to modeling results. Nonetheless, he pointed out the need to distinguish between the threshold tests of admissibility, all of which have several factors, and the specific factors of admissibility that a given court will likely consider in determining whether the threshold has been met.

As discussed in Part V, *supra*, tests for admissibility are *Frye*, *Daubert,* and FRE 702 or its state-court equivalent. The *Frye* test includes "general acceptance in the relevant scientific community." Such acceptance can be established through the testimony of experts familiar with the degree to which a given groundwater model is accepted as valid. Evidence of general acceptance may also be found in journals or other professional publications that address relevant scientific issues (e.g. groundwater models, etc.). The three *Daubert* factors on which he focused included whether the techniques employed: 1) have a known error rate, 2) are subject to standards governing their application and, 3) enjoy widespread acceptance.

222 See Hays, supra note 125.

The first factor struck the PCSR judge as vague. While oft repeated by the parties and in the literature, the known error rate had never been quantified, nor had any other court decided whether the absence of a known error rate, or the magnitude of a known error rate, was fatal to the admissibility of hydrologic modeling evidence.

On standards, he believed the trend was toward accepting the ASTM guidelines as the appropriate standards to govern the operation of groundwater models. He cited his own ruling in the PCSR case and the Fourth Special Master's Report in the Arkansas River compact case as examples. The choice to apply consistent guidelines will not alter, in his opinion, the general acceptance by courts of modeling principles. Applying the guidelines will merely change the stage of litigation at which the adequacy of the procedures used, the assumptions made, and the internal consistency of the results are called into question and resolved by the court.

Regarding the third factor, widespread acceptance, he noted that the factor is common to both *Frye* and *Daubert* inquiries. However, the FRE 702 and its state-court equivalents require that the trial judge ensure that scientific evidence be both: a) *relevant,* whether the evidence will be useful to the trier of fact insofar as it tends to make the existence or absence of a fact more probable than not; and b) *reliable,* whether the scientific principles to which the witness is testifying are reasonably reliable, and whether the witness is qualified to opine on such matters. He concluded that this rule confers broad discretion upon the trier of fact, and results in an almost uniform acceptance of modeling principles by the courts.

5. CONFINED AQUIFER NEW USE RULES IN THE SAN LUIS VALLEY OF COLORADO

In June, 2004, the Colorado State Engineer adopted rules governing the major aquifers in the San Luis Valley in south central Colorado (*Rules Governing New Withdrawals of Ground Water in Water Division 3 Affecting the Rate or Direction of Movement of Water in the Confined Aquifer System* ("Rules")). Later that month, the State Engineer filed the Rules with the Water Clerk, Water Division No. 3, the water court for the Rio Grande River basin. Subsequently, several parties filed statements either in protest or support of the Rules (so-called "statements of opposition").

After a number of intermediate steps and actions, the trial on protests to the Rules began in January, 2006 and proceeded through March of the same year. A central feature of the case was the State of Colorado's Rio Grande Decision Support System (RGDSS), the river basin model that formed the foundation for the groundwater model that was to be central to some of the challenges in the case.

The Protestors argued that the State Engineer had not met its burden of proof and that the Rules were unconstitutional because they violate the right, under Colorado's constitution, to appropriate the waters of the State to the extent that the Rules prohibited diversions of water that would not cause material injury to vested rights. They specifically challenged the provisions that automatically require that every new appropriation be offset by the retirement or change to an equivalent existing water right, (i.e., 100% augmentation), without regard to whether such new appropriation causes injury to a vested water right. They also attacked the provisions related to the treatment of evapotranspiration of groundwater of non-irrigated native vegetation, claiming that the provisions lacked a rational basis and were therefore facially unconstitutional.

The hydrology and geology of the San Luis Valley (the "Valley") are highly complex, and the Valley has many features that are unique when compared to other river basins within the state. This complexity prompted the Protestors to raise a number of questions related to whether: (1) the Valley-wide water balance was a true measure of the aquifer's sustainability; (2) additional new water could be appropriated and pumped from the confined aquifer without affecting the sustainability of the system; (3) additional new water could be appropriated and pumped from the confined aquifer without affecting the Rio Grande Compact; (4) reducing artesian pressure in the confined aquifer resulted in the need for one-to-one augmentation; and (5) pumping in the unconfined aquifer affected the artesian pressure in the confined aquifer, regardless of the amount of water being pumped from the confined aquifer.

For the State Engineer, RGDSS was the primary tool used to support the Rules. The Protestors argued that the model was unacceptable as used by the State because: (1) it did not converge (on a solution) and, thus, could not be used for any predictive purposes; (2) the output from the model did not represent reasonable, valid, or even physically possible results; (3) the Rule erroneously refers to the "RGDSS Ground Water Model" as being the program developed by the USGS commonly known as MODFLOW; (4) the model was not sufficiently calibrated, nor had there been any sensitivity testing done to establish its use as an appropriate tool for regulatory purposes; (5) the model was not a valid functioning model; (6) only steady-state model simulations can provide a reliable evaluation of long-term sustainability of new groundwater development; (7) the current version of the RGDSS groundwater model could not be relied upon to predict evapotranspiration (ET); and (8) the complete model was not available for use in the specific study on which the legislature relied to enact the statute that led to the Rules.

Note that the Protestors claimed that the model had not been "sufficiently *calibrated*," had not been subjected to any "*sensitivity* testing," and as a result was not a "*valid*" model. Notwithstanding these claims, the Court, after 26 trial days between January and March and over a year of preliminary activity, found that the "…RGDSS groundwater model is reasonably accurate and reliable and is sufficient for its intended uses under the Rules."[223]

The Court further found that:

> The RGDSS groundwater model was developed following proper protocols and procedures, that it is calibrated to a degree sufficient for its intended uses under the Rules, and that the inputs to said model are reasonably accurate and may be relied upon for purposes of the Rules. The model's accuracy for application to specific circumstances is properly subject to a rebuttable presumption that the version of the RGDSS groundwater model in use at the time an application for a plan for augmentation is filed, accurately determines the amount, time, and location of depletions and fluctuations in artesian pressures that would be caused by a new withdrawal of groundwater from the Confined Aquifer System…[224]

The Court clearly found that the model was carefully and adequately developed. Echoing Woessner and Anderson's suggested approach (discussed *supra*, Part IV), the Court seemed to recognize the inherent uncertainty associated with models, the need for caution, the role of judgment and experience, and ultimately the realization that our understanding and modeling of complex systems is incomplete, but evolving. As the Court said, "[u]nderstanding of the San Luis Valley's hydrogeology is incomplete and therefore some findings, beliefs, assumption and conclusions will likely be brought into question over time and must all be open to re-examination utilizing the scientific method."[225]

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223 O. John Kuenhold, Findings of Fact, Conclusions of Law, J. and Decree, In re. Protests to Confined Aquifer New Use Rules for Div. 3, Case No. 2004CW24, 5 (2004).page 5.
224 Id., page 5.
225 Id., page 5

BIBLIOGRAPHY

(Organized by topic)

MODELS, CALIBRATION, VALIDATION, AND VERIFICATION

K.C. Abbaspour, *Calibration of Hydrologic Models: When is a Model Calibrated?*, In Zerger, A. and Argent, R.M. (eds) MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, pp. 2449-12455, (December 2005).

Mary P. Anderson & William W. Woessner, *The Role of the Postaudit in Model Validation*, 15 Advances in Water Res. Research 167 (1992).

________________________________, Applied Groundwater Modeling – Simulation of Flow and Advective Transport (Academic Press, Inc., 1992).

E.Scott Bair, *Models in the Courtroom*, *in* Model Validation: Perspectives in Hydrological Sciences (M.G. Anderson & P.D. Bates eds., John Wiley & Sons, Ltd. 2001).

Sten Bergstrom, *Principles and Confidence in Hydrologic Modeling*, 22 Nordic Hydrology 123 (1991).

Keith Beven, *How far can we go with distributed hydrologic models?*, 5 Hydrology and Earth System Sciences 1, (2001).

Keith Beven & Andrew Binley, *The Future of Distributed Models: Model Calibration and Uncertainty Prediction*, 6 Hydrological Processes 279 (1992).

D.P. Boyle et al., *Towards Improved Streamflow Forecasts; The Value of Semi-Distributed Modeling*, 37 Water Res. Research 2749 (2001).

John D. Bredehoeft & Leonard F.Konikow, Editorial, *Model Validation,* 31 Ground Water 178 (March-April, 1993).

Thian Gan & Getu Biftu, *Automatic Calibration of Conceptal Rainfall-Runoff Models: Optimization Algorithms, Catchment Conditions, and Model Structure*, 32 Water Res. Research 3513 (1996).

Hoshin Vijai Gupta et al., *Toward Improved Calibration of Hydrologic Models: Multiple and Noncommensurable Measures of Information*, 34 Water Res. Research 751 (1998).

Nien-Sheng Hsu et al., *Proposed Daily Streamflow-Forecasting Model for Reservoir Operation*, 121 J. of Water Res. Plan. and Manag. 132 (1995).

Vet Klemes, *Empirical and Causal Models in Hydrology*, *in* Scientific Basis of Water-Resources Management (National Academy Press 1982).

____________, *Dilettantism in Hydrology: Transition or Destiny?,* 22 Water Res. Research 177S (1986).

____________, Common Sense and Other Heresies: Selected Papers on Hydrology and Water Resources Engineering, Canadian Water Resources Association (2000).

____________, *Operational Testing of Hydrological Simulation Models*, 31 Hydrological Sciences Jour. 1 (1986).

P. Krause, D.P. Boyle, F. Base, *Comparison of Different Efficiency Criteria for Hydrologic Model Assessment*, ADVANCES IN GEOSCIENCES 5 (205).

C.P. Kumar, *Pitfalls and Sensitivities in Groundwater Modelling*, IE(I) JOURNAL 84 (August 2003).

Keith Loague and Joel E. VanderKwaat, *Physics Based Hydrologic Response System: Platinum Bridge, 1958 Edsel, or Useful Tool*, HYDRO. PROCESS. 18 (2004).

David Meko and Donald A. Graybill, *Tree-ring reconstruction of Upper Gila River discharge*, 31 Water Res. Bull. 4, 605-616 (1995).

M. Mroczkowski et al., *The Case for More Powerful Validation of Conceptual Catchment Models*, 33 WATER RES. RESEARCH 2325 (1997).

J.E. Nash & J.V. Sutcliffe, *River Flow Forecasting Through Conceptual Models: Part I – A Discussion of Principles*, 10 J. OF HYDROLOGY 282 (1970).

Naomi Oreskes et al., *Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences*, SCIENCE, Feb. 4, 1994, at 641.

Charles Perrin et al., *Does a Large Number of Parameters Enhance Model Performance? Comparative Assessment of Common Catchment Model Structures on 429 Catchments*, 242 J. OF HYDROLOGY, 275 (2001).

David E. Prudic, Richard G. Niswonger, and Russell W. Plume, *Trends in Streamflow on the Humboldt River between Elko and Imlay, Nevada, 1950–99*, USGS RESOURCES SCIENTIFIC INVESTIGATIONS REPORT 2005-5199, (2005).

Jens C. Refsgaard, *Parameterization, Calibration, and Validation of Distributed Hydrologic Models*, 198 J. OF HYDROLOGY 69 (1997).

J. Rivera-Santos, A Methodology for Parameter Estimation in Conceptual Precipitation-Runoff Models with Emphasis on Error Analysis (1988) (unpublished Ph.D. thesis, University of Colorado, Boulder) (on file with University of Colorado library).

U.S. DEPT. OF INTERIOR, PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM: FINAL ENVIRONMENTAL IMPACT STATEMENT (April 2006).

John J. Warwick, *Interplay Between Parameter Uncertainty and Model Aggregation Error*, 25 WATER RES. BULL. 275 (1989).

William W. Woessner & Mary P. Anderson, *Good Model-Bad Model, Understanding the Flow Modeling Process, in* SUBSURFACE FLUID-FLOW (GROUND-WATER AND VADOSE ZONE) MODELING, at 1288, (Ritchey & Rumbaugh eds., 1996).

MODEL CRITERIA AND GUIDELINES

Am. Society of Civil Engineers Task Committee on Definition of Criteria for Evaluation of Watershed Models, *Criteria for Evaluation of Watershed Models*, 119 J. of Irrig. and Drain. Engr. 429 (1993).

American Society of Testing and Materials (1993-96)

- Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem (D 5447-93) (1993)
- Standard Guide for Comparing Ground-Water Flow Simulations to Site-Sepcific Information (D 5490-93) (1993).
- Standard Guide for Defining Boundary Conditions in Ground-Water Flow Modeling (D 5609-94) (1994).
- Standard Guide for Defining Initial Conditions in Ground-Water Flow Modeling (D 5610-94) (1994).
- Standard Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application (D 5611-94) (1994).
- Standard Guide for Documenting a Ground-Water Flow Model Application (D 5718-95) (1995).
- Standard Guide for Subsurface Flow and Transport Modeling (D 5880-95) (1995).
- Standard Guide for Calibrating a Ground-Water Flow Model Application (D 5981-96) (1996).

T.E. Reilly & A.W. Harbaugh, USGS Guidelines for Evaluating Ground-Water Flow Models, Scientific Investigations Report 2004-5038 (2004).

SCIENTIFIC EVIDENCE, EXPERT TESTIMONY, AND CASE MANAGEMENT

American Association for the Advancement of Science (AAAS), *Court Appointed Scientific Experts (CASE); A Demonstration Project*, http://www.aaas.org/spp/case/case.htm (last visited Feb. 17, 2009).

David E. Bernstein, *Expert Witnesses, Adversarial Bias, and the (Partial) Failure of the Daubert Revolution*, 93 Iowa L. Rev. 451 (2008).

Margaret G. Farrell, *Coping with Scientific Evidence: the Use of Special Masters*, 43 Emory L. J. 927 (1994).

Joe S. Cecil an. Thomas E. Willging, *Accepting Daubert's Invitation: Defining A Role for Court-Appointed Experts in Assessing Scientific Validity*, 43 Emory L. J. 995 (1994).

Federal Judicial Center, Reference Manual on Scientific_Evidence (2d ed. 2000).

________________, Manual For Complex Litigation (4th ed. 2004).

John J. Gibbons, *Tenth Anniversary of the Supreme Court Decision in Daubert v. Merrell Dow Pharmaceutical, Inc: The Respective Roles of Trial Appellate Courts in Daubert-Kumho Rulings*, 34 Seton Hall L. Rev. 127 (2003).

The Judicial Panel on Multidistrict Litigation & The Federal Judicial Center, Ten Steps to Better Case Management: A Guide for Multidistrict Litigation Transferee Court Clerks.

Francis E. McGovern, *Toward a Functional Approach for Managing Complex Litigation*, 53 University of Chicago Law Review 2 (Spring, 1986).

National Academy of Sciences, The Age of Expert Testimony; Science in the Court Room, Report of Workshop, Washington, DC, 2002.

James K. Sebenius, *The Computer as Mediator: Law of the Sea and Beyond*, 1 Journal of Policy Analysis and Management 1 (Autumn, 1981).

CASE EXAMPLES

C.M. Brendecke, Review of the Kansas Analysis of Colorado Compliance with the Arkansas River Compact 1997-1999 and Prospective Compliance (Apr. 2002).

Colorado Division of Water Resources, *The Republican River Compact,* http://water.state.co.us/wateradmin/RepublicanRiver.asp (last visited Feb. 14, 2009).

Jonathan W. Hays, Order Dismissing Application (C.R.C.P. Rule 41(b)(1)) Concerning the Application for Water Rights of the Park County Sportsmen's Ranch (2001).

O. John Kuenhold, Findings of Fact, Conclusions of Law, J. and Decree, In re. Protests to Confined Aquifer New Use Rules for Div. 3, Case No. 2004CW24, 5 (2004).

Arthur L. Littleworth, First Report of the Special Master in *Kansas v. Colorado* (Volumes I & II) (1994).

_______________, Second Report of the Special Master in *Kansas v. Colorado* (1997).

_______________, Third Report of the Special Master in *Kansas v. Colorado* (2002).

_______________, Fourth Report of the Special Master in Kansas v. Colorado (2003).

Vincent L. McKusick, First Report of the Special Master (Subject: Nebraska's Motion to Dismiss) in *Kansas v. Nebraska and Colorado* (2000).

______________, Second Report of the Special Master (Subject: Final Settlement Stipulations) in *Kansas v. Nebraska and Colorado* (2003).

______________, Final Report of the Special Master with Certification of the Adoption of RRCA Groundwater Model in *Kansas v. Nebraska and Colorado* (2003).

Memorandum from Steven Miller & Randy Seaholm to the Colorado Water Conservation Board: Request for Expenditure from Litigation Fund for Kansas v. Colorado Costs, (March 3, 2004).

Spronk Water Engineers, Inc. & S.S. Papadopulos and Assoc., Kansas Analysis of Colorado Compliance with the Arkansas River Compact 1997-1999 and Prospective Compact Compliance (Denver, Colorado, April 2001, revised January 2002) (copy on file with author).

APPENDICES

APPENDIX A
SELECTED EXAMPLES OF MODEL (CODE) DESCRIPTIONS

RiverWare (U.S. Bureau of Reclamation)

RiverWare is a general-purpose, interactive model building tool used to develop water-distribution models for short-term operations and scheduling, mid-term operations and planning, and longer-term policy and planning. The modeling framework was developed by the Center for Advanced Decision Support for Water and Environment Systems (CADSWES) at the University of Colorado with funding provided by U.S. Bureau of Reclamation, Tennessee Valley Authority (TVA), and Electric Power and Research Institute (EPRI).

Within RiverWare, the user constructs the basic network of a river system that may include reservoirs, diversions, river reaches, confluences, or other components. (An example of a RiverWare computer screen for the Yakima River Basins can be seen in Figure A-1.) Data associated with each component can be entered on-screen through spread sheets or imported from the database. The operations policy and rules associated with reservoirs or other system components within the basin are added to RiverWare through an existing constraint editor. Current modeling methods within RiverWare include basic reservoir simulation and water distribution through the network using linear programming, goal programming, and rule-based simulation approaches.

FIGURE A-1. Example of RiverWare Computer Screen for Yakima River

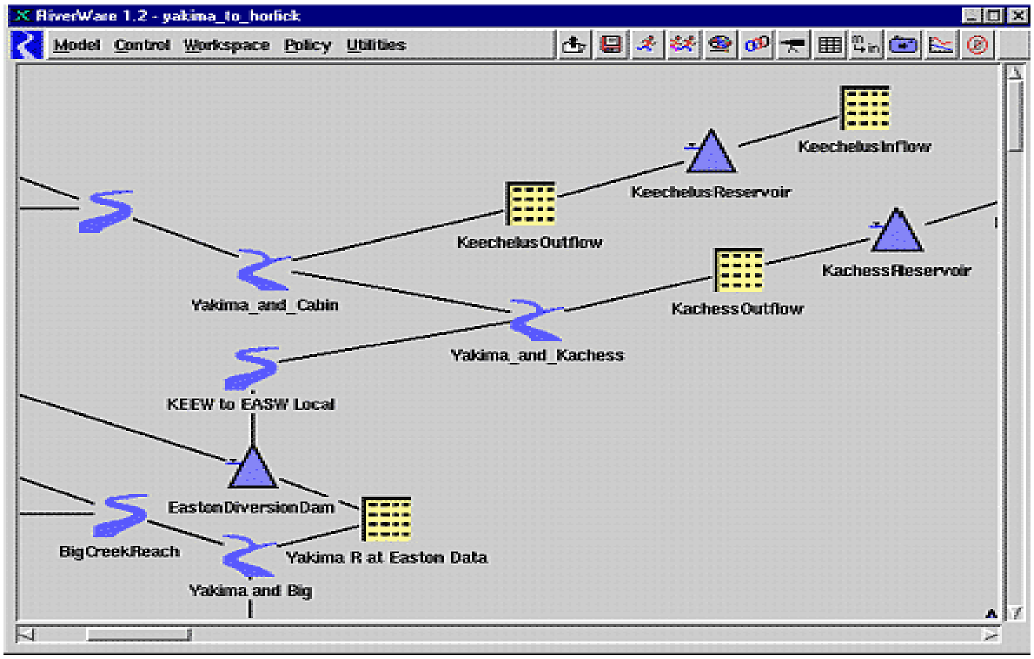


Figure 5. Computer screen showing model layout of RiverWare for the upper Yakima River showing two reservoirs, a diversion dam, inflows, outflows and six reaches.

CALSIM (CALIFORNIA DEPARTMENT OF WATER RESOURCES)

The California Department of Water Resources has developed a general purpose water resources simulation model, CALSIM, that enables users to develop system representations and specify operational criteria. CALSIM represents a fundamental change in the modeling approach used to simulate the operation of California's water resource systems, particularly the coordinated operation of the Federal Central Valley Project (CVP) and the California State Water Project (SWP). Model users now specify the system objectives and constraints as input to the model, rather than embedding the simulation goals and logic in thousands of lines of procedural code as is common in traditional simulation models. While CALSIM is not a prescriptive optimization model, it utilizes optimization techniques to efficiently route water through a network given user-defined priority weights. A linear programming (LP)/mixed integer linear programming (MILP)[1] solver determines an optimal set of decisions for each time period given a set of weights and system constraints.

The physical description of the system is expressed through a user-interface with tables outlining the system characteristics. The priority weights and basic constraints are also entered in the system tables. A new modeling language, Water Resources Engineering Simulation Language (WRESL), has been developed to serve as an interface between the user and the LP/MILP solver, time-series database, and relational database. Specialized operating criteria are expressed in WRESL. The WRESL expressions can be compartmentalized to provide for a highly organized arrangement of logical units and to serve as self-documenting modules. CALSIM is intended to replace the California Department of Water Resources' existing simulation model, DWRSIM, as well as PROSIM, another simulation model of the SWP/CVP system extensively used by the U.S. Bureau of Reclamation. However, the structure of the CALSIM engine is highly generic, such that the model can be applied to many other water resource systems.

HYDROLOGIC ENGINEERING CENTER HYDROLOGIC MODELING SYSTEM (HEC-HMS) (U.S. ARMY CORPS OF ENGINEERS)

The Hydrologic Modeling System is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology, and systems operation. HMS features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the user movement between the different parts of the program. Program functionality and appearance are the same across all supported platforms.

Time-series, paired, and gridded data are stored in the Data Storage System HEC-DSS (U.S. Army Corps of Engineers (USACE) 2003). Storage and retrieval of data are handled by the program and are generally transparent to the user. Precipitation and discharge gauge information can be entered manually within the program or can be loaded from previously created DSS files. Results stored by the program in the database are accessible by other HEC software. Data entry can be performed for individual basin elements such as subbasins and stream reaches or simultaneously for entire classes of similar elements. Tables and forms for entering necessary data are accessed from a visual schematic of the basin. All computations are performed in metric units. Input data and output results may be U.S. customary or metric and are automatically converted when necessary.

1 Linear programming is a mathematical routine for optimizing a linear objective function while, at the same time, meeting a set of linear equalities and inequalities. Mixed integer linear programming constrains some of the variables to take on only interger values.

MODFLOW (2005) (U.S. GEOLOGICAL SURVEY)

MODFLOW is a three-dimensional finite-difference groundwater model that was first published in 1984. It has a modular structure that allows it to be easily modified to adapt the code for a particular application. Many new capabilities have been added to the original model. Harbaugh (2005) documents a general update to MODFLOW, which is called MODFLOW-2005 in order to distinguish it from earlier versions.

MODFLOW-2005 simulates steady and nonsteady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains,and flow through river beds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (restricted to having the principal directions aligned with the grid axes), and the storage coefficient may be heterogeneous. Specified head and specified flux boundaries can be simulated as can a head dependent flux across the model's outer boundary that allows water to be supplied to a boundary block in the modeled area at a rate proportional to the current head difference between a "source" of water outside the modeled area and the boundary block.

In addition to simulating ground-water flow, the scope of MODFLOW-2005 has been expanded to incorporate related capabilities such as solute transport and ground-water management; however, this distribution incorporates only the ground-water flow parts of MODFLOW. The ground-water flow equation is solved using the finite-difference approximation. The flow region is subdivided into blocks in which the medium properties are assumed to be uniform. In plan view the blocks are made from a grid of mutually perpendicular lines that may be variably spaced. Model layers can have varying thickness. A flow equation is written for each block, called a cell. Several solvers are provided for solving the resulting matrix problem; the user can choose the best solver for the particular problem. Flow-rate and cumulative-volume balances from each type of inflow and outflow are computed for each time step.

HYDROLOGIC SIMULATION PROGRAM (HSPF) (U.S. GEOLOGICAL SURVEY)

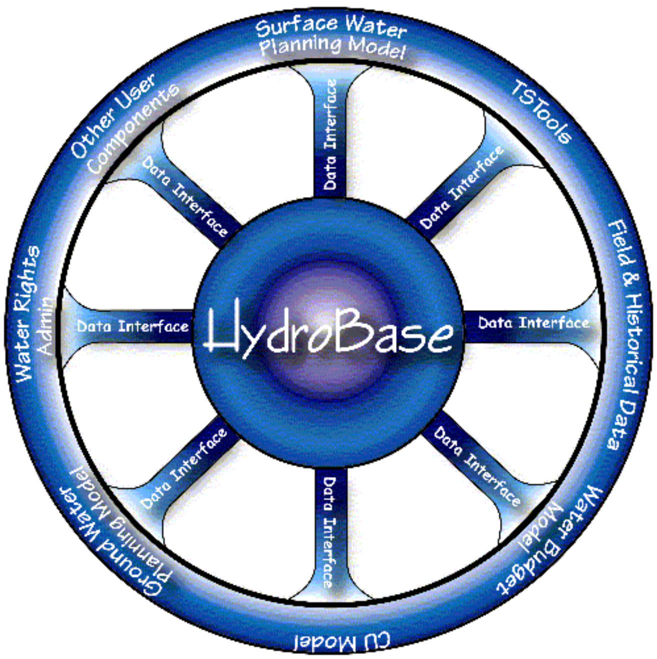
HSPF simulates for extended periods of time the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments.

HSPF uses continuous rainfall and other meteorologic records to compute streamflow hydrographs and pollutographs. HSPF simulates interception soil moisture, surface runoff, interflow, base flow, snowpack depth and water content, snowmelt, evapotranspiration, ground-water recharge, dissolved oxygen, biochemical oxygen deman (BOD), temperature, pesticides, conservatives, fecal coliforms, sediment detachment and transport, sediment routing by particle size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton. Program can simulate one or many pervious or impervious unit areas discharging to one or many river reaches or reservoirs. Frequency-duration analysis can be done for any time series. Any time step from 1 minute to 1 day that divides equally into 1 day can be used. Any period from a few minutes to hundreds of years may be simulated. HSPF is generally used to assess the effects of land-use change, reservoir operations, point or nonpoint source treatment alternatives, flow diversions, etc. Programs, available separately, support data preprocessing and postprocessing for statistical and graphical analysis of data saved to the Watershed Data Management (WDM) file.

The model was developed in the early 1960s as the Stanford Watershed Model. In the 1970s, water-quality processes were added. Development of a Fortran version incorporating several related models using software engineering design and development concepts was funded by the Athens, Ga., Research Lab of EPA in the late 1970s. In the 1980s, preprocessing and postprocessing software, algorithm enhancements, and use of the USGS WDM system were developed jointly by the USGS and EPA. The current release is Version 11. An interactive version (see HSPEXP) was developed by the USGS in the 1990s.

COLORADO DECISION SUPPORT SYSTEM (COLORADO DEPARTMENT OF NATURAL RESOURCES)

The Colorado Decision Support System (CDSS) is a hydrologic computer model resources management system developed by the Colorado Water Conservation Board (CWCB) and the Colorado Division of Water Resources (DWR) covers the following to assist water users and managers to make timely, informed decisions regarding historic and future use of Colorado's water. CDSS has been structured on the following principles: 1) development of accurate, user-friendly databases that are helpful in the administration and allocation of the water resources of the State of Colorado; 2) provision of data and models to evaluate alternative water administration strategies, which can maximize utilization of available resources in all types of hydrologic conditions; 3) establishment of a functional system that can be used by decision-makers and others and be maintained and upgraded by the State; 4) creation of the capability to accurately represent current and potential federal and state administrative and operating policies and laws; and 5) promotion of information sharing among government agencies and water users. The system is structured around the HydroBase concept in Figure A-2 below.



Portions of the CDSS database cover the entire state. Currently there are complete systems, including data, tools and models, for the Colorado and Rio Grande Basins. Work continues on the South Platte Basin system. Long range plans of both the CWCB and DWR are to eventually complete a DSS system for the Arkansas River Basin. A DSS in the Republican River Basin is not planned at this time.

Within its DSS Colorado's DNR has developed a Stream Simulation Model (StateMod). The StateMod model is a generic water resource model capable of simulating stream diversions, instream flow demands, well pumping, reservoir operations and river flows on a monthly or daily basis for any stream system. Fully developed and calibrated StateMod models represent all direct flow and storage water rights and reservoir operations in the following river basins: Upper Colorado River and Gunnison River basins, White River and Yampa River basins, San Juan River and Dolores River basins, and Rio Grande basin in Colorado and the Bear River basin in Wyoming. From simple to complex environments and across a wide scale of basins the publicly-available StateMod model can be used to negotiate cooperative settlements, develop water resources policy between multiple entities, and optimize benefits of western water resources.

MODSIM–DSS (COLORADO STATE UNIVERSITY)

MODSIM-DSS is a generalized river basin Decision Support System and network flow model developed at Colorado State University designed specifically to analyze complex river basin management problems. MODSIM-DSS is designed for constantly evolving and multifaceted river basin management environment.

MODSIM-DSS is structured as a Decision Support System, with a graphical user interface (GUI) allowing users to create any river basin system topology. Data structures embodied in each model object are controlled by a data base management system. Formatted data files are prepared interactively and a highly efficient network flow optimization model is automatically executed from the interface without requiring any direct intervention by the user. Results of the network optimization are presented in useful graphical plots.

MODSIM-DSS can be linked with stream-aquifer models for analysis of the conjunctive use of groundwater and surface water resources. MODSIM-DSS can also be used with water quality simulation models for assessing the effectiveness of pollution control strategies. MODSIM-DSS can also be used with geographic information systems (GIS) for managing spatial data base requirements of river basin management.

PACSIM (PLATTE AND COLORADO SIMULATION MODEL) (DENVER WATER BOARD)

The Platte and Colorado River Simulation Model (PACSM) is an integrated system of computer programs developed by Denver Water to simulate streamflows, reservoir operations and water supply in the South Platte and Colorado River basins. PACSM includes the operation of Denver's raw water collection system as well as the system operations of many other entities.

PACSM uses daily hydrology from the years 1947 through 1991, which include the drought conditions of the 1950s. The hydrology is then applied to existing and proposed operating conditions. In PACSM, the river system is represented as a series of measurement points called "nodes.. Each node represents a diversion, a reservoir, a stream gage, a stream segment requiring a minimum amount of streamflow, or any location where hydrology information is needed. There are more than 470 nodes in PACSM that are "linked" by river channels, canals, pipelines or aqueducts. At each node, many types of information are available. For example, at a reservoir node the information includes inflow, evaporation, elevation, exchange operations, seepage, and reservoir releases.

In PACSM, water is allocated to a diversion or reservoir based upon the following: 1) available streamflow, 2) water rights, 3) physical diversion or storage capacity, and 4) demand. Because the 45-year model period incorporates daily data at over 470 locations, the input and output data files are very large.

To determine the collection system's yield, the model is run at a trial level of demand based on existing system facilities and water rights, and historic virgin flows during the 1947-1991 study period. If the simulation shows that there is surplus water in the reservoirs throughout the model period, the model simulation is repeated with an increased demand. Conversely, if the simulation indicates that the demand cannot be met at all times because the reservoirs have emptied, the simulation is repeated with a reduced demand. This iterative process continues until the model simulation shows reservoir storage becoming virtually empty during the study period without causing any shortfall in meeting demand.

CENTRAL RESOURCE ALLOCATION MODEL (CRAM) (HYDROSPHERE-AMEC)

Central Resource Allocation Model (CRAM) is a generalized network modeling tool, that combines a network flow model, originally developed by Quentin Martin at the Texas Water Development Board, with customizing capability to provide user with accounting functions and iterative solutions to address: 1) hydrological and physical features of a basin; 2) reservoir operations; 3) hydropower; 4) bank storage; 5) evaporation; 6) dynamic return flow; 7) well pumping; 8) water quality constituent concentration; and 9) conveyance loss. It also can incorporate institutional features such as: 1) storage accounts; 2) instream flow requirements; 3) water exchanges; 4) water rights and decrees; 5) interstate compacts; and 6) water supply contracts.

CRAM is a system of compiled DLL modules (Dynamic Link Library modules) linked to Microsoft Excel, allowing integration of the network optimization code with Excel's spreadsheet and graphing capabilities. Its advanced features have the ability to add custom VBA programming (Visual Basic for Applications programming).

APPENDIX B
MATHEMATICAL APPROACHES TO MODEL CALIBRATION

Table B.1 contains a list of the kinds of criteria that are often used or recommended to summarize and assess the modeling errors (the difference between observed values [d_t] and simulated values [$o_t(q)$]) in the calibration processes. Some measure absolute error, some mean error, some bias, and some the correlation among errors. All are designed to give the model builder information on which to base adjustments to parameters.

TABLE B.1. Examples of Modeling Error Estimates Used in Calibration

Type of Error Measure	Formula
Root Mean Square Error	$((\sum (d_t - o_t(\theta))^2)/n)^{1/2}$
Mean Absolute Error	$(\sum \lvert d_t - o_t(\theta)\rvert)/n$
Maximum Absolute Error	$\max \lvert d_t - o_t(\theta)\rvert$
Nash-Sutcliffe Measure	$1 - (\sum(d_t - o_t(\theta))^2/\sum(d_t - \underline{d})^2)$
Bias (Mean Error)	$(\sum(d_t - o_t(\theta)))/n$
Autocorrelation of Error	$(\sum(d_t - o_t(\theta))(d_{t+1} - o_{t+1}(\theta)))/n$

Where: d_t is observed value at time step t,
$o_t(q)$ is simulated value at time step t,
q is an array of calibration parameters,
$\underline{d}$ is the mean value of observations,
n is the number of observed and simulated values, and
all summations (å) are for t from 1 to n.

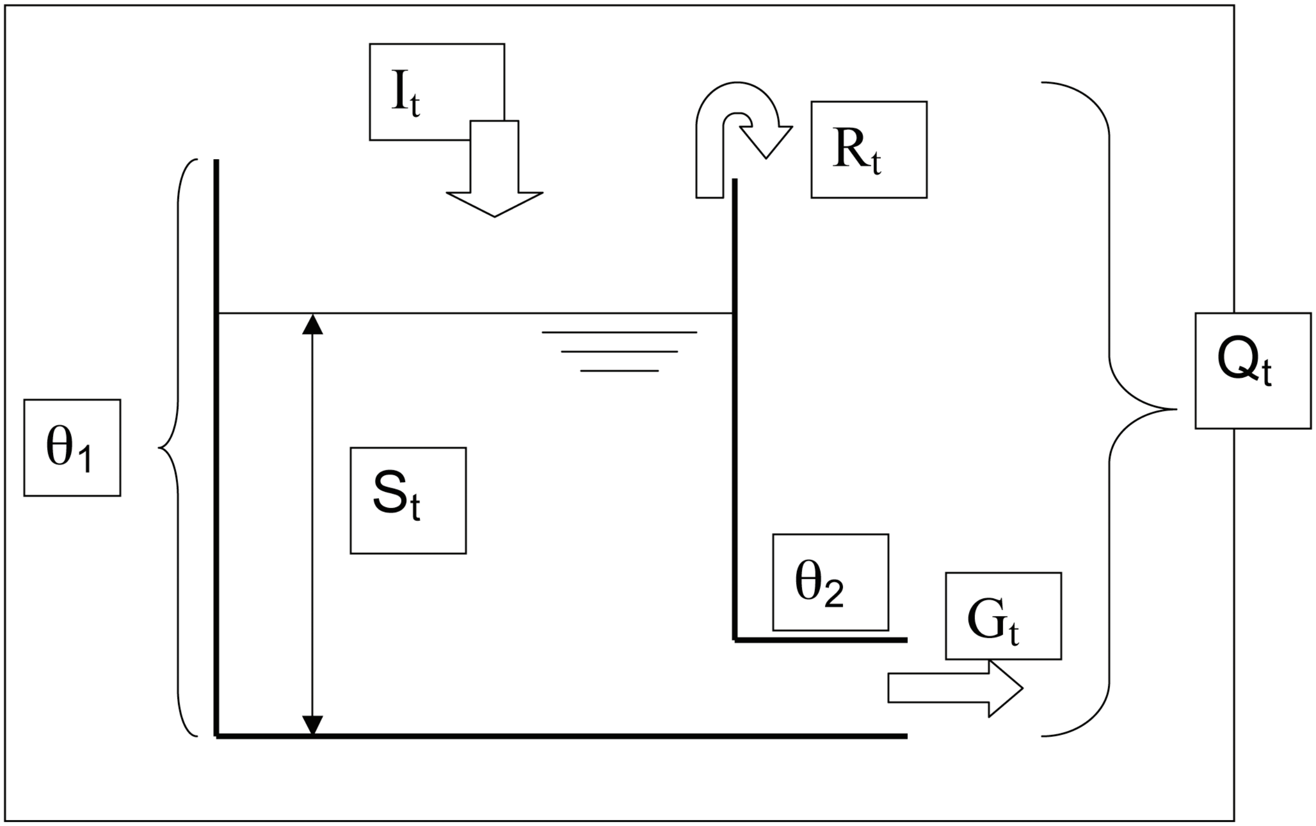
The objective in all cases is the selection and adjustment of parameter values that minimize the error measure. In most model calibration processes, not all parameters are adjusted, but rather a subset of parameters.

Figure B.1 below is a simple schematic example of a two parameter-reservoir/flow model in which the total outflow, Q_t, is the sum of runoff (or spill), R_t, and reservoir outflow, G_t. (Assume that objective of the model is to predict total outflow, runoff, and reservoir outflow based on inflow). The storage, S_t, is a function of inflow, I_t, and reservoir outflow, G_t. The two parameters are q_1, the depth of the reservoir and q_2, a rate measure of outflow. The runoff, R_t, is zero unless S_t is equal to q_1 (i.e., the reservoir is full). Reservoir outflow, G_t, depends on the parameter q_2 and storage, S_t.

If we assume that there are observed data values of inflow, storage, runoff, reservoir outflow, and total outflow, then these data may be used to provide initial estimates of q_1 and q_2. The model is then run with an initial value of storage, S_1 (storage at the beginning of time period 1) and the observed values of inflow. The output of the model is a set of values for storage, reservoir outflow, runoff, and total outflow.

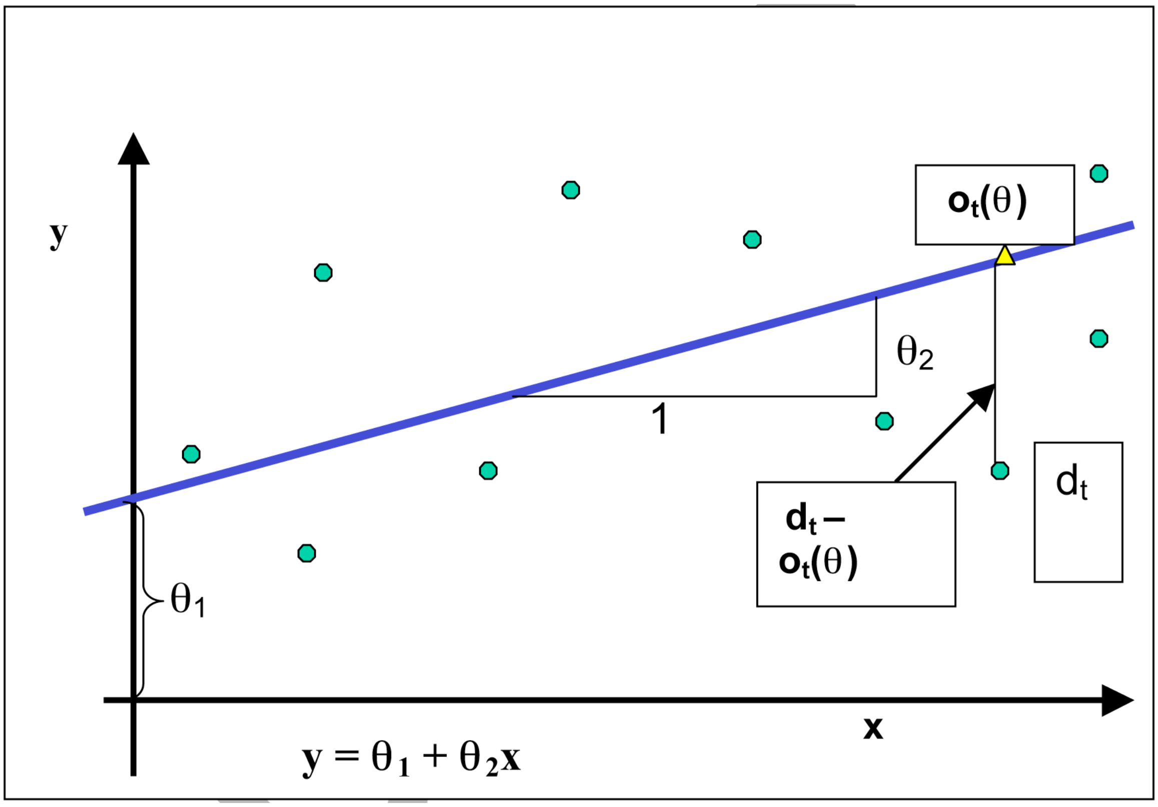
The calibration process – the adjustment of q_1 and q_2 – then consists of using the output of the model, $o_t(q)$, and the observed values, d_t, and one of the error measures like those in Table B.1 to improve the performance of the model. This process can be (and usually is) iterative.

FIGURE B.1. **Example of Simple Reservoir/Flow Model**



Another example of parameter estimation and adjustments (not related directly to the simple model above) is illustrated in Figure B.2 in which an output measure, y, is related to an input measure, x. The relationship is expressed in the linear equation shown at the bottom of the figure – a two parameter relationship depending on q_1 and q_2. The circles in the figure represent the observed data (measured values of x and y with the y values constituting the d_t's), and the points on the line represent the model data, (y values associated with these points are the $o_t(q)$'s). Calibration in this case would mean adjusting the slope of the line, q_2, and the y intercept, q_1, using one of the criteria in Table B.1, to minimize the error.

FIGURE B.2. Schematic Example Parameter Adjustment



APPENDIX C
COMMENTS ON HYDROLOGIC MODELING PAPER (HYDROLOGIC MODELS IN THE COURTROOM WORKING PAPER, DANIEL F. LUECKE AND DIVIDING THE WATERS MODEL ASSESSMENT COMMITTEE, JUNE 2005 [REVISED JUNE 2007])

Jonathan Hays

I. With respect to the topic of error types, I have taken the liberty of including some language from my Orders in the *Application of Park County Sportsmen's Ranch*, which I paraphrased from the ASTM and which may or may not be helpful to achieving the ends of the Paper. Use what you like, ignore the rest: I have no pride of authorship (well, maybe a little).

Calibration. The ATSM Guide defines *calibration* as the process of refining a model representation of the hydrogeologic framework to achieve a desired degree of correspondence between the model simulation and field observations. In practice, model calibration is frequently accomplished through trial-and-error adjustment of the mode1's input data to match field observations, and continues until the degree of correspondence between the model simulation and the observed physical characteristics is consistent with project objectives. Calibration is evaluated through analysis of *residuals* (d_t-o_t in your Table 1 formulae), i.e., the difference between the observed value and the simulated value of a given variable, and is conducted to bring the mean of the residuals close to zero, and to minimize the *standard erro*. of the residuals. Most site-specific ground-water flow models must be calibrated prior to use in predictions. In these cases, calibration is a necessary, but not sufficient, condition, that must be obtained to have confidence in the model's predictions.

If it becomes apparent during calibration that there are no realistic values for the hydraulic properties of the aquifer that will allow the model to reproduce the calibration targets, then the conceptual model of the site may need to be revisited, or the construction of the model may need to be revised. In addition, the source and quality of the data used to establish the calibration targets may need to be reexamined. Calibration often necessitates reconstruction of portions of the model, resulting in changes or refinements in the conceptual model. The modeler then revisits previous steps to achieve a better representation of the physical system.

Verification. I think that *verification* and *validation* are synonyms. I've used the term as it is used in the ATSM. Calibration of a ground-water model to a single set of field measurements does not guarantee a unique solution. In order to reduce the problem of *nonuniqueness*, the model calculations may be compared to another set of field observations that represent a different set of boundary conditions or stresses. This process is referred to in the ATSM Guide as *verification*. In model verification, the calibrated model is used to simulate a different set of aquifer stresses for which field measurements have been made. The model results are then compared to the field measurements to assess the degree of correspondence. If the comparison is not favorable, additional calibration or data collection is required. Successful verification of the ground-water flow model results in a higher degree of confidence in model predictions.

Sensitivity Analysis. Sensitivity analysis is a quantitative method of determining the effect of parameter variation on model results. The purpose of a sensitivity analysis is to quantify the uncertainty in the calibrated model caused by uncertainty in the modeled values of aquifer parameters. It is a means to identify the model inputs that have the most influence on model calibration and predictions. Sensitivity analysis provides users with an understanding of the level of confidence in model results and identifies data deficiencies. Sensitivity of a model parameter is often expressed as the relative rate of change of a selected model calculation with respect to a given parameter. If a small change in the input parameter causes a significant change in the output, the model is sensitive to that parameter.

II. With respect to the differing views of *Bredehoeft/Konikow, Oreskes,* and *Woessner/Anderson,* I agree with your analysis. We live in a real world of groundwater modeling techniques, in which the best evidence of aquifer or river basin characteristics is in the form of computer modeling results, however imperfect those results may be.

III. Your topic, *Criteria for Judging Adequacy of Models*, addresses the essential, pragmatic problem regarding the court's reliance upon modeling results. All scientific evidence and expert opinion offered at trial is subject to two different measures: admissibility and weight. Hence, a given model may be adequate in terms of meeting the threshold requirements of admissibility, and yet be unpersuasive to the court. This is necessarily the case when opposing parties present different models, both of which are found by the court to be admissible, but which present conflicting results. I suspect that groundwater modeling results generally have been and will be received in evidence, at least conditionally, so the issue at trial will usually focus on the accuracy of the modeling results.

I'm including some of the details of my decision in the Park County Sportsmen's Ranch case (96 CW 14, Water Division 1) that you referred to, with the hope that they may be interesting, if not instructive.

> The Applicant (PCSR) proposed to create storage by withdrawing 140,000 acre-feet (AF) from the South Park Formation, a saturated aquifer approximately 25 miles long, and 5 miles wide at its extremes. The formation consists primarily of sandstone and is 6000' thick at its extreme. The cone of depletion that will be created by PCSR's pumping was to constitute the proposed "storage vessel." The withdrawn water would be discharged into the South Platte River stream system for delivery to the City of Aurora under an existing contract between the City of Aurora and PCSR.
>
> PCSR proposed to store water, during times that the South Platte River system is free, by diverting excess stream flows into recharge reservoirs and ditch fields that will be located upon the upper surface of the South Park Formation. The water thus diverted and stored will percolate into the underlying aquifer, recharging it and reducing the volume of the depletion cone that has resulted from PCSR's pumping. PCSR claims the amount of this recharge as the actual volume of the water it will store.

The South Park Formation is tributary to the South Platte River system. PCSR has no water rights in the system, other than the 1996 rights that it seeks in this application; hence, its pumping from the aquifer constitutes an out-of-priority diversion that will eventually result in depletions to the stream system. PCSR intends to augment these depletions, at times when there is no water in the surface reservoirs, by pumping additional water from the aquifer for direct discharge to the stream. PCSR intended to determine the quantity and timing of depletions by use of the MODFLOW computer model to determine aquifer characteristics that govern the timing and amount of recharge, the fluctuation in the size of the depletion cone, and timing, location and amount of depletions to the stream.

The depletion cone would exist beyond the life of the project, until it is eliminated by recharge from natural sources, and would fluctuate, in size, in tandem with precipitation patterns. Quantification and timing of recharge, like quantification and timing of stream depletions, also depended on the validity and reliability of PCSR's MODFLOW computer model.

In Colorado, the admission of scientific evidence and expert opinion is controlled by C.R.E. Rule 702. *People v. Schreck*, 22 P.2d 68 (Colo. 2001). *Schreck* held that Rule 702, rather than the *Frye* test[1], represents the appropriate standard for determining the admissibility of scientific evidence, i.e. that the scientific principles upon which the evidence is based is reliable, and that the resulting evidence/opinion is relevant. The court further held that, when a trial court applies Rule 702 to determine the reliability of scientific evidence, its inquiry should be broad in nature and consider the totality of the circumstances of each specific case. In doing so, the court may consider a wide range of factors, such as those mentioned in *Daubert* and by other courts; however, such factors may or may not be pertinent, and thus are not necessary to ever.

1 Frye v. U.S., 293 F. 1013 (App. D.C. 1923)

Rule 702 inquiry. Hence the *Schreck* rule is less restrictive than the *Daubert* rule.

In this case, the focus of Rule 702 is upon the reliability of the MODFLOW model output and the expert opinion based on model output. The relevance of such output and opinion turns upon the usefulness of such evidence to the court.

The court found that the model, itself, is widely used to model aquifer parameters, among other uses, and that it is capable of producing reliable, relevant results. However, the court concluded that, in order for computer modeling results to be reliable, and hence relevant, the model must be operated in a manner that is consistent with accepted modeling techniques. The court held that, in this case, the techniques applicable to the operation of a ground-water flow model such as MODFLOW are set forth in the American Society For Testing And Materials (ASTM) *Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem* (ASTM Guide D-5447), and *Calibrating a Ground-Water Flow Model Problem* (ASTM Guide D-5981). If the model were to be operated by some other method or standards, there would have to be sufficient evidence to establish that such other method or standards produce valid and reliable results.

The court found that, as applied in this case, the model generated information that was not sufficiently reliable to support the experts' opinion or the court's reliance on modeling results, principally because.

1. The model was not calibrated in accordance with accepted standards.No sensitivity analysis was conducted on the model.
2. The model produced anomalous results that PCSR's experts were unable to explain, specifically that repeated model runs based upon identical data, produced different outcomes. For example, the residual error in water level prediction, in two successive runs on each of 12 wells, ranged between 6' and 198'.
3. The residual error between observed and model-predicted levels for 15 of 33 flowing springs exceeds 1 foot, and ranged between +46 feet and –26 feet. The absolute residual mean was 14 feet.
4. PCSR's expert and model designer, Dr. Harvey Eastman, recognized and reported the need for:
    a) Additional data, the need for additional model calibration,
    b) The need for explanation of the anomalous results, and,
    c) The need for further evaluation of the model target data, before he could defend the admissibility of the model results at trial. PCSR declined to follow Dr. Eastman's advice.
5. An independent peer review was begun, but not completed.[2]

I don't think that it makes much difference to the results in this case whether one applies the *Frye, Daubert/Schreck,* or Rule 702 standards for admissibility of scientific evidence. Under any of these tests, the proponent must show that the correct protocol was followed in conducting the test at issue.

You ask: "Who gets in the door if they have a good case, but not a good model." The answer depends upon how critically the Judge or Master discharges the "gate-keeping" function. The exclusion of the modeling results in the PCSR case is probably an anomalous result, occasioned by factors unlikely to be repeated by Applicants or experts in the future. PCSR was a three-person partnership in which one partner served as the attorney who tried the case, and another was the principal in the hydrology firm that adapted Modflow to model to the South Park formation. An employee of the firm, a Ph.D. Geologist, actually designed and developed the on-site testing procedures. He was the principal expert witness at the trial, and the author of the letter to his employer in which he challenged the reliability of his own modeling results and questioned his own model's defensibility at trial. I think that the two partners, attorney and expert, were blinded by their investment in the project and were unrealistic in their belief that their model would be uncritically accepted at trial. I don't expect that this unhappy combination of events will recur in future litigation.

2 The case is on appeal to the Colo. Supreme Court, so my conclusions may soon be upended.

My conclusion is that groundwater modeling evidence will be regularly received in evidence at trials in both State and Federal courts, because the model and its results will meet the threshold for admissibility. The research and preparation in developing a model and generating results is too costly for a litigant to risk its outright exclusion at trial. Hence, in the majority of cases the outcome will depend upon the weight given, by the trier of fact, to the modeling results. In PCSR, the opposing parties were so confident of their ability to undermine PCSR's model that they did not offer a model of their own, and declined PCSR's offer to run the model using the opposer's data. The opposers made these decisions after PCSR had provided them with their model and modeling results.

If my assumption about the general admissibility of modeling evidence is correct, then the issue will be the weight the trier of fact gives to the results. However, we need to distinguish between the threshold tests of admissibility and the factors that a court will likely consider in determining whether the threshold has been met.

The tests for admissibility are *Frye, Daubert*, and FRE 702 or its state-court equivalent. The *Frye* test includes "general acceptance in the relevant scientific community." Such acceptance can be established through the testimony of experts familiar with the degree to which, e.g., a given groundwater model is accepted as valid. Evidence of general acceptance may also be found in journals and other publications that address, e.g., groundwater models. The *Daubert* factors include whether the techniques employed: 1) have a known error rate, 2) are subject to standards governing their application and, 3) enjoy widespread acceptance.

The first factor seems vague to me. It's oft repeated, but never to my knowledge quantified. I don't believe that any court has decided whether the absence of a known error rate, or the magnitude of a known error rate, is fatal to the admissibility of groundwater modeling evidence.

Turning to the second factor, I believe the trend is toward accepting the ASTM guidelines as standards governing the operation of groundwater models. I infer this from my own ruling in the PCSR case and the Fourth Special Master's Report in the Arkansas River case that you reported in your draft. These outcomes don't alter my opinion regarding the general acceptance by courts of groundwater modeling principles, it merely changes the stage of litigation when the adequacy of the procedures used, the assumptions applied and the internal consistency of the results are called into question and resolved by the court.

The third factor, general or widespread acceptance, is common to both *Frye* and *Daubert* inquiries. FRE 702 and its state-court equivalents require that the trial judge ensure that scientific evidence be both a) *relevant*, i.e., whether the evidence will be useful to the trier of fact insofar as it tends to make the existence or absence of a fact more probable than not; and b) *reliable,* i.e., whether the scientific principles to which the witness is testifying are reasonably reliable, and whether the witness is qualified to opine on such matters. This rule confers broad discretion upon the trier of fact, and I believe results in an almost uniform acceptance of groundwater modeling principles by the courts.

At the risk of redundancy, courts will accept modeling theory in nearly every case, and will weigh the resulting data/ opinions on a case-by-case basis. On rare occasions, a court may grant a motion to strike the evidence at the end of the Applicant's case, which may or may not result in dismissal of the Application at that point.

You consider some alternatives to adversarial litigation of groundwater models. My only addition to your analysis concerns the viability of determining, prior to trial, what models and what results will be admitted into evidence. If the parties agree on a single model, there's no problem. If the parties disagree on whether a model or models meet the threshold of admissibility, the question is whether to sever the admissibility issue from the other issues in dispute. The real consideration governing the parties' request to bifurcate the issues is an economical one. Even if there is extensive evidence apart from that relating to modeling, bifurcation would not be judicially economical unless the *admissibility* of the modeling results are at issue, and unless the exclusion of the results and opinions would result in the dismissal of the Application. As a practical matter, most water litigation that requires more than a month of trial time is bifurcated or trifurcated to meet the court's docketing demands. Upon reflection, perhaps the better practice is to try modeling issues first, irrespective of whether the outcome is dispositive of the Application.

With respect to the use of court-appointed experts, courts have the inherent power to appoint their own experts. Most of the western states have codified this in the form of an evidentiary rule paralleling that of FRE 706[3]. Personally, I would not appoint a court expert except in extraordinary circumstances. The adversary system has proven effective, so far. For example, opposing counsel have been effective, through cross-examination, in challenging DNA profiling, and by expert testimony, in demonstrating the weaknesses in such areas as eye-witness identification.

I don't have an answer to the problem of educating judges and special masters to be rigorous gate-keepers. Perhaps more accurately in the context of groundwater modeling, the problem is educating them to be discerning in determining the weight, if any, to be given to the expert testimony that is presented.

At the risk of exceeding the scope of your inquiry, an example of our weakness as judges of expert testimony, in groundwater modeling in particular, is in our meager knowledge of statistics. I challenge any judicial officer to explain in laymen's terms the meaning and significance of the formulae in Table 1 of your working paper. The most essential one, in my view is the Root Mean Square Error, which appears to me to be the same as the *standard error of the mean*. I have seen this value referred to in water quality cases as well as groundwater cases, but no witness has explained the concept, or what its significance was to the case at hand. My rudimentary understanding is that the standard error (SE) is a statistical measure of the variance of predicted values. My further understanding is that the SE can be used to establish a level of confidence, or confidence interval, i.e., a range of values within which predicted values will probably fall. For example, the SE times 1 (SE x 1) yields a confidence interval of about 0.68. Thus, just over 2/3 of the predicted values will fall within a one-SE range. A common confidence interval applied to experimental data is 0.95, and is represented by SE x 1.96. Similarly, a confidence interval of 0.99 = SE x 2.57[4]. By way of example, assume that the SE of the predicted static water level in an aquifer under certain conditions is 50'. One could then predict, with 95% confidence, that the SWL under those same conditions will fall within a range of 1.96 x 50', or 98' (49' either side of the predicted level). This not only communicates a sense of how finely calibrated the model is, but also provides the trier of fact with the highest and lowest SWL's that might actually exist – a sort of best/worst case scenario that would be helpful to the court in imposing terms or conditions upon the Application. The same general principles apply to the other formulae that you have listed: they are useful only to the extent that they are explained to and understood by the judge or special master.

3 AZ, CA, CO, ID, NE, NM, SD, and UT. KS, NV. OK, TX and WA case law recognizes the practice, sometimes limited to custody and competency matters. OR discourages the practice, and expressly rejected adoption of a FRE 706 equivalent.

4 R.C. Hurlburt, Comprehending Behavioral Statistics, Brooks/Cole Publishing, 1994.

APPENDIX D
THE TWO KINDS OF ERRORS IN HYPOTHESIS TESTING

Type I Error

Type I error, also known as an "**error of the first kind**" or a "**false positive**": the error of rejecting a null hypothesis when it is actually true. Plainly speaking, it occurs when we are observing a difference when in truth there is none. Type I error can be viewed as the error of excessive credulity.

Type II Error

Type II error, also known as an "**error of the second kind**" or a "**false negative**": the error of failing to reject a null hypothesis when it is in fact false. In other words, this is the error of failing to observe a difference when in truth there is one. Type II error can be viewed as the error of excessive skepticism.

In **statistics,** a **null hypothesis** (H_0) is a plausible hypothesis (scenario) which may explain a given set of data. A null hypothesis is tested to determine whether the data provide sufficient reason to pursue some ***alternative hypothesis***

There are two kinds of errors that can be made in significance testing: (1) a true null hypothesis can be incorrectly rejected and (2) a false null hypothesis can fail to be rejected. The former error is called a Type I error and the latter error is called a Type II error. These two types of errors are defined in the table.

TABLE D.1. Two Kinds of Errors in Hypothesis Testing

	Hypothesis True	Hypothesis False
Accept Hypothesis	Correct Decision	***Type II Error***
Reject Hypothesis	***Type I Error***	Correct Decision

The probability of a Type I error is called the Type I error rate; the probability of a Type II error is the Type II error rate. The decision rule used to accept or reject the hypothesis links the error rates. A very conservative criterion for accepting leads to a large Type I error rate and a low Type II error rate. A more liberal criterion has the opposite effect, i.e., a low Type I rate and a high Type II rate.

APPENDIX E

ADMISSIBILITY OF EXPERT OPINION BASED ON COMPUTER MODELING – WHAT DOES DAUBERT REQUIRE? (ENVIRONMENTAL LAW ADVISORY, JUNE 2003)

Environmental Law *Advisory A monthly update on law, policy and strategy* June 2003 Admissibility of Expert Opinion Based on Computer Modeling – What Does *Daubert* Require?

Expert testimony inevitably plays a central, sometimes decisive, role in the outcome of environmental cases. Experts typically testify about such issues as source identification, travel time, direction and extent of migration, potential pathways and duration of exposure, relative contributions of multiple overlapping sources of contamination and/or exposure, and effects of exposure on human health.

Use of computer software to create models to explain and predict the behavior and effects of chemicals at a specific site is now commonplace, particularly in the fields of hydrogeology and toxicology. Admissibility of expert opinions based on computer models therefore has received much recent attention from federal courts.

The evolving doctrine of *Daubert v. Merrell Dow Pharmaceuticals, Inc*., 509 U.S. 579 (1993), requires scientific expert opinion to be both scientifically valid and applicable to the facts of the case. Because the doctrine can lead to outright exclusion of a scientific expert, the snares and pitfalls of handling such experts have never been more treacherous. Knowing where those dangers lie and how to avoid them can make the difference between winning and losing.

This Advisory addresses some major recent applications of the *Daubert* doctrine to computer modeling, with a special focus on two problems: (1) expert reliance on other experts to create a model and (2) the handling of formulas and variables in modeling.

Daubert Basics

To be admissible under Federal Rule of Evidence 702, expert testimony must come from a qualified expert, assist the trier of fact, and meet three foundational requirements: the testimony must be (1) based on sufficient facts or data, (2) the product of reliable principles and methods, and (3) a reliable application of principles and methods to the facts of the case. The *Daubert* doctrine focuses primarily on the second and third foundational requirements: whether the expert's reasoning or methodology is scientifically valid and whether that reasoning or methodology can be properly applied to the facts at issue. In short, *Daubert* is about the "reliability" of the scientific principles and methods at issue and about the adequacy of the "fit" between that science and the facts of the case.

To determine the reliability of a scientific opinion, the court may look at any relevant factor, but courts pay particular attention to four factors named in *Daubert*: whether the expert's theory has been or can be tested; whether it has been subjected to peer review and publication; the known or potential error rate of the technique; and whether the technique is generally accepted in the scientific community. *Daubert*, 509 U.S. at 593-94.

The *Daubert* doctrine places the judge in the role of a "gatekeeper" who can bar the admission of scientifically unreliable evidence, but the judge must not make ultimate conclusions about the persuasiveness of the evidence. "Vigorous cross-examination, presentation of contrary evidence and careful instruction on the burden of proof are the traditional and appropriate means of attacking shaky, but admissible evidence." *Daubert*, 509 U.S. at 596. The *Daubert* doctrine calls for *exclusion* of an expert's testimony when the risk of jury confusion and prejudice is so great that these traditional and appropriate means of attack will not suffice.

Use of Computer Models by Environmental Experts

Computer models are often efforts to simulate physical processes, especially when the process is not susceptible of direct observation or physical experiment. Because environmental processes such as contaminant fate and transport are often complex and hard to observe, environmental experts frequently use computer models to develop or validate their testimony. *Daubert* questions inevitably follow.

At a basic level, a computer model consists of one or more computer programs designed to perform a series of mathematical operations. These programs generally must be written, or at least adapted, for the particular case. And this need to write or adapt the software creates opportunities for coding errors, both conceptual and mechanical. The formulas to be applied must themselves have a sound scientific basis, and they must be applied in a scientifically appropriate sequence. They must contain the appropriate variables, appropriately defined, with no critical variable left out and no extraneous variable included that might foul up the calculation.

Even if the design of the program is scientifically reliable – all of the formulas are well-thought out, logically sequenced, and based on sound science – the software itself may not execute the operations properly. If the code works properly and the model is a properly working, scientifically reliable "machine," the underlying data fed into that "machine" must be handled right too. Are the sources of the data appropriate for the variables defined in the program? Are the data complete and, if not, what approach was taken to the missing data? Was the entry of data handled carelessly? If the data are mishandled, "garbage in," as the saying goes, likely will yield "garbage out."

Finally, even if both the computer program and the underlying data pass muster, the question remains whether the results generated by the program actually "fit" the relevant legal issues in the case. If the model, for example, projects a likely causal relationship between exposure to a toxic chemical and a particular liver disease for white males over 65, does that say anything at all about the relationship between exposure to that chemical and a different liver disease found in a ten-year-old African-American female plaintiff?

Daubert potentially requires a court to consider all of these issues in deciding whether to admit scientific testimony.

Application of *Daubert* to Computer Models

Courts analyze a *Daubert* challenge to a computer model by considering the reliability of the model itself, as well as the reliability of the expert's application of the model. Recent case law addresses important issues that arise when experts apply environmental computer models: (1) experts relying on other experts; and (2) identifying and determining values for variables in a model.

Testifying Expert Relying on Another Expert's Modeling Expertise

The *Daubert* questions of "reliability" and "fit" are conceptually distinct from the question whether an expert is properly qualified to present the intended testimony, and whether that testimony will assist the trier of fact. For example, regardless how qualified an expert may be, a party cannot rely on qualifications alone to demonstrate that the expert's testimony is sufficiently reliable. Nonetheless, a court may give a very well-qualified expert the benefit of the doubt.

The scope of an expert's qualifications can influence a *Daubert* challenge in another way as well. An environmental expert testifying based on a computer model may possess expertise in the relevant physical processes, but not in the creation of the model itself. As a result, the expert may have had to rely in part on the expertise of a computer modeler to use a scientifically reliable methodology, and the reliability of the testifier's final conclusions may hinge on the other expert's choices.

"An expert witness is permitted to use assistants and normally they need not themselves testify." *Dura Auto. Sys. of Ind., Inc. v. CTS Corp.*, 285 F.3d 609, 612 (7th Cir. 2002). The opposing party can depose them to test the work they did, and the expert witness can be asked if he supervised them carefully and whether his relying on their assistance was standard practice in his field. If so, Federal Rule of Evidence 703 allows the expert to rely on the assistants, and their work need not be introduced in evidence.

The same rule may apply to the situation when a testifying expert is relying on another expert's opinion. Courts have held consistently that experts can rely on the opinions of other experts in reaching their conclusions, provided the other expert's underlying methodology is also reliable. *See Nutrasweet Co. v. X-L Engineering Co.*, 227 F.3d 776, 789-790 (7th Cir. 2000) (affirming admission of expert testimony about source of groundwater contamination where expert used soil degradation data obtained from another expert). Under *Daubert*, courts have limited the ability of one expert, in effect, to testify for another. In the words of Judge Posner in *Dura*, "A scientist, however, well-credentialed he may be, is not permitted to become the mouthpiece of a scientist in a different specialty. That would not be responsible science." 283 F.3d at 614.

In *Dura*, the plaintiff relied solely on a hydrogeologist to testify about the area from which groundwater that contaminated a city well field could have flowed. The witness was offered to address two issues: (1) the map of the "capture zone" – the area from which the contamination could have flowed – and (2) if the defendant's plant was in the capture zone, how much of the contamination in the well field was attributable to groundwater that had flowed from under the plant. For his opinion on the first issue, the hydrogeologist relied on a computer model of the groundwater flow, even though he was not himself expert in computer modeling and was not competent to judge whether the modelers had made scientifically correct choices. The trial judge excluded the hydrogeologist's testimony, and the Seventh Circuit affirmed. *Dura Auto. Sys. of Ind., Inc. v. CTS Corp.*, 285 F.3d 609, 615 (7th Cir. 2002).

The lesson of *Dura* is that a party planning to offer an expert witness needs to be careful in identifying the scope of the witness's expertise and the relation of that expertise to the opinions the expert will give. If the expert is not merely exercising her own expertise in supervising subordinates, but instead is relying on the scientific expertise of others as a ground of her opinion, then those other experts should be disclosed; they should submit expert reports if the applicable rules require reports; and they should be prepared to testify at a *Daubert* hearing about the reliability of their methods.

Identifying and Calculating Variables in Computer Models

Often a party contesting the reliability of a computer model concedes the scientific reliability of the overall computer program, but challenges either the expert's failure to include or exclude certain variables, or the expert's handling of a variable. The degree of *Daubert* scrutiny that this issue receives may depend on such factors as the transparency of the expert's assumptions and methodology, the importance of the variable to the model and the model to the expert's opinions, and the extent to which the expert's handling of the variables is inconsistent with scientific literature or established standards.

The Eleventh Circuit takes the view that failure to include all available variables generally goes to the probativeness of a model, not its admissibility. *See Quiet Technology DC-8, Inc. v. Hurel-Dubois UK Ltd.*, 326 F.3d 1333, 1345 (11th Cir. 2003). Thus, in *Quiet Technology*, there was no dispute about the scientific validity of "computational fluid dynamics" software or about the expert's use of certain types of aerodynamic data in connection with the software. The expert's "methods and results" were discernible and "rooted in real science," and therefore were empirically testable and susceptible to effective cross-examination. *Id.* at 1346. The challenges to the expert went to the accuracy of his results not the validity of his use of the model.

Eighth Circuit cases have both rejected and sustained a *Daubert* challenge to the handling of variables in an otherwise valid model. Plainly an expert is on fairly safe ground using a model that is well-accepted in the field and is not the sole basis for his ultimate conclusion. In *United States v. Dico, Inc.*, 266 F.3d 864, 870-871 (8th Cir. 2001), the government's hydrogeologist Robertson testified that TCE contamination originated on Dico's property. Dico argued that Robertson's methods were unreliable because he excluded evidence of alternative sources of contamination from his computer model. On appeal, the court held that the model itself was reliable – it was sanctioned by EPA, in standard use by hydrogeologists, and used by Dico's own expert. Furthermore, the model did not form the basis of Robertson's conclusion about the origin of contamination. He had merely used it to analyze the capture zones of remediation wells on Dico's property. Thus, any problems with the data put into the model were "without consequence as to the validity of his analysis of alternative sources for the contamination."

Smith v. BMW, 308 F.3d 913, 921(8th Cir. 2002), on the other hand, illustrates both the risk of wholesale reliance on a computer model without adherence to scientific standards and the risk that the testimony of one's own expert may rehabilitate the methodology of an expert whose testimony failed the *Daubert* test. *Smith* was a product liability case involving an airbag that allegedly malfunctioned in an automobile accident. Plaintiff's accident reconstruction expert, Williams, used a computer model to calculate the "barrier equivalent velocity" of the accident – testimony necessary to show that the velocity was high enough to cause a properly designed airbag to deploy during the accident. The *Daubert* challenge went to Williams' handling of two essential inputs for the computer program: the "principal direction of force" and the amount of "frontal displacement" of the car.

First, according to a defense expert and the trial judge, Williams' value of 20 degrees for direction of force was inconsistent with Williams' own theory of the case because it could not generate the counterclockwise rotation of the car that Williams relied on to explain the displacement of the car's front end. On appeal, however, the court concluded that Williams had actually testified to a direction of force *no greater than* 20 degrees and had reached this conclusion based on an investigation of witnesses, the vehicle, and the accident scene. Values less than 20 degrees would increase both the barrier equivalent velocity and the counterclockwise rotation, strengthening plaintiffs' case. Thus, any flaws in Williams' approach to direction of force went to the weight of the evidence, not its admissibility.

Second, in measuring displacement, Williams assumed that the car was rectangular when in fact it was not, and scientific literature called for use of an exemplar that reflected a vehicle's actual dimensions rather than a rectangle. On this point, the Eighth Circuit affirmed an exclusion of Williams' testimony because Williams provided no evidence explaining why his measurements using the rectangle would be accurate. Since the computer program could not calculate barrier equivalent velocity without the displacement measurements, Williams could not testify as to the velocity either.

Although Williams was not permitted to give this critical testimony about velocity, the appellate court noted that this gap in plaintiffs' evidence did not warrant summary judgment. A *defense* expert had corrected Williams' displacement measurements and run the program with the corrected measurements. There was evidence that the corrected velocity calculated by the program was high enough to trigger release of an air bag.

Conclusion

The lesson of these cases is that the expert relying on a computer model should generally be explicit about her assumptions and her methods – a testable methodology and results will be likelier to get to the jury. Furthermore, exclusion is less likely if the expert grounds her opinion in sources of evidence in addition to the model. Also, unless the case requires the use of novel techniques, the expert should generally avoid applying the model in a fashion that is inconsistent with the scientific literature or with established scientific practice. Finally, in responding to an opposing expert who uses a model, a party should be careful in deciding whether its own expert should merely criticize the opponent's methodology or instead should offer calculations of her own; such calculations may buttress the opponent's case.

Computer models are admissible in evidence and experts have used them effectively, but they must be built carefully based on accepted scientific models, using assumptions clearly grounded in the specific site conditions, and defended by a qualified expert who can demonstrate proper application of formulas and variables.

APPENDIX F
REFORMING THE CULTURE OF PARTIALITY: DEFUSING THE BATTLE OF EXPERTS IN WESTERN WATER WARS (MIRIAM MASID, 2007)

ABSTRACT OF DISSERTATION

The admissibility of expert testimony in water matters is based on the rules of evidence in civil cases. Problems with expert testimony continue to plague the courts even after the change in the rules of evidence and guidance from the U.S. Supreme Court in the *Daubert Trilogy* of cases. There is a movement abroad in civil cases to change the way expert witnesses interact in the courtroom to make the expert accountable to the court, and to provide expert evidence that is more useful to the judge.

An empirical study was conducted to assess the need for reform concerning expert witness testimony in Western United States water cases; and to assess the receptiveness of judicial and quasi-judicial officers to various reforms that have been proposed or adopted in England, Australia and other jurisdictions.

A survey was created for the members of Dividing the Waters (DTW) a water education project for judges and quasi-judicial officers. The study revealed that western water judges and administrative officers experience the same problems with expert witness testimony that are experienced in other common law adversarial systems abroad. The DTW survey also revealed substantial support for many of the reforms adopted in England, Wales and Australia which involve a change in the culture of the adversarial use of expert witness evidence.

The DTW judges and administrative officers support reforms that will make experts acknowledge that their role and paramount duty is to be an advisor to the court, and not to be an advocate of the parties. They want greater transparency in expert witness reports. The judges and administrative officers want to know: what instructions the expert received; what the expert relied upon to base his or her opinion; what assumptions the expert made; whether and to what extent the written reports were edited by the parties or attorneys; whether the reports are inconsistent with other reports made by the expert in another tribunal; and whether the parties have used or intend to use a "shadow expert".

There is overwhelming support to require the experts to meet prior to trial or the hearing in order to narrow the issues, and to provide a joint report of matters upon which the experts agree and those upon which they disagree. They want the parties to consider whether or not a single expert should be appointed, and they want to encourage more frequent use of court appointed experts. Proposed rules are offered for consideration to implement the reforms that are supported by the majority of the participants in Dividing the Waters.

APPENDIX G

2009(04) RULE CHANGE

THE COLORADO RULES OF CIVIL PROCEDURE
FOR
COURTS OF RECORD IN COLORADO

CHAPTER 10
GENERAL PROVISIONS

Rule 90. Dispositions of Water Court Applications

(a) The water clerk shall receive and file all applications and number them upon payment of filing fees. The water clerk shall not accept for filing any application that is not accompanied by the required filing fee. Each application filed within each division shall be consecutively numbered, preceded by the year and the letters CW (e.g. 2009CW100) to identify such applications as concerning water matters. The applicant for a finding of reasonable diligence relating to a conditional water right and/or to make a conditional water right absolute shall include in the application a listing of the original and any other prior case numbers pertaining to the conditional water right included in the application; thereafter, the assigned case number for the application shall appear on any document, pleading, or other item in the case. Referee rulings and water court judgments and decrees shall include all relevant prior case numbers.

(b) The water clerk shall include in the resume all applications filed during the preceding month that substantially contain the information required by Rule 3 of the Uniform Local Rules for All State Water Court Divisions and the standard forms approved by the water judges under C.R.S. § 37-92-302(2)(a), which together provide the information sufficient for publication to the public and potential parties. The water clerk, in consultation with the referee pursuant to Rule 6 of the Uniform Local Rules For All State Water Court Divisions, shall promptly refer to the water judge for consideration and disposition any application that does not substantially contain the information required by Rule 3 of the Uniform Local Rules For All State Water Court Divisions and the standard forms approved by the water judges under C.R.S. § 37-92-302(2)(a). Any such application shall not be published in the resume pending disposition by the water judge. The water clerk shall promptly inform the applicant that the application has been referred to the water judge and provide the applicant with a list of the required information that was not contained in the application.

(c) In determining whether or not to order publication of the application in the resume pursuant to C.R.S. § 37-92-302(3)(a), the water judge shall promptly review the application and shall employ an inquiry notice standard in conducting the review. Upon a finding that the application does not provide sufficient inquiry notice contemplated by Rule 3 of the Uniform Local Rules for All State Water Court Divisions and the standard forms approved by the water judges under C.R.S. § 37-92-302(2)(a) to justify publication, the water judge shall set a date pursuant to C.R.C.P. 41(b)(2) and C.R.C.P. 121, Section 1-10, by which date the application will be dismissed unless, prior to that date, a sufficient application is filed. The application will retain its original filing date unless and until the application is dismissed.

(d) For purposes of relation back of the filing date of a subsequent applicant's application for a water right or conditional water right pursuant to C.R.S. § 37-92-306.1, the subsequent application shall be filed within sixty days of the date the prior application is published in the resume.

(e) Upon request, the water clerk shall provide a prospective applicant or opposer with one copy of the form for the relevant application or statement of opposition. The standard forms for applications and statements of opposition may also be found in the "Water Courts" section of the Colorado Judicial Branch web page.

CHAPTER 36
UNIFORM LOCAL RULES
FOR ALL
STATE WATER COURT DIVISIONS

Rule 2. Filing and Service Procedure

(a. For all cases filed pursuant to C.R.C.P. 90 after July 1, 2009, applicants and opposers represented by counsel shall electronically file and serve through the approved judicial branch e-filing service provider all applications, pleadings, motions, briefs, exhibits, and other documents on all parties and on the state and division engineer. C.R.C.P. Rule 121, Section 1-26, Electronic Filing, applies to water court filings. The state or division engineer shall also electronically file and serve upon applicants and opposers in the proceedings their consultation reports described in §§ 37-92-302(2)(a) & (4). Applicants and other parties who are not represented by an attorney shall file with the water clerk a single copy of the application and all other documents in original paper format. The water clerk on behalf of persons not represented by an attorney shall scan and upload such paper-filed documents to the approved judicial branch e-filing system. All documents and correspondence filed after the initial application shall contain the case number. Proof of service of documents, orders, and rulings shall occur through the e-filing system.

(b) An applicant shall file and serve upon all parties at least 15 days prior to hearing on any application before the water judge, a proposed order that sets forth any necessary findings, terms or conditions that the applicant reasonably believes the court should incorporate into the decree.

Rule 3. Applications for Water Rights

(a. Applications filed under C.R.C.P. 90 for determination of a water right, determination of a conditional water right, a change of water right, a determination that a conditional water right has become a water right, approval of a plan for augmentation, a finding of reasonable diligence, approval of a proposed or existing exchange of water, approval to use water outside of the state, and any other matter for which such a standard form exists shall be filed using the standard forms adopted by the water judges, or a format patterned after the standard form containing the information required by the applicable standard form. The applicant shall be responsible for providing all information required by the forms and this Rule 3.

(b) More than one water right, claim or structure may be incorporated in any one application under one caption, provided that the required information is given for each water right, claim, or structure, and that each has the same ownership.

(c) Where more than one water right was conditionally decreed under one case number, each water right so decreed may, but need not be, incorporated again in an application for a finding of reasonable diligence or to make absolute; however, such an application shall not be combined with any other case or application except by leave of court.

(d) The following guidelines shall apply in filing applications:

(1) Every application shall include the legal description of the location of the point of diversion and of the place of storage, if any, of the subject water right, and a general description of the place of use.

(2) In areas having generally recognized street addresses, the street address and also the lot and block number, if applicable, shall be set forth in the application in addition to the legal description of the point of diversion or place of storage.

(3) Every application shall state the name and address of the owner or reputed owner of the land upon which any new diversion or storage structure or modification to any existing diversion or storage structure is or will be constructed, or upon which water is or will be stored, including any modification to the existing storage pool. The applicant may rely upon the real estate records of the county assessor for the county or counties in which the land is located to determine the owner or reputed owner of potentially affected land.

(4) The actual address of the applicant and the mailing address, if different, shall be given in all cases. An address in care of an attorney is not acceptable in the absence of special circumstances which must be set out fully in an accompanying statement and approved by the water judge.

(e) An application for determination of matters relating to underground water rights shall be governed by the following additional requirements:

(1) Such application shall designate each well, using the state engineer's well permit registration or recording number, if one exists. If a permit required by law has been issued by the state engineer, copies of the permit and the well completion and pump installation report, if completed, shall be attached to the application. If the permit was denied, a copy of the order of denial containing the denial number shall be attached. If this documentation is not available at the time of filing of the application, it shall be supplied as soon as practicable.

(2) If the name of the applicant is not the same as the name appearing on the well permit, then prima facie evidence of ownership of the well site must be submitted to the court. Copies of recorded deeds are preferred for this purpose.

(f) An application for approval of a change of water right or plan for augmentation shall include a complete statement of such change or plan, including a description of all water rights to be established or changed by the plan, a map showing the approximate location of historical use of the rights, and records or summaries of records of actual diversions of each right the applicant intends to rely on to the extent such records exist.

Rule 6. Referral to Referee, Case Management, Rulings, and Decrees

(a. The water judge shall promptly refer to the water referee all applications except those the water judge determines to retain for adjudication. The referee upon referral by the water judge has the authority and duty in the first instance to promptly begin investigating and to rule upon applications for determinations of water rights, determinations of conditional water rights, changes of water rights, approval of plans for augmentation, findings of reasonable diligence in the development of conditional water rights, approval of a proposed or existing exchange of water, approval to use water outside of the state, and other water matters, in accordance with the applicable constitutional, statutory, and case law. Upon investigating the matter, the referee may re-refer an application to the water judge for adjudication.

(b) The referee's authorities and duties include: assisting potential applicants to understand what information is required to be included in an application; in accordance with C.R.C.P. 90, consulting with the water clerk to ascertain whether applications substantially contain the information required by Water Court Rule 3 and the standard forms approved by the water judges and, if not, providing the applicant through the water clerk a list of the required information that was not included in the application; investigating each application to determine whether or not the statements in the application and statements of opposition are true and becoming fully advised with respect to the subject matter of the applications and statements of opposition; conferring with the division engineer and the parties concerning applications and working with the division engineer and the parties to obtain additional information that will assist in narrowing the issues and obtaining agreements; and issuing the referee's ruling and proposed decree in the case. The referee's ruling and proposed decree shall set forth appropriate findings and conditions as required by C.R.S. § § 37-92-303 & 305, and shall be in an editable format acceptable to the water judge.

(c) The referee shall work promptly to identify applications that will require water judge adjudication of the facts and/or rulings of law and re-refer those applications to the water judge.

(d) The applicant shall have the burden of sustaining the application and, in the case of a change of water right, a proposed or existing exchange of water, or a plan for augmentation, the burden of showing the absence of injurious effect. Expert reports, disclosures, and opinions presented to the referee shall include the signed Declaration of Expert set forth in the applicable water court form.

(e) To promote the just, speedy, and cost efficient disposition of water court cases, the goals of the referee, as contemplated by C.R.S. § 37-92-303(1), shall include a ruling on each unopposed application within sixty days after the last day on which statements of opposition may be filed, and all other applications as promptly as possible. In pursuit of this goal, the referee shall initiate consultation with the division engineer in every case promptly after the last day for filing statements of opposition. The division engineer's written report on the consultation is due within thirty days of the date the referee initiates consultation in accordance with C.R.S. § 37-92-302(4), except that for applications that require construction of a well, the division engineer's written report is due within four months after the filing of the application in accordance with C.R.S. § 37-92-302(2)(a). Upon request, the referee may extend the time for filing the division engineer's written report. The division engineer may submit additional written reports upon receipt of new information and shall provide them to the referee and all parties. The referee shall not enter a ruling on applications for determination of rights to groundwater from wells described in C.R.S. § 37-90-137(4) until the state engineer's office has had the opportunity to issue a determination of facts concerning the application in accordance with C.R.S. § 37-92-302(2)(a). The referee and the division engineer may confer and jointly agree to forego consultation in a particular case because it is not needed; and, if so, the referee shall enter a minute order as provided in section (o) of this Rule 6.

(f) For good cause, upon agreement of the parties, or sua sponte, the referee may extend the time for ruling on the application beyond sixty days after the last day on which statements of opposition may be filed, but not to exceed a total of one year following the deadline for filing statements of opposition, except that the referee may extend the time for entering a ruling to a specified date that is not more than six months after the expiration of the one year period, upon finding that there is a substantial likelihood that the remaining issues in the case can be resolved, without trial before the water judge, in front of the referee.

(g) If no statements of opposition to an application have been filed, the applicant's attorney shall promptly provide the referee with a proposed ruling and decree for consideration by the referee. The referee will prepare the ruling and decree for pro se applicants, and in all cases may convene such conferences or hearings as will assist in performance of the referee's duties.

(h) For all applications in which statements of opposition are filed, the attorney for the applicant, or the referee if the applicant is not represented by counsel, shall set a status conference with the referee and all parties. The status conference shall occur within sixty days after the deadline for filing of statements of opposition, unless the deadline is extended by the referee for good cause. The status conference may be conducted in person or by telephone. All parties must attend the status conference unless excused by the referee. The referee shall advise the division engineer of the status conference and invite or require the division engineer's participation. To assist discussion at the status conference, applicants are encouraged to prepare and circulate a proposed ruling and proposed decree to the referee and the parties in advance of the conference.

(i) During the status conference, the referee and the parties will discuss the issues raised by the application and any statements of opposition, what additional information or investigations will be necessary to assist the parties and the referee to understand and resolve disputed issues and to assist the referee's preparation of a proposed ruling and proposed decree, and determine whether it will be possible to resolve the application and any objections without re-referring the application to the water judge for adjudication.

(1) If it is unlikely that the application and objections can be resolved without adjudication by the water judge, then the referee shall promptly re-refer the application to the water judge in accordance with C.R.S. § 37-92-303.

(2) If the applicant or another party does not believe that the application can be resolved without water judge adjudication and so notifies the other parties and the referee at the status conference, then the party shall promptly file a motion to refer the application to the water judge in accordance with C.R.S. § 37-92-303(2).

(3) The provisions of Water Court Rule 6 (j)-(l) apply to applications that remain before the referee upon agreement of the parties as a result of the status conference.

(4) As a condition for remaining before the referee instead of referring the application to the water judge for adjudication, the parties shall waive their statutory right to re-refer the application to the water judge for the period established in the case management plan. During such period the application may be referred to the water judge only with the consent of all parties or the consent of the referee.

(j) The parties shall discuss at the status conference whether expert investigations will be needed. If expert investigations are needed, the referee and the parties will discuss whether it would be appropriate for the parties to engage a single expert to make the necessary investigation and report the results of the investigation to the parties. The use of a single expert is not mandatory, and any party may choose to utilize its own expert. If all parties agree that the use of a single expert is desirable, the single expert shall be chosen by mutual agreement among the parties. If all parties agree that the use of a single expert is desirable, but the parties cannot agree on who should be selected, the referee may appoint a single consulting expert. The parties shall divide the costs of a single consulting expert equally among themselves unless a different cost allocation is agreed upon by the parties. If the parties agree to use a single expert in proceedings before the referee, then, absent the consent of all parties, that expert shall not be permitted to testify as an expert for a party in the same proceeding if the application is re-referred to the water judge or if a protest is filed by a party to the ruling of the referee.

(k) In consultation with the parties, the referee shall establish a case management plan for obtaining the necessary information and preparing a proposed ruling and proposed decree. The case management plan shall set forth a timetable for disposition of the application.

(l) Regardless of whether any expert is involved in the proceedings before the referee, the referee shall not be bound by the opinions and report of the expert, may make investigations without conducting a formal hearing, including site visits, and may enter a ruling supported by the facts and the law. The case management plan shall contain a listing of the disputed issues to the extent known, the additional information needed to assist in resolution of the disputed issues, additional investigations needed to assist in resolving the disputed issues, an estimate of the time required to complete the tasks, the time for filing a proposed ruling and proposed decree, the time for opposers to file comments on the proposed ruling and proposed decree, the time for the applicant to file status reports, and a schedule for further proceedings. The referee may make such interim rulings, including scheduling additional status conferences and allowing amendments to the case management plan, as will facilitate prompt resolution of the application and issuance of a proposed ruling and proposed decree. The proceedings before the referee shall be completed and the proposed ruling and proposed decree issued no later than one year following the deadline for filing of statements of opposition, except that the referee may extend the time as specified in subsection (f) above.

(m) If the parties are able to reach a resolution of the application, and the referee finds it to be supported by the facts and the law, the referee shall work with the parties to fashion an appropriate proposed ruling and proposed decree for filing with the water judge for approval. If such a resolution cannot be reached within the time period allowed by the case management plan, the referee shall enter a ruling on the application, which may be protested to the water judge as provided in C.R.S. § 37-92-304(2), or the referee may re-refer the application to the water judge, or any party may file a motion to re-refer the application to the water judge in accordance with C.R.S. § 37-92-303.

(n) At any time after the status conference on applications to which statements of opposition have been filed, or after the filing of applications to which no statements of oppositions have been filed, if some further information is reasonably necessary for the disposition of the application, the referee may require the applicant to supply the information in writing, by affidavit or at an informal conference or at a hearing. The referee may ask the division engineer for information as part of the referee's ongoing informal investigation, but shall discontinue making such requests if the state or division engineer has become a party to the case.

(o) The referee shall enter minute orders summarizing all conferences with the parties or the division or state engineers.

(p) The referee shall have the authority to dismiss for failure to prosecute applications of parties who fail to comply with the requirements of the Water Court Rules or any case management plan, and to dismiss statements of opposition of parties who fail to comply with the requirements of the water court rules or any case management plan. Such dismissal may be protested to the water judge by any party within twenty days of receipt of the order of dismissal.

(q) Any time period contained in the water court rules, or the applicable rules of civil procedure, for an action by the referee or a party may be extended by the water judge for good cause. At any time the water judge determines that an application can be resolved without adjudication by the water judge, the water judge may refer the application back to the referee for disposition. To assist in the adjudication of water matters that are before the water judge, the water judge may direct the referee to perform identified tasks.

Rule 8. Briefs

Briefs shall be filed and served in accordance with Water Court Rule 2. A brief shall not exceed thirty pages, double-spaced, without permission of the court. Counsel are encouraged to include a table of contents and a table of cases cited, which shall not be counted as part of the thirty-page limit.

Rule 11. Pre-Trial Procedure, Case Management, Disclosure, and Simplification of Issues.

The provisions of C.R.C.P. Rules 16 and 26 through 37 shall apply except that they shall be modified as follows:

(a) C.R.C.P. 16(b)-(e) shall be modified as follows:

(b) Presumptive Case Management Order. Except as provided in section (c) of this Rule, the parties shall not file a Case Management Order and subsections (1)-(10) of this section shall constitute the Case Management Order and shall control the course of the action from the time the case is at issue, unless the water court orders otherwise for good cause shown. The time periods specified in this case management order are provided to take into account protested or re-referred cases that involve computer modeling or detailed technical analysis. Parties and counsel are encouraged to request a Modified Case Management Order, pursuant to section (c), to shorten time periods whenever possible, unless the water court orders otherwise for good cause shown.

(1) At Issue Date. Water matters shall be considered to be at issue for purposes of C.R.C.P. Rules 16 and 26 forty- five (45) days after the earlier of either of the following: entry of an order of re-referral or the filing of a protest to the ruling of the referee, unless the water court directs otherwise. Unless the water court directs otherwise, the time period for filing a Certificate of Compliance under subsection (b)(7) of this Rule shall be no later than 75 days after a case is at issue.

(2) Responsible Attorney. For purposes of Rule 16, as modified herein, the responsible attorney shall mean applicant's counsel, if the applicant is represented by counsel, or, if not, a counsel chosen by opposers, or the water court may choose the responsible attorney. The responsible attorney shall schedule conferences among the parties, prepare and file the Certificate of Compliance, and prepare and submit the proposed trial management order.

(3) Confer and Exchange Information. No later than 15 days after the case is at issue, the lead counsel for each party and any party who is not represented by counsel shall confer with each other about the nature and basis of the claims and defenses, the matters to be disclosed pursuant to C.R.C.P. 26(a)(1), the development of a Certificate of Compliance, and the issues that are in dispute.

(4) Trial Setting. No later than 60 days after the case is at issue, the responsible attorney shall set the case for trial pursuant to C.R.C.P. 121, section 1-6, unless otherwise ordered by the water court.

(5) Disclosures.

(A) The time for providing mandatory disclosures pursuant to C.R.C.P. 26(a)(1) shall be as follows:

(I) Applicant's disclosure shall be made 30 days after the case is at issue;

(II) An opposing party's disclosure shall be made 30 days after applicant's disclosures are made.

(B) The time periods for disclosure of expert testimony pursuant to C.R.C.P. 26(a)(2) shall be as follows:

(I) The applicant's expert disclosure shall be made at least 240 days before trial;

(II) The applicant's supplemental expert disclosure, if any, shall be made after the first meeting of the experts held pursuant to subsection (b)(5)(D)(I) of this Rule, and served at least 180 days before trial;

(III) An opposer's expert disclosure shall be made at least 120 days before trial;

(IV) If the evidence is intended to contradict or rebut evidence on the same subject matter identified by another party under subsection (b)(5)(B)(III) of this Rule, such expert disclosure shall be made at least 90 days before trial.

(C) Additional Expert Disclosures. In addition to the disclosures required by C.R.C.P. 26(a)(2)(B)(I), the expert's disclosure shall include:

(I) A list of all expert reports authored by the expert in the preceding five years; and

(II) An executable electronic version of any computational model, including all input and output files, relied upon by the expert in forming his or her opinions. The court may require the party to whom this information is disclosed to pay the reasonable cost to convert the data from the electronic format in which it is maintained in the expert's normal course of business to a format that can be used by the expert for the opposing party(ies).

(D) Meeting Of Experts To Identify Undisputed Matters of Fact and Expert Opinion and To Refine and Attempt to Resolve Disputed Matters of Fact and Expert Opinion.

(I) The expert witness(es) for the applicant and the opposer(s) shall meet within 45 days after the applicant's initial expert disclosures are made. The meeting(s) may be in person or by telephonic means. The purpose of the meeting is for the experts to discuss the matters of fact and expert opinion that are the subject of the expert(s) disclosures and with respect to such disclosures: to identify undisputed matters of fact and expert opinion, to attempt to resolve disputed matters of fact and expert opinion, and to identify the remaining matters of fact and expert opinion in dispute. The applicant may subsequently file a supplemental disclosure pursuant to Water Court Rule 11(b)(5)(B)(II) to address matters of fact and expert opinion resolved in or arising from the meeting(s) of the experts.

(II) The expert witness(es) for the applicant and the opposer(s) shall meet within 25 days after the opposers' expert disclosures are made. The meeting may be in person or by telephonic means. The purpose of the meeting is for the experts to discuss the matters of fact and expert opinion that are the subject of the expert(s) disclosures and, with respect to such disclosures: to identify undisputed matters of fact and expert opinion, to attempt to resolve disputed matters of fact and expert opinion, and to identify the remaining matters of fact and expert opinion in dispute. Within 15 days after such meeting, the experts shall jointly submit to the parties a written statement setting forth the disputed matters of fact and expert opinion that they believe remain for trial, as well as the undisputed matters of fact and expert opinion, arising from the expert disclosures.

(III) The content of the meetings of the experts and the written statement produced pursuant to Water Court Rule 11(b)(5)(D)(II) shall be considered as conduct or statements made in compromise negotiations within the ambit of CRE 408. The meetings of the experts shall not include the attorneys for the parties or the parties themselves.

(E) Declaration By Expert. Expert reports, disclosures, and opinions are rendered to the water court under professional standards of conduct and duty to the court. No person, including a party's attorney, shall instruct an expert to alter an expert's report, disclosures, or opinion. This does not preclude suggestions regarding the factual basis, accuracy, clarity, or understandability of the report, disclosure, or opinion, or proofreading or other editorial corrections, or an attorney communication of legal opinion to the expert of the attorney's client. The expert shall not include anything in his or her expert report, disclosure, or opinion that has been suggested by any other person, including the attorney for the expert's client, without forming his or her own independent judgment about the correctness, accuracy, and validity of the suggested matter. Matters of legal opinion pertinent to formulation of the expert's report, disclosure, or opinion are within the professional province and duty to the court of the attorney who represents the client who has retained the expert. Each expert witness's written disclosure, report, or opinion shall contain a declaration by the expert as set forth in the applicable water court form.

(F) Proposed Decree. Applicant shall provide proposed findings of fact, conclusions of law and decree at the time of its initial C.R.C.P. 26(a)(2) disclosures. All opposers shall provide comments on the proposed decree, including the language of specific decree provisions deemed necessary by the opposers, at the time of opposers' initial C.R.C.P. 26(a)(2) disclosures. Applicant shall respond to opposers' suggested decree language by providing an additional draft decree at the time of its rebuttal C.R.C.P. 26(a)(2) disclosures. In circumstances where, as a result of identification of witnesses and documents within the time frame for such identification set forth in this Presumptive Case Management Order but with insufficient time to allow responsive discovery or supplementation by an opposing party, then modification of this Presumptive Case Management Order shall be freely granted.

(6) Settlement Discussions.

(A) No later than 35 days after the case is at issue, the parties shall explore possibilities of a prompt settlement or resolution of the case.

(B) No later than 60 days before trial the parties shall jointly file a statement setting forth the specific disputed issues that will be the subject of expert testimony at trial.

(7) Certificate of Compliance. No later than 75 days after the case is at issue, the responsible attorney shall file a Certificate of Compliance. The Certificate of Compliance shall state that the parties have complied with all requirements of subsections (b)(3)-(7) (except (b)(5)(B) through (F) and (b)(6)(B)), inclusive, of this Rule or, if they have not complied with each requirement, shall identify the requirements which have not been fulfilled and set forth any reasons for the failure to comply. A request for a Case Management Conference shall be made at the time for filing the Certificate of Compliance.

(8) Time to Join Additional Parties and Amend Pleadings. The time to join additional parties and amend pleadings shall be in accordance with C.R.C.P. 16(b)(8).

(9) Pretrial Motions. Unless otherwise ordered by the court, the time for filing pretrial motions shall be no later than 35 days before the trial date, except that motions pursuant to C.R.C.P. 56 shall be filed at least 90 days before the trial date.

(10) Discovery Schedule. Until a case is at issue, formal discovery pursuant to C.R.C.P. 26 through 37 shall not be allowed. Informal discovery, including discussions among the parties, disclosure of facts, documents, witnesses, and other material information, field inspections and other reviews, is encouraged prior to the time a water case is at issue. Unless otherwise directed by the water court or agreed to by the parties, the schedule and scope of discovery shall be as set forth in C.R.C.P. 26(b), except that depositions of expert witnesses shall not be allowed until 30 days after the time for filing of the opposers' C.R.C.P. 26(a)(2) disclosures. The date for completion of all discovery shall be 50 days before the trial date.

(c) Modified Case Management Order. Any of the provisions of section (b) of this Rule may be modified by the entry of a Modified Case Management Order pursuant to this section.

(1) Stipulated Modified Case Management Order. No later tha. 75 days after the case is at issue, the parties may file a Stipulated Proposed Modified Case Management Order, supported by a specific showing of good cause for each

modification sought including, where applicable, the grounds for good cause pursuant to C.R.C.P. 26(b)(2). Such proposed order need only set forth the proposed provisions which would be changed from the Presumptive Case Management Order set forth in section (b) of this Rule. The Court may approve and enter the Stipulated Modified Case Management Order, or may set a Case Management Conference.

(2) Disputed Motions for Modified Case Management Orders. C.R.C.P. 16(d) shall apply to any disputes concerning a Proposed Modified Case Management Order. If any party wishes to move for a Modified Case Management Order, lead counsel and any unrepresented parties shall confer and cooperate in the development of a Proposed Modified Case Management Order. A motion for a Modified Case Management Order and one form of the proposed Order shall be filed no later than 75 days after the case is at issue. To the extent possible, counsel and any unrepresented parties shall agree to the contents of the Proposed Modified Case Management Order but any matter upon which all parties cannot agree shall be designated as “disputed” in the Proposed Order. The proposed Order shall contain specific alternate provisions upon which agreement could not be reached and shall be supported by specific showing of good cause for each modification sought including, where applicable, the grounds for good cause pursuant to C.R.C.P. 26(b)(2). Such motion need only set forth the proposed provisions which would be changed from the Presumptive Case Management Order set forth in section (b) of this Rule. The motion for a Modified Case Management Order shall be signed by lead counsel and any unrepresented parties, or shall contain a statement as to why it is not so signed.

(3) Court Ordered Modified Case Management Order. The water court may order implementation of a Modified Case Management Order if the Court determines that the Presumptive Case Management Order is not appropriate for the specific case. The Court shall not enter a Court Ordered Modified Case Management Order without first holding a Case Management Conference pursuant to C.R.C.P. 16(d).

(d) C.R.C.P. 16(c), C.R.C.P. 16(f)(3)(VI)(C), and C.R.C.P. 16(g) shall not apply to water court proceedings.

APPENDIX 1 to CHAPTER 36
UNIFORM LOCAL RULES
FOR ALL
STATE WATER COURT DIVISIONS

COLORADO WATER COURT FORMS

Form 2. Declaration of Expert Regarding Report, Disclosure, and Opinion

Form 2

<table>
<tr><td>District Court, Water Division No. _______ , Colorado
Court Address:

____
CONCERNING THE APPLICATION FOR WATER RIGHTS OF:
Applicant:

In the _________River or its Tributaries

I. ________________ County</td><td>

COURT USE ONLY</td></tr>
<tr><td></td><td>Case Number:
Division.
Courtroom:</td></tr>
<tr><td colspan="2"><u>DECLARATION OF EXPERT REGARDING REPORT, DISCLOSURE, AND OPINION</u></td></tr>
</table>

Expert reports, disclosures, and opinions are rendered to the water court under professional standards of conduct and duty to the court. No person, including a party's attorney, shall instruct an expert to alter an expert's report, disclosure, or opinion. This does not preclude suggestions regarding the factual basis, accuracy, clarity, or understandability of the report, disclosure, or opinion, or proofreading or other editorial corrections, or an attorney communication of legal opinion to the expert of the attorney's client. The expert shall not include anything in his or her expert report, disclosure, or opinion that has been suggested by any other person, including the attorney for the expert's client, without forming his or her own independent judgment about the correctness, accuracy, and validity of the suggested matter. Matters of legal opinion pertinent to formulation of the expert's report, disclosure, or opinion are within the professional province and duty to the court of the attorney who represents the client who has retained the expert. Each expert witness's written disclosure, report, or opinion shall contain a declaration by the expert as set forth in the applicable water court form.

Accordingly, I, ______________________, (name of expert) state the following:

(1) I understand that my role as an expert, both in preparing this report or disclosure and in giving evidence, is to assist the court to understand the evidence or to determine facts in issue. The opinions expressed in my disclosures and in my report are my own professional opinions.

(2) I have endeavored in my report and disclosures to be accurate and complete, and have addressed matters that I regard as being material to the opinions expressed, including the assumptions that I have made, the bases for my opinions, and the methods that I have employed in reaching those opinions.

(3) I have been advised by the attorney for my client of the disclosure requirements of the rules of the court, and I have provided in my report and disclosures the information required by those rules. I have not included anything in my report and disclosures that has been suggested by anyone, including the attorney for my client, without forming my own independent judgment on the matter.

(4) I will immediately notify, in writing, the attorney for the party for whom I am giving evidence if, for any reason, I consider that my existing report or disclosures requires any correction or qualification; and, if the correction or qualification is significant, will prepare a supplementary report or disclosure to the extent permitted by the applicable rules of the court.

(5) I have used my best efforts in my report and disclosures, and will use my best efforts in any evidence that I am called to give, to express opinions within those areas in which I have been offered or qualified as an expert by the court, and to state whether there are qualifications to my opinions.

(6) I have made the inquiries that I believe are appropriate and, to the best my knowledge, no matters of significance that I regard as relevant have been withheld from the court.

(7) I have disclosed any financial or pecuniary interest that I have in the results of this lawsuit or in any property or rights that are the subject of the lawsuit for which my report and disclosures are being submitted.

Dated this ___ day of _______, ___.

____

Declarant

Amended and Adopted by the Court, En Banc, February 19, 2009, these amendments to C.R.C.P. 90 and Water Court Rules 2, 3, 6, 8, 11, and Form 2 are applicable to applications filed on or after July 1, 2009, but any portions thereof that can be adapted for use by the water judge or referee without prejudice to the parties may be utilized in existing cases. . .

Justice Eid would not adopt that portion of Water Court Rule 11(b)(5)(D)(III) that excludes parties or attorneys for the parties from attending the meetings of the experts.

BY THE COURT:
/s/ Gregory J. Hobbs, Jr.
Gregory J. Hobbs, Jr.
Justice, Colorado Supreme Court

NJC

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Dividing the Waters