

**CONFUSION WHERE GROUND AND
SURFACE WATERS MEET: GILA RIVER
GENERAL ADJUDICATION, ARIZONA
AND THE SEARCH FOR *SUBFLOW***

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Abstract

Arizona is presently in the midst of a general adjudication for the Gila River system -- the watershed which comprises the southern two-thirds of the state. The purpose of the adjudication is to prioritize all water claims in the river system: both state-established and federally reserved rights. Arizona adheres to a bifurcated (or divided) system of water law which only recognizes a component of ground water -- called *subflow* -- to be appropriable. Wells which pump non-appropriable water -- called *tributary flow* -- are not to be included in the adjudication. The problem is that federal laws do not recognize this artificial bifurcation.

The challenge lies in identifying a *subflow zone* which satisfies the hydrologic fiction of existing state precedents and the hydrologic reality of federal statutes. At the core of the problem lies the fate of Arizona's perennial stream water and the fulfillment of federally reserved tribal water rights. Thus, larger questions loom: can Arizona law reconcile its glutinous past with a water-scarce future, will the adjudication ever reach a finality, and even if it does, will it be a finality that all sides can live with?

Chapter 1

Introduction

1.1 THE WEST AND ITS WATER

The American West has always been driven by the scarcity of its water. First and foremost, this scarcity changed its water law. The law of the West -- known as the prior appropriation doctrine -- formed the foundation of this scarcity-driven society. With the amount of available stream water being dwarfed by the immensity of its barren landscape, the doctrine became the manifesto that no drop of stream water should flow out to sea unused.

And so it didn't. By the end of the 19th century, western streams were being drained dry by irrigators, miners, and municipalities so that during lean years, the junior-most claim holders were being left with little to no water. But wet years were a different story completely. Thirsty settlers watched in dismay as spring snow-melt rippled and roared its way through swollen river channels and out to sea. Scarcity once again drove the West, this time in the form of the Reclamation Act of 1902. Canyons and valleys were clogged with concrete and the West watched contentedly as the annual spring surge to sea was stopped short of its destination, transforming deep and dark canyons into vast pools of dimensionless turquoise. Still, this water was not enough. Scarcity, always just around the corner with the next rainless season, finally drove the West into the ground -- not to die -- but towards the ancient liquid reserves that ooze and percolate through the earth's sedimentary depths; sucking this fossil water to the surface as if the aquifers were infinite and scarcity, that specter of the West who is always present but never seen, was finally laid to rest once and for all.

The specter of scarcity has kept the West on the run -- re-inventing law, clogging its river-carved canyons, and funneling-up fossil water from hundreds of feet below. If the American West has defined itself in its first century of existence by a one hundred year

dash -- a fast-paced foot-race from a scarcity which is always trailing at its boot-heels -- it must now enter the 21st century with the realization that the finish line is no where in sight and that scarcity is only breaking into pace for a millennium-long marathon. All the native sources of water have been tapped: stream flow has dwindled, the best canyons have been filled, and aquifer levels are falling fast. With the hope of bountiful rainfall evaporating in the cloudless sky, the West must be willing to quit running and meet with scarcity at the table -- not at the poker table for a game of five-card stud -- but at the bargaining table, and when the cards are dealt one of the biggest hands will be held by a third player -- the American Indian -- who is playing high-stakes water rights after decades of being outlawed from the frenzied race.

1.2 ARIZONA AND ITS WATER

Arizona's on-going Gila River General Adjudication is a testament that there is no place left to run. The dual objectives of the adjudication are to prioritize (under prior appropriation statutes) and protect all water rights in the Gila River system. All refers to both state and federally-protected water rights; including federally reserved Indian water rights.

Both goals have proven difficult to accomplish. Prioritization depends on a knowledge of the extent that appropriable waters (ie., waters which are governed under the law of prior appropriation) extend into the ground water zone. In Colorado and New Mexico, all waters -- both ground and surface -- are considered appropriable. Arizona law, however, does not recognize the connectedness between ground and surface waters, but instead adheres to a bifurcated (or divided) water law system in which only a component of ground water -- called *subflow* -- is considered appropriable. Not only does this pose a problem for prioritizing all water claims, it also poses an even bigger problem for protecting claims not governed under state law. Federal statutes do not recognize this artificial bifurcation, yet the fact that federal and state claims are scattered throughout the

river system seems to suggest that federally-protected claims will be diminished by pumping ground water which Arizona law considers to be non-appropriable.

Herein lies the challenge. Arizona must identify a *subflow* zone which adheres to its own legal precedents while simultaneously satisfying the hydrologic reality recognized in federal statutes. This challenge is complicated by a diversity of views. It is inevitably a legal problem. Although there are strong legal precedents which support Arizona's bifurcated water law system, law books are unclear in defining the line where appropriable water ends and non-appropriable water begins. It is also a hydrological problem which revolves around the effect of ground water pumping on a nearby stream, yet most hydrologists view the bifurcated water system as a ridiculous antiquity of a former era. Finally, it is an administrative problem. How can any *subflow* zone comport to both the hydrologic fiction of state law and the hydrologic reality of federal law while simultaneously being easy to delineate?

On the one hand, determining the extent of *subflow* is only a small part of the ongoing Gila River General Adjudication. On the other hand, it is the link which connects Arizona law to its past and future. Not only does *subflow* hold the historical key to understanding how Arizona's archaic system of water law has been perpetuated into the present, it also offers the opportunity to confront this past so that the future goals of the adjudication can be met.

1.3 STRUCTURE OF REPORT

This report addresses five main questions:

1. What are the immediate and long range goals of the Gila River General Adjudication and how are these goals dependant on the *subflow* determination?
2. Why did Judge Goodfarb's "50%/90 day test" (which was the original test developed by the Arizona Superior Court for defining the extent that appropriable waters extend into the ground water zone) fail in the 1993 Interlocutory Review?

3. What scientific, historical, and legal reasons make the delineation of *subflow* such a complicated and controversial problem?
4. What are the advantages and disadvantages of the new methods proposed for delineating *subflow*? and
5. What are the advantages and disadvantages of Judge Goodfarb's new *subflow* ruling? (ie., Is it substantiated with evidence, will it meet all the goals of the adjudication, and will it be able to stand up to another appeal?)

Shown below is a chapter-by-chapter overview of the report:

Chapter 2: The Problem. This chapter discusses the origin and goals of the Gila River General Adjudication with an emphasis on how the process has stumbled in its attempt to define the extent that appropriable water extends into the ground water zone (called the *subflow* zone) using the "50%/90 day test."

Chapter 3: Science of Problem. This chapter focuses on describing the hydrologic process of capture and then investigating the available methods for calculating the amount of stream depletion due to a nearby pumping well.

Chapter 4: History of Problem. This chapter traces the historical evolution of water law both in the West (in general) and in Arizona paying special attention to the 1931 Southwest Cotton ruling -- the ruling which has served as the basis for perpetuating Arizona's bifurcated water law system into the present.

Chapter 5: Law of Problem. If it is cloudy that the "50%/90 day test" is bad law, it is less clear what will make a better solution. In briefs submitted before the court on September 24, 1993 and October 4, 1993; law firms which represent each interest group attempt to decode the legal riddle at the river's edge.

Chapter 6: Proposed Solutions to Problem. This chapter scientifically and legally scrutinizes the *subflow* solutions forwarded in the January 1994 evidentiary hearings. While there is undoubtedly a wide diversity of solutions, the real question becomes: which solutions, if any, are acceptable for meeting the larger objectives of the adjudication?

Chapter 7: Fate of Problem. This chapter analyzes Judge Goodfarb's new *subflow* ruling and its prospect for satisfying past precedents, present realities, and future goals.

The Gila River General Adjudication is part state law, part federal law, and part hydrology. Inevitably, the separate parts will overlap. *Cappaert v. United States* (1978) is an overlap of federal law and hydrology and prioritizing all water claims in the Gila River system is an overlap of state and federal law. The main focus of this report is the search for *subflow* -- a fuzzy term which is part law and part hydrology. As shown in the Ven diagram in Figure 1.1, a successful conclusion to the Gila River General Adjudication will occur when all these separate parts converge.

The report discusses state, federal, and scientific events that have occurred decades apart. Table 1.1 will be helpful in sequencing these events as they are discussed throughout the report.

Ven diagram of overlapping legal and scientific influences
Figure 1.1

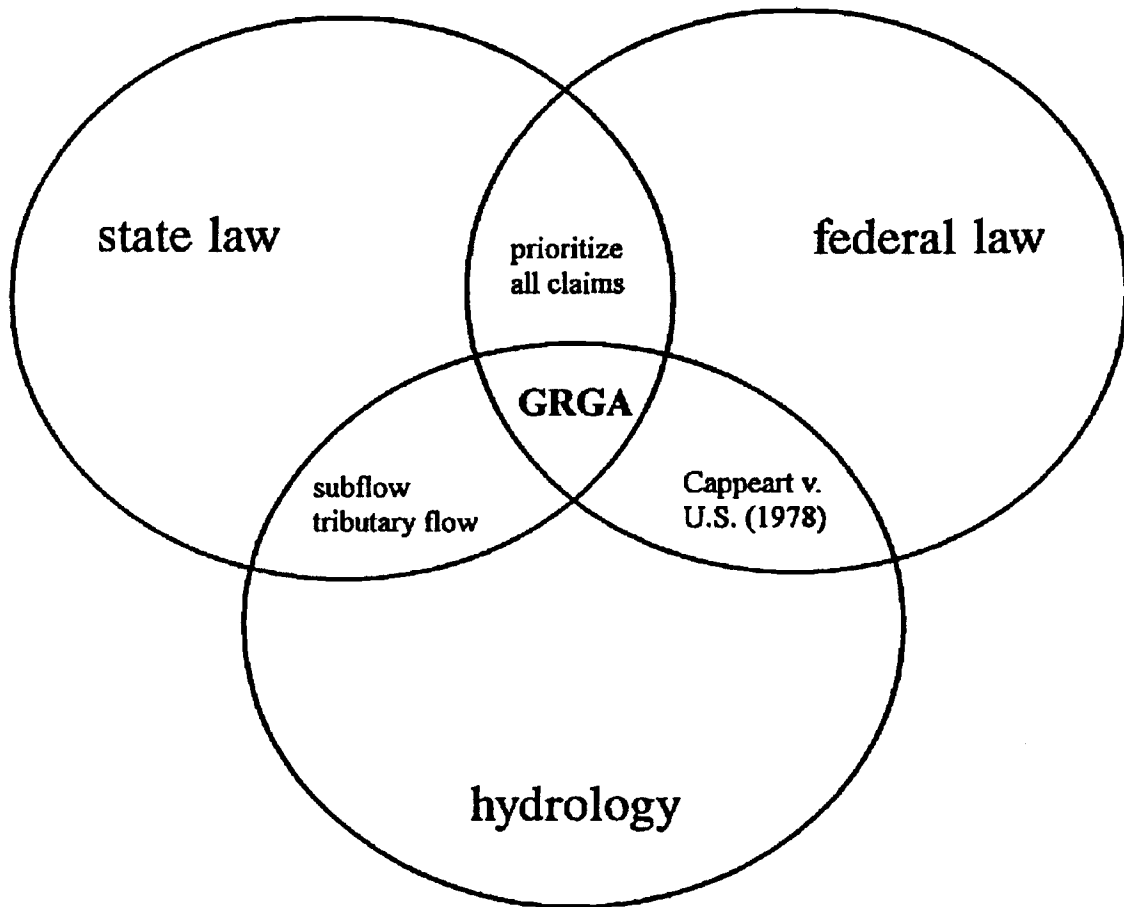


Table 1.1
Time Line of Events

1864	Arizona's territorial constitution
1894	C.S. Kinney's Law of Irrigation (first edition)
1902	Reclamation Act
1908	Winter's Doctrine
1910	C.S. Kinney's Law of Irrigation (second edition)
1911	Arizona statehood
1919	Arizona Water Code
1926	Proctor v. Pima Farms Company
1931	Southwest Cotton Ruling
1935	C.V. Theis publishes report on ground water flow to a well

Table 1.1
(continued)

1941	C. V. Theis publishes report on stream depletion due to a nearby pumping well
1953	Bristor v. Cheatham
1963	Arizona v. California (establishment of PIA standard for quantifying federally reserved Indian water rights)
1974	Salt River Valley Water Users Association file petition to determine the water rights in a section of the Salt River
mid-1970s	Suits filed by Arizona Indian tribes and everybody else which inspired the Gila River General Adjudication
1978	Cappaert v. United States (federal precedent which recognizes the connection between ground and surface waters)
1979	Arizona legislature enacts adjudication
1983	Gila River General Adjudication begin after resolution of jurisdictional dispute in Arizona v. San Carlos Apache Tribe of Arizona
1987	Evidentiary hearings on connection between ground and surface waters
1988	Judge Goodfarb drafts the "50%/90 day test" for determining the extent of appropriable waters
1990	Objections are filed against the "50%/90 day test" on the basis that certain wells in the "50%/90 day test" zone are not pumping <i>subflow</i>
1993	Rejection of "50%/90 day test" in the Interlocutory Review
1993	Legal briefs and technical reports submitted on the extent of <i>subflow</i>
1994	Evidentiary hearings on the extent of <i>subflow</i>
1994	New <i>subflow</i> solution
???	End of Gila River General Adjudication

Chapter 2

The Problem

Summary

Arizona is presently in the midst of a general stream adjudication for the Gila River system -- the watershed which comprises the southern two-thirds of the state. Although the immediate goal of prioritizing water rights in the watershed seems simple enough, Arizona struggles "without" to reach a comprehensive solution which meets federal statutes and struggles "within" to define the extent in which appropriable water extends into the ground water zone. Arizona's attempt to fulfill the later high-lights the over-riding question of the adjudication: can Arizona succeed in doing both?

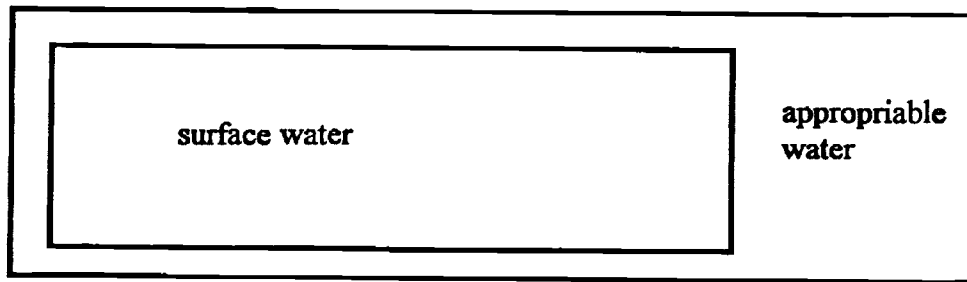
2.1 INTRODUCTION -- ARIZONA'S BIFURCATED WATER LAW SYSTEM

Where does ground water end and surface water begin? First-hand observation tells us that surface water is simply what's in the stream. Ground water, though we can't see it, must run below our feet and in the ground. The stream bank is where they meet. Furthermore, although the two are separate, they must ultimately be connected. The same water that flows through the ground may eventually seep into the stream and the same water that runs in the stream may seep back into the ground. Although an apparently straightforward question to a person standing in a stream fishing or gliding through a current on a canoe, the answer has eluded Arizona law makers.

The reason for this revolves around Arizona's adherence to a bifurcated water law system. Surface water is governed by the law of prior appropriation and ground water is governed under property right statutes. So long as we live in a world where there is only ground water or only surface water, either can operate as an effective system. When both are present, problems become evident. In Arizona there is no coherent law where ground and surface waters meet. There are some general ideas and some vague legal criteria, but

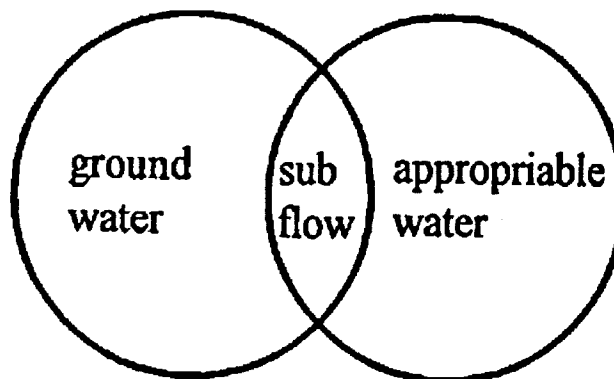
mostly there is confusion. For example, all appropriable water falls under the law of prior appropriation -- a doctrine developed originally to deal exclusively with surface water allocation. However, not all appropriable water is surface water (Figure 2.1).

Figure 2.1
Ven diagram of stream water and appropriable water

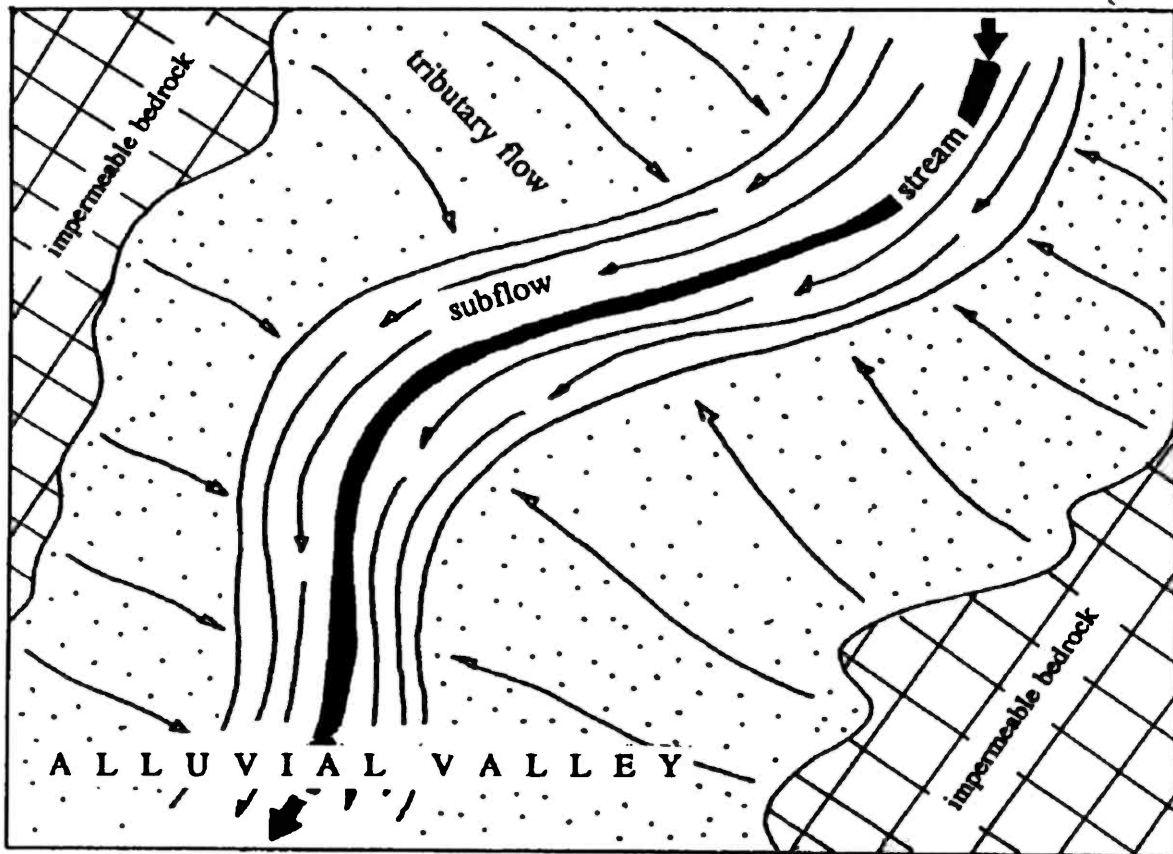


Furthermore, Arizona's ground water code of reasonable use was originally developed to deal exclusively with ground water. However, not all ground water is non-appropriable (Figure 2.2). To simplify as much as possible, ground water is legally divided into two separate components: tributary flow and *subflow*. Tributary flow is non-appropriable ground water which flows toward a stream and *subflow* is appropriable ground water which flows adjacent and parallel to a stream. A cartoon of tributary flow and *subflow* is shown in Figure 2.3.

Figure 2.2
Ven diagram of ground water and appropriable water



Cartoon of *subflow* and tributary flow
Figure 2.3



2.2 WHAT IS A GENERAL STREAM ADJUDICATION?

Now consider a stream that is used by only a few appropriators. As long as surface water is abundant in comparison to water consumption, there is little need for a public record of individual water claims. However, the law of prior appropriation (under "first in time, first in right" statutes) guarantees that senior water claims will be protected from subsequent junior claims. Thus, as water use increases on a stream, it becomes highly advantageous for senior appropriators to file their claims in the form of a public record that will hold up in a court of law. A public water claim will typically contain the following information:

1. date (year and season),
2. location, and
3. quantity of diversion

as well as

4. purpose, and
5. place that the diverted water is used.

If the public record serves as the *basis* for securing an individual's investment in stream water, a general stream adjudication is the *process* by which all surface water claims are protected. In an adjudication, all water users in the watershed go to court and submit proof of their water claims. Depending on the size of the watershed, this process could include hundreds or thousands of claims.

The immediate purpose of a general stream adjudication is to simply *prioritize* all appropriable water claims (governed under the law of prior appropriation). In this regard, a general stream adjudication is usually just a *means* by which a larger *ends* is sought. This *ends* may involve a highly-charged clash between major water users or a conflict across jurisdictional borders. Thus, the larger objective of a stream adjudication is usually to minimize litigation between individual claimants and to create an environment in which legitimate disputes can be settled in an informed and enlightened manner.

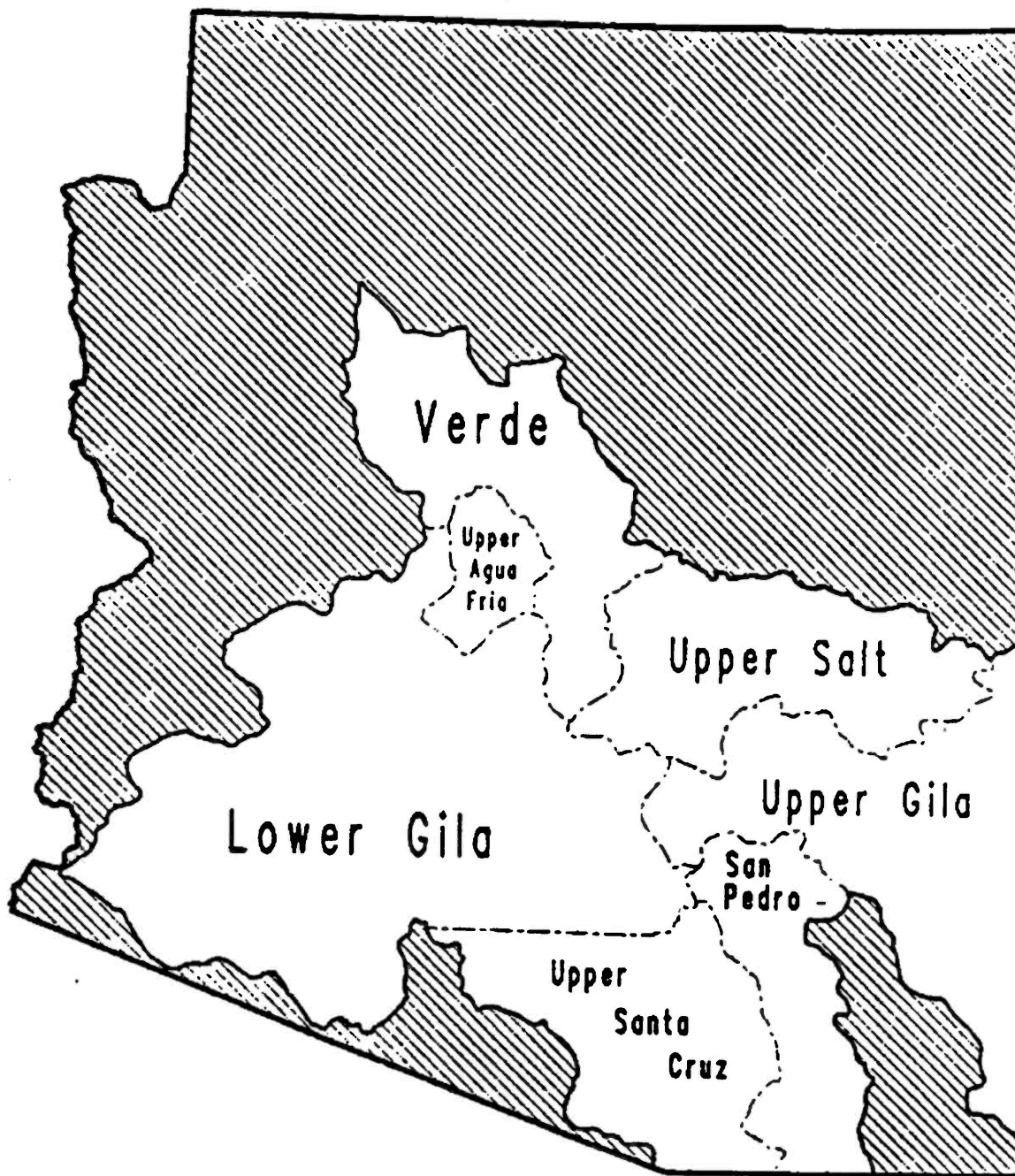
2.3 THE GILA RIVER GENERAL ADJUDICATION.

The Gila River General Adjudication began in 1974, when the Salt River Valley Water Users's Association filed a petition to determine the water rights in section of the Salt River, a tributary of the Gila River (Moore and Weldon, 1985). Subsequent petitions enlarged the adjudication to include all the tributaries of the Gila River System and the Gila River itself. More than 65,000 statements of water rights claims have been filed by nearly 24,000 parties (Glennon and Maddock, 1994).

2.3.1. Purpose and Place

The Gila River system's watershed comprises the southern two-thirds of the state.

Gila River Watershed, Arizona
Figure 2.4



The immediate goal of the adjudication is simply:

"to determine the extent and priority of the rights of all persons to use water in the Gila River system and source" (Interlocutory Review, 1993).

System and source here has been interpreted by the Arizona supreme court to mean all appropriable waters and all persons refers to all water users -- whether under state or federal jurisdiction (Leshy and Belanger, 1988).

This immediate purpose seems relatively straight-forward -- simply to create a *prioritized list* of all appropriable water claims in the Gila River system. The larger objective, and the underlying impetus behind the adjudication, revolves around several suits filed by Arizona Indian tribes in the 1970's: suits that have resulted in a conspicuous push by the federal government to quantify federally reserved Indian water rights in Arizona.

2.3.2 State Jurisdiction but Federal Control?

Either the state or federal government has the authority to adjudicate a stream system. Although federal interests are usually protected from state jurisdiction, the 1952 McCarran Act abolishes this barrier in the special case of a general stream adjudication. On the one hand, a *state-controlled* adjudication may be more desirable since the subtleties and intricacies of local water codes are more efficiently handled in a state-ran adjudication. For the immediate objective of the adjudication (simply prioritizing all water claims in the river system), this indeed might be the case. On the other hand, a *state-controlled* adjudication may be less desirable since it has been suggested that Indian claims could be "indirectly diminished" under state jurisdiction (Leshy and Belanger, 1988). Though there is no legal basis to perpetuate such fears, there is little question that state economic interests fly in the face of relinquishing semi-precious water within the borders of Arizona to Indian tribes.

Since Arizona has a significant self-interest in the fate of all waters in the Gila River watershed and since federal intervention seemed all but eminent, the state legislature enacted the general stream adjudication in 1979. This enactment was quickly followed by the San Carlos Apache Tribe's appeal of the state-run adjudication. Whether good or bad, the Arizona v. San Carlos Apache Tribe of Arizona (1983) Supreme Court ruling reconfirmed Arizona's option to run the adjudication itself.

The McCarran Act is by no means a scathless triumph for Arizona. Nor is it a Pyrrhic Victory. However, Arizona now finds in its hands a double-bladed sword that Indian tribes fear will swath at its "practicably irrigable acreage (PIA)" water (guaranteed under the Winters Doctrine (1908) and reconfirmed under *California v. Arizona* (1963)) and a sword that Arizona, if not careful, may quite easily turn on itself. This danger manifests itself in three ways.

First, the McCarran Act strictly limits the adjudication to a *judicial* proceeding. Arizona adjudications formerly fell under the authority of a water resources administration agency (Leshy and Belanger, 1988). While such an agency doesn't necessarily imply a susceptibility to political or economic influence, the judicial requirement insures a strict legal execution of the adjudication.

Second, the McCarran Act requires that adjudications be complete and comprehensive. Complete implies that federal water rights cannot be singled out separately from other claims but must instead be included as a part of the total picture (Leshy and Belanger, 1988). So while the McCarran Act does give Arizona the ostensible option of control, it limits this control within the strict confines of a general stream adjudication. This control is further constrained by the comprehensive requirement which implies that the federal government's surrendered authority is purely procedural; or, in other words, federal water claims are still protected under federal statutes (Leshy and Belanger, 1988). Although this certainly does not guarantee conflict in every state, Arizona's adherence to the hydrologic fiction of a legally bifurcated water system

startlingly contrasts federal statutes which recognize hydrologic reality. In particular, *Cappaert v. United States* (1978) recognizes that downstream surface water claimants should be protected from upstream connected ground water pumping. Arizona's unwillingness to recognize the hydrologic connection of all waters certainly does not guarantee a comprehensive adjudication. In light of this, Arizona has envisioned the route to *comprehensiveness* to be a two-tiered adjudication where:

The result is to create two different versions of the law in Arizona on the groundwater/surface water interface -- one where only some groundwater pumpers that appreciably deplete surface streams are subject to regulation to protect surface water rights, and a second where all such groundwater pumpers are regulated. The difference between the two turns on whether federal or state water rights are threatened by such pumping; federal rights are protected under federal law, but state rights are not fully protected because of the order's narrow, hydrologically imperfect definition of "subflow" (Leshy and Belanger, 1988). (emphasis added)

Finally, and most importantly, review and subsequent intervention (within certain legal bounds) is granted to the federal government if the state-controlled adjudication runs somehow afoul of the McCarran Act (Leshy and Belanger, 1988). Is Arizona on track for a comprehensive solution? It is a question that should be asked over and over again throughout the adjudication since it will inevitably be a question that it will have to answer to in the end.

2.4 ARIZONA'S DOUBLY BIFURCATED WATER SYSTEM

Upon deciding to take jurisdictional control of the adjudication, Arizona was then confronted with the choice of how to reach a comprehensive solution. Comprehensiveness could be reached in one of two ways: either (1) constructing an environment where state and federal statutes converge and interact or (2) constructing a segregated environment in which federal and state claims co-exist as separate un-interacting entities. By choosing the later (and thus re-confirming its sophistic confidence

that hydrologic principles must strictly obey arbitrarily drawn lines), Arizona has multiplied its bifurcated problems by two and created a *doubly* bifurcated water system.

2.4.1 The State v. Federal Bifurcation: The Struggle from "Without"

Federal statutes and state statutes may serve as effective water law systems within their respective borders. However, the prospect of a border where the two meet suggests eminent problems. These problems are confounded by unclear concepts conveyed in both federal and state statutes.

Federal confusion is most evident in *Cappaert v. United States* (1978). While it is clear that *federal surface-water claims* are protected from subsequent ground-water pumping, it is less clear whether *federal ground-water claims* are similarly protected from subsequent ground water pumping. If *Cappaert* truly does apply to ground water claims, its implications on the fate of the adjudication would be both novel and significant.

2.4.2 Subflow v. Tributary Flow Bifurcation: The Struggle from "Within"

As already mentioned, state statutes become muddled where ground and surface waters meet. This became readily apparent at the onset of the adjudication. Most recently, the failed attempt to settle this issue with the "50%/90 day test" became both the focus and farce of Arizona's attempt to perpetuate its *doubly* bifurcated water system.

As already discussed, the immediate purpose of the adjudication is simply to prioritize all appropriable waters in the Gila River system and source. If we momentarily forget about the federal tier of the adjudication, prioritization of state claims rests on a clear distinction between appropriable and non-appropriable waters. Once the jurisdictional dispute was resolved in 1983, the next task for the Arizona Supreme Court was to determine the *appropriableness* of certain ground waters. In 1986, the supreme court sought to investigate and answer the following question:

"Is ground water included within the phrase "river and source" as it is used in (the Arizona Constitution) to define appropriable waters, and, if so, to what extent is it included" (Interlocutory Review, 1993)?

As highlighted by John Leshy and James Belanger in Arizona Law Where Ground and Surface Waters Meet (1988) and as discussed in chapter 4 of this report, the larger passage in the constitution from which "river and source" is taken remains one of the more controversial, misinterpreted, and undoubtedly influential passages in Arizona's water code; and in itself could be the subject of an extended debate. Regardless, "river and source" has been legally de-coded by the court to include a component of ground water; only to the extent, however, that it can be determined to be *subflow*. The effect of this interpretation on the adjudication is clear. All wells pumping *subflow* should be included in the adjudication as being subject to the law of prior appropriation, and unlike wells which are withdrawing tributary ground water, should no longer be governed by an owner's right to remove water percolating under the owner's land. Or in other words, *subflow* is appropriable and tributary flow is not.

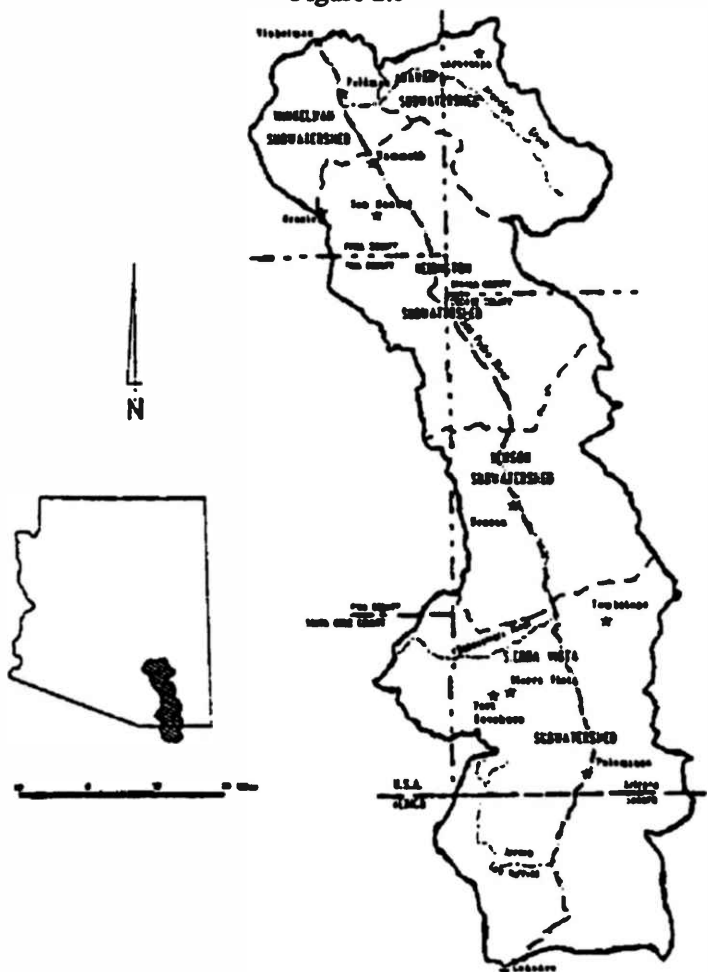
Such a revelation is no surprise in a bifurcated water law system:

(I)n a state that follows prior appropriation for surface water and common law reasonable use for groundwater, a junior in time groundwater pumper who irrigates on tract is not liable to surface water senior if the source of the pumped water is "percolating water" and not "subflow" of the surface stream. So long as the distinction between the types of the water are clearly drawn, the results in the cases can be predicted (Sax and others, 1991). (emphasis added)

In Arizona, the distinction between tributary flow and *subflow* is not clearly drawn. There are no equations, mathematical limits, or fixed physical criteria which clearly identify this dividing line in either the constitution or subsequent court rulings. In light of this, it became quickly apparent that evidentiary hearings were necessary to quantify the ambiguous, yet legal, concept of *subflow*. Evidence and expert testimony was presented in two evidentiary hearings held in October 1987 and January 1988; both of which dealt

with the relationship between ground and surface waters within the San Pedro Basin, a sub-basin of the Gila River Watershed.

San Pedro Basin, a sub-basin of the Gila River Watershed
Figure 2.5

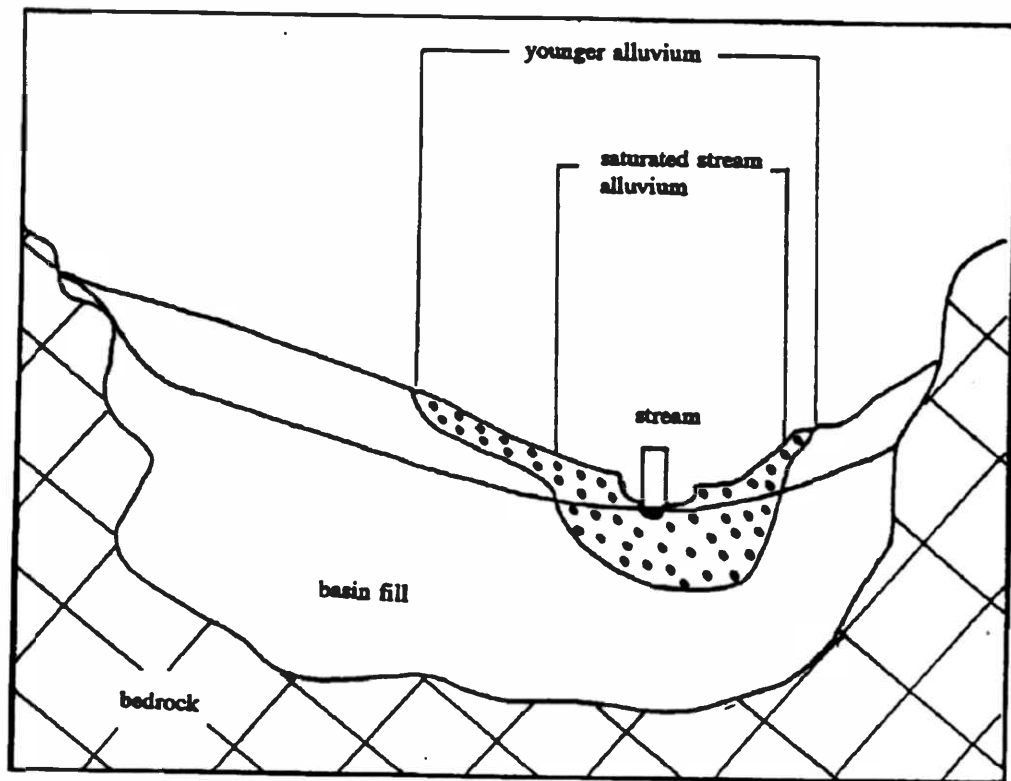


2.5 JUDGE GOODFARB'S RULE

In accordance to hydrologist Leonard Halpenny's suggestion that wells which withdraw water from the "younger alluvium" are presumed to be depleting surface water, Judge Goodfarb of Maricopa County Superior Court drafted the following legal distinction between appropriable and non-appropriable waters.

"As to wells located in or close to that younger alluvium, the volume of stream depletion would reach 50% or more of the total volume pumped during one growing season for agricultural wells or during a typical cycle of pumpage for industrial, municipal, mining, or other uses, assuming in all instances and for all types of use that the period of withdraw is equivalent to 90 days of continuous pumping for the purposes of the technical calculation" (General Adjudication, 1988).

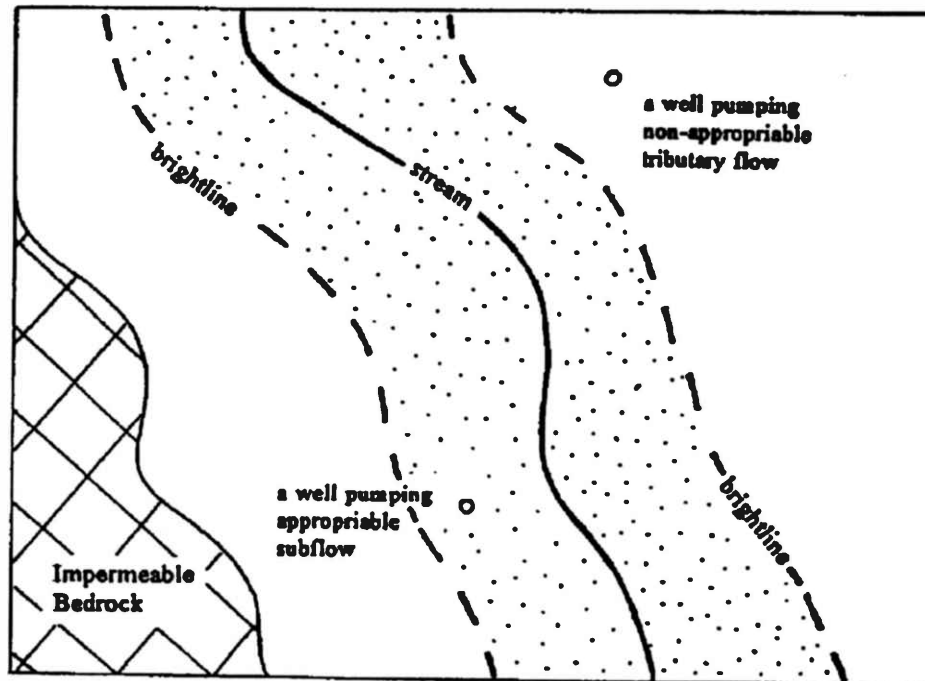
Cartoon of the younger alluvium (cross-sectional view).
Figure 2.6



The above test is more commonly referred to as the "50%/90 day test" or the "50/90 rule." The manner in which the "50/90 rule" was drafted leaves little question of its intent; namely, to allow for a convenient technical solution for determining the extent that appropriable water extends into the ground water zone. This technical solution, in turn, would be used to create a "brightline" on either side of the stream: wells inside of which would be considered depletors of appropriable water (and subsequently included in

the adjudication) and wells outside of which would be considered pumpers of tributary flow (or non-appropriable ground water).

How the brightline will work (plan view)
Figure 2.7



2.6 DEPARTMENT OF WATER RESOURCE'S "50/90 RULE" SOLUTION

The ultimate goal of Judge Goodfarb's rule was to categorize all wells in the Gila River system into the following three zones:

- a. wells which are withdrawing appropriable *subflow*,
- b. wells which significantly diminish federally reserved rights, and
- c. wells with no significant effect on either appropriable or federally reserved rights.

Categorization would be conducted in a two stage process. First, the "brightline" boundary between appropriable and non-appropriable water would be determined. Second, all wells in the Gila River system would be categorized in one of the above three zones to be used in the adjudication.

2.6.1. Stage 1

The actual technical calculation of the "brightline", in accordance to the court order, was left in the hands of the Arizona Department of Water Resources (DWR).

DWR suggested the following methodology.

1. All perennial and intermittent stream reaches (with a minimum in-stream annual flow of 90 days) were to be identified. Both ephemeral and intermittent stream reaches which did not meet the 90 day in-stream flow requirement were assumed not to demonstrate the degree of ground and surface interconnectedness deemed necessary by the "50%/90 day test."

2. An analytical means to determine the distance between a stream and the "brightline" using Jenkins' (1968) dimensionless solution of C. V. Theis' (1941) stream depletion equation was selected as the technical method¹. Theis' stream depletion equation is written as follows:

$$\frac{Q_{stream}}{Q_{well}} = \frac{2}{\pi} \int_0^{\pi/2} e^{-k \sec^2 u} du \quad (1)$$

where,

$$k = 1.87 \frac{a^2 S}{T t} \quad (2)$$

and,

a is the distance from the stream to the "brightline",

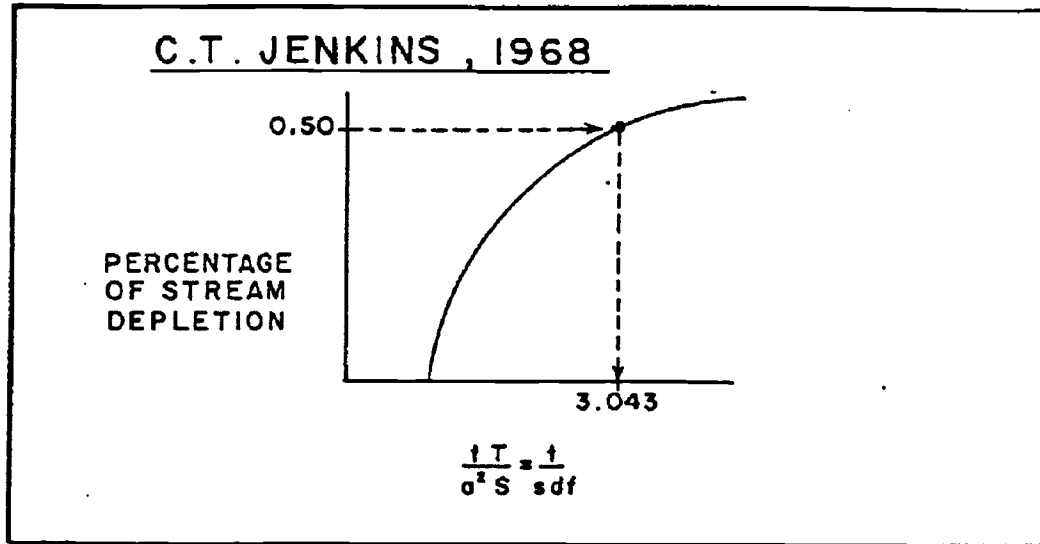
S is the storage coefficient of the younger alluvium,

T is the transmissivity of the younger alluvium.

¹A more complete discussion of Theis's method is given in Section 3.4 in Chapter 3

DWR then proposed to use Jenkins' dimensionless "type curve" shown in Figure 2.8 to determine the distance a from the stream to the "brightline".

Stream depletion curve. (DWR, 1991)
Figure 2.8



Since the maximum allowable stream depletion (50%) and the time of pumping ($t = 90$ days) are known, the distance a is easily computed using the equation,

$$3.043 = \frac{tT}{a^2S} \quad (3)$$

derived from the above curve. Rearranging the equation and substituting for t results in the final form proposed by DWR:

$$a = \sqrt{\frac{29.58T}{S}} \quad (4)$$

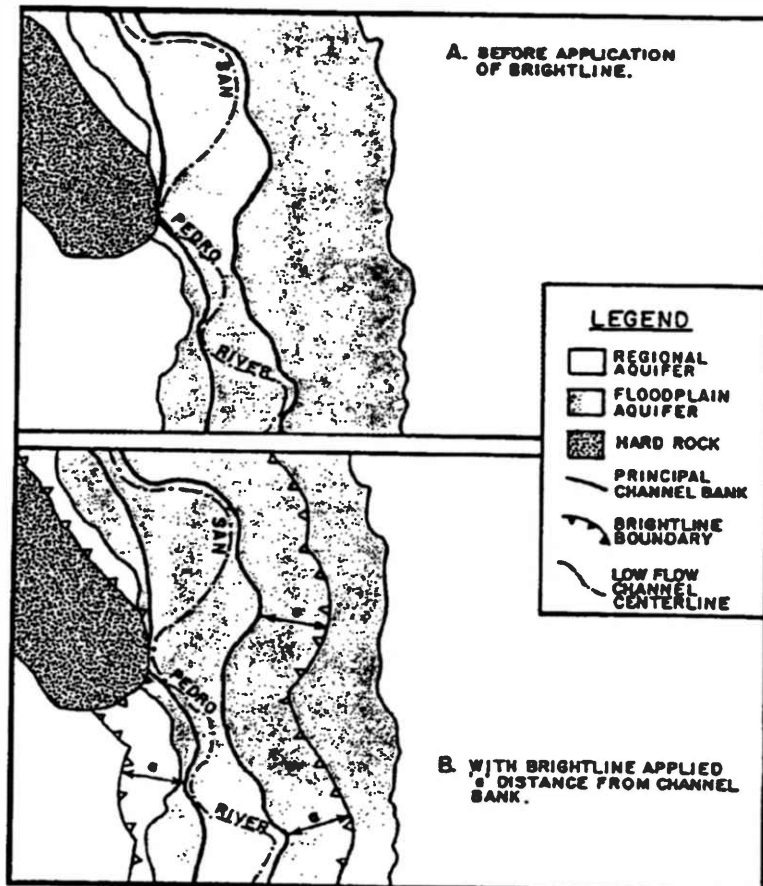
Transmissivity (T) and storativity (S) values for specific well locations could be obtained using pump-test data from USGS or DWR reports.

3. In order to calculate a , however, it is essential to know where the stream is. An obvious statement, but undoubtedly a realistic concern for river courses such as the San Pedro whose path may either alter gradually over time or abruptly after

intense storm events. To solve this problem, aerial photography was proposed as the method for delineating the narrow corridor in which the river channel forever struggles to reach a dynamic equilibrium; more commonly referred to as the modern floodplain. For all technical calculations, the edge of the floodplain would serve as the starting point for measuring a .

4. Finally, the brightline would have to be adjusted where impermeable boundaries exist within the analytically determined zone. In most cases, in accordance to Halpenny's original suggestion, the "brightline" would coincide with the younger alluvium (Figure 2.9).

Constructed brightline based on the "50%/90 day test" (DWR, 1990)
Figure 2.9



2.6.2 Stage 2

The final step in fulfilling the court order was simply to categorize each well into one of the three groups so that the adjudication could proceed. This required little more than cataloging the results determined from the technical calculation into a Hydrographic Survey Report (HSR, 1990, 1992).

2.7 APPEALING THE "50%/90 DAY TEST"

In accordance to the court ordered "50%/90 day test," DWR successfully applied its technical test and created a HSR for the San Pedro Basin (1990). Standing alone and separate from existing legal precedents and economic policies, the rule represented a reasonable solution based loosely on the premise that a well which withdraws over half of its water from the stream after a season (90 days) of continuous pumping should be considered a user of appropriable stream water.

In a land of scarce water which is sought by many, arbitrary lines are an ill-suited standard. At the risk of oversimplifying, it is easy to think of the issue as a conflict between two groups -- the 'mountain toppers' and the 'vortex pullers'². The former claims that all groundwater is connected to the surface stream (even a drop of rain that falls on the mountainous edge of the basin) and the later claims that all wells pump *tributary* ground water unless a vortex due to the pumping forms in the stream; which in this extreme case, suggests *subflow* depletion. If not a complete representation of the diverse interests involved, it does capture the full range of perspectives concerning where ground water ends and where appropriable water begins.

Because water issues are usually so highly-charged in Arizona, the "50/90 rule" may have been doomed from the start. Scientifically, the technical aspect of the solution

²A more humorous term "duck sucker" was coined for the vortex pullers at the Evidentiary Hearings in February, 1994 before the Honorable Stanley Z. Goodfarb. One can easily visualize the poor duck, tail-feathers and all, disappearing down the vortex created by the pumping.

was based on mathematical assumptions which are rarely encountered in a semi-arid region; raising doubts concerning its hydrologic accuracy. The core of the problem, however, was in the wording of the "50%/90 day test" ruling.

Shortly after the 1987 evidentiary hearings, several water users filed a motion that certain wells in the designated "brightline" zone should not be included in the adjudication because they do not pump *subflow* -- the legal term which refers to appropriable ground water in Arizona. They argued that the "50%/90 day test" failed to properly account for such a category of water. Combined with the fact that the larger objectives of the adjudication depended on an accurate delineation of appropriable ground water, it was decided that it would be a senseless waste of time and effort to proceed any further in the adjudication without resolving the issue. So in a special court injunction, the supreme court asked the question:

Did the trial court err in adopting its 50%/90 day test for determining whether underground water is "appropriable" under ARS 45-141 [or state law] (Interlocutory Review, 1993)?

Inevitably, the answer was: yes it did fail.

2.8 REJECTING THE "50%/90 DAY TEST"

The reasons behind "50%/90 day test" failure are outlined in an Interlocutory Review filed by the Arizona Superior Court in July 1993. The rejection is based primarily on legal precedents established in the 1931 court case Maricopa County Municipal Water Conservation District No. One v. Southwest Cotton Co. 39 Ariz. 65. 4 P.2 369 (1931) [referred to here after as Southwest Cotton]. The Interlocutory Review perceived its role as "interpreting Southwest Cotton, not refining, revising, correcting, or improving it". They felt that the growth of agriculture, mining, municipal and industrial interests had been partly based on the expectations derived from the Southwest Cotton Court ruling.

More than six decades have passed since Southwest Cotton was decided. The Arizona legislature has erected statutory frameworks for regulating surface water and groundwater based on Southwest

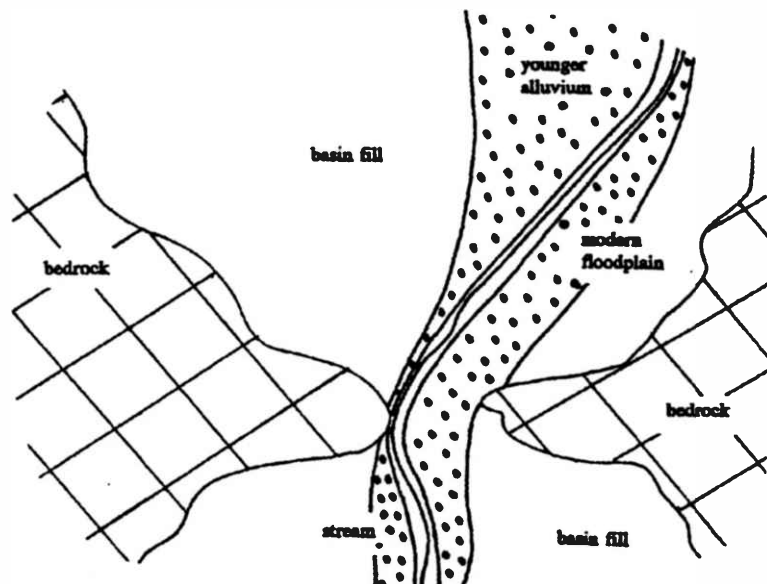
Cotton. Arizona's agricultural, industrial, mining and urban interests have accommodated themselves to those frameworks." (Interlocutory Review, 1993)

Specifically, the 1993 Interlocutory Review identifies three key reasons for rejection, the first two of which are based entirely on the six-decade old ruling.

First, the Interlocutory Review felt that the Southwest Cotton held a narrow view of *subflow*. The "50/90 rule" was based on Halpenny's recommendation to include all wells in the younger alluvium. Contrary to Southwest Cotton's narrow interpretation which held that "*subflow* is found within or immediately adjacent to the streambed", the Interlocutory Review suggests that the younger alluvium may, in some cases, extend from ridgeline to ridgeline (Figure 2.10). This is at odds with the intentions of the Southwest Cotton and the Interlocutory Review bluntly states:

Subflow is a narrow concept. Thus, all water in a tributary aquifer is not subflow (Interlocutory Review, 1993).

Cartoon of a ridgeline to ridgeline occurrence of the younger alluvium
Figure 2.10



Second, the Interlocutory Review stated that the volume/time test used for the "50/90 rule" was also not supported in the law. The Southwest Cotton did not define *subflow* in terms of an acceptable amount of stream depletion over a given period of time; rather, it defined *subflow* in terms of "whether the water is more closely associated with the stream than with the surrounding alluvium."

Whether a well is pumping subflow does not turn on whether it depletes a stream by some particular amount in a given period of time. ... (I)t turns on whether the well is pumping water that is more closely associated with the stream than the surrounding alluvium (Interlocutory Review, 1993).

The final reason revolves around the arbitrary nature of the proposed "brightline". Why not the "60%/90 day test" or the "40%/80 day test?" In light of this, the static "brightline" was both "too big" and "too small."

1. Too Big: Depending on an individual well's distance from the *subflow* region, each well will begin to deplete streamflow at a unique time. However, the "50%/90 day test" classifies all wells within the "brightline" region as being depleters before pumping even begins. Thus the "brightline" was "too big".
2. Too small: On the other hand, the "50%/90 day test" completely disregards the actual volume being depleted. For example, one well may be pumping 51% from stream depletion while only pumping at a rate of 1 cfs. Another well may be pumping only 49% from stream depletion while pumping at a rate of 10 cfs. The former would be included in the adjudication while the later would not. This does not make sense. In this case, the static "brightline" is "too small."

Although the Interlocutory Review rejects the "50%/90 day test," it falls way short of identifying a new solution. However, it does make a feeble attempt to provide clues that may be helpful in identifying the new zone. Whether a well is pumping *subflow* will turn on

whether the well is pumping water that is more closely associated with the stream than the surrounding alluvium. For example, comparison of such characteristics as elevation, gradient, and

perhaps chemical makeup can be made. Flow direction can be an indicator. If the water flows in the same general direction as the stream, it is more likely related to the stream. on the other hand, if it flows toward or away from the stream, it likely is related to the surrounding alluvium (Interlocutory Review, 1993)

Thus, the 1993 Interlocutory Review and the 1931 Southwest Cotton ruling form the legal basis to which the new *subflow* zone must adhere. The problem with this is that these statutes endorse a hydrologically fictional term which is difficult to find given the vagueness of the language used in both precedents. The challenge lies in identifying a new solution that will stand up on any new appeal, not only from within state borders, but from the federal government and tribes alike. Before investigating possible *subflow* solutions, the science, history, and law of the problem are explored in chapters 3, 4, and 5.

Chapter 3

Science of Problem

Summary

This chapter explores the difficulty of quantifying capture and one of its elements, stream depletion due to ground water pumping. Field, analytical, and numerical solutions for quantifying the effect of ground water pumping on a nearby stream are discussed with an emphasis on assessing (1) local-scale hydrologic accuracy, (2) utility on an administrative level, and (3) ability to encompass large-scale watershed response; more commonly referred to as capture. Although numeric ground-water models are the only tool for making basin-wide capture estimates; time, expense, and a heavy reliance on large and accurate data sets may limit their application in some situations.

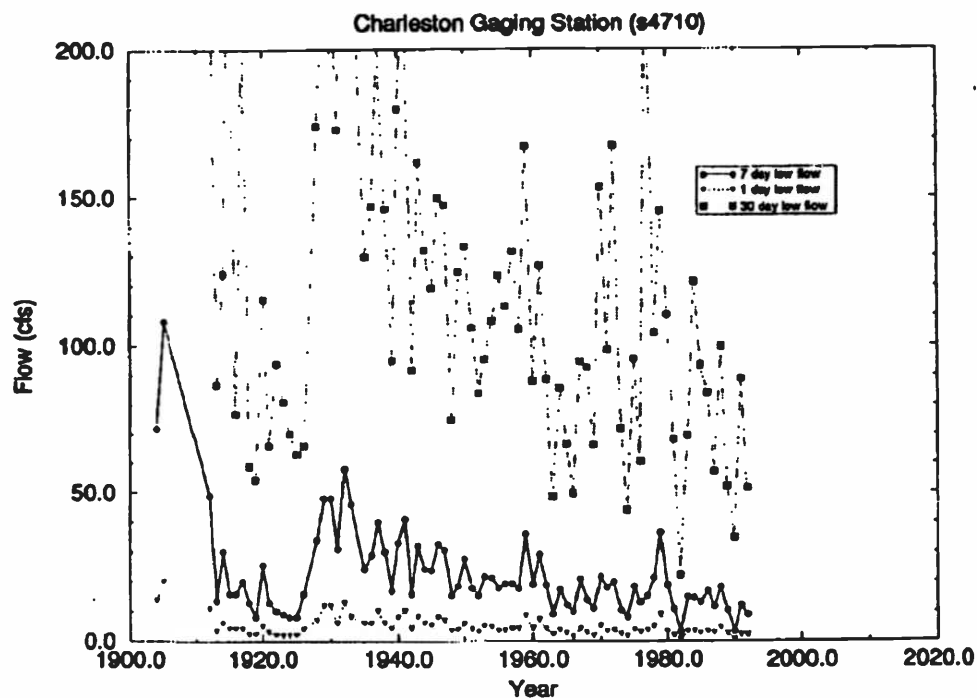
3.1 INTRODUCTION

Arizona's perennial streamflow has diminished by 85% over the past half century in the wake of several major surface water diversion projects and massive ground water pumping (Leshy and Belanger, 1988). Despite its enormity, the disappearance of Arizona's streams has occurred largely unnoticed for three reasons. First, the process of stream depletion is not visible to the human eye. Whereas it is very easy to observe the amount of water being channeled from the stream through a surface-diversion gate, it is impossible to visually separate the stream component of water being discharged from a near-stream well. Second, the amount of stream depletion is obscured by high-flow events. Summer monsoon storms and spring snow-melt can fill southwestern streams to their banks regardless of the existence of ground-water pumping. Third, the effect of ground-water pumping on a nearby stream is delayed over time. For example, switching-on a well is followed by a delay before stream depletion begins and switching-off a well is followed by a delay before stream depletion ends. As explained in section 3.2, ground-

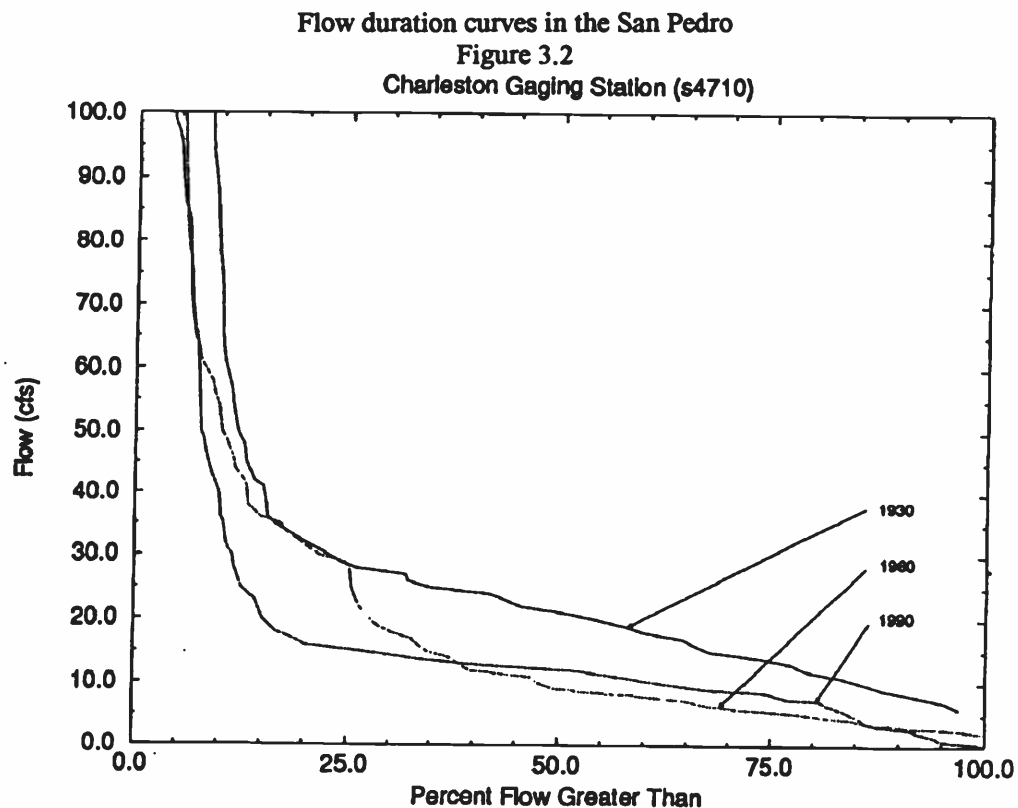
water pumping may occur for decades before its effect is even felt on a connected stream system.

The San Pedro River (at the Charleston gaging station in the Upper San Pedro Basin, Arizona) illustrates the deceptive nature of stream depletion. Despite decades of irrigation and municipal pumping, daily and seasonal fluctuations in stream flow can hide the effect of nearby ground water pumping. Stream depletion only becomes observable during the "dry times" of the year when a majority of water in the stream is contributed from connected ground water flow. The n-day low flow is the n-day period which contains the lowest flow for a given year. The 7, 30, and 90 day low flows are plotted for the Charleston gaging station in Figure 3.1. Each low flow condition has decreased over the past 60 years. Portions of the San Pedro River have historically been perennial (meaning it flows each day of the year) yet the low flow curves suggest these portions' eventual diminishment towards an intermittent regime sometime in the future.

1,7, and 30 day low flow in the San Pedro River -- Sierra Vista, Arizona
Figure 3.1



The effect on the low flows is more dramatically illustrated in annual flow duration curves. An annual flow durations curve is a graph of stream discharge versus the percentage of time that the flow exceeds that stream discharge. Figure 3.2 presents annual flow duration curves at the Charleston gage for the years 1930, 1960 and 1990. As shown in the figure, the median flows in the San Pedro (50% exceedence) diminished to nearly half from 1930 to 1960, and then show recovery by 1990. The recovery is most likely due to the retirement of agricultural lands in the 1980's.



Low flow and flow duration curves are empirical. They reveal little about the exact source or amount of stream depletion. Nor can they be used as a predictive tool. The six-decade long trends in Figure 3.1 and Figure 3.2 may have resulted from a combination of factors. For example, micro-changes in the climate (such as the amount,

distribution, and frequency of precipitation)¹ and gradual changes in land use (such as cattle grazing or the absence of beaver habitat)² have both been linked to the San Pedro's transformation from a swampy network of connecting pools to its present form as a narrowly-incised sandy channel.

Streamflow can potentially be diminished by any pumping well in the connected aquifer. The exact extent (both time and amount) of this diminishment for each individual well is obscured by a complex mesh of regional, local, and historic factors. Over the past 50 years; many field, analytical, and numerical techniques have been developed for this reason. Ultimately, the effectiveness of the various methods can be judged by their:

1. local-scale hydrologic accuracy,
2. utility on an administrative level, and
3. ability to encompass large-scale watershed response (or capture).

3.2 CONTROLLING CAPTURE – THE BIG PICTURE

In 1940, C.V. Theis introduced the fundamental ground-water principle:

Under natural conditions ... previous to the development of wells, aquifers are in a state of approximate dynamic equilibrium. Discharge from wells is thus a new discharge superimposed upon a previous stable system, and must be balanced by an increase in the recharge of the aquifer, or by a decrease in the old natural discharge, or by a loss of storage in the aquifer, or by a combination of these (Theis, 1940).

Thus, according to Theis, prior to development by wells, a regional ground-water system exists in a state of approximate dynamic equilibrium, and this equilibrium is maintained by a long-term balance between natural recharge and discharge processes in

¹There has been no strong evidence of climatological changes in the San Pedro Basin from the 1930's to present. There has been normal hydrologic fluctuation from year-to-year as is to be expected.

²There has been relatively little change in natural habitat density from the 1930's to present (Julie Stromberg, personal communication, 1994) The beaver populations disappeared around the turn of the century.

the groundwater basin. Over the millennium, wet years in which recharge exceeds discharge offset dry years when discharge exceeds recharge. If R is the average recharge and D is the average discharge, the equilibrium condition is written as,

$$R = D \quad 3-1$$

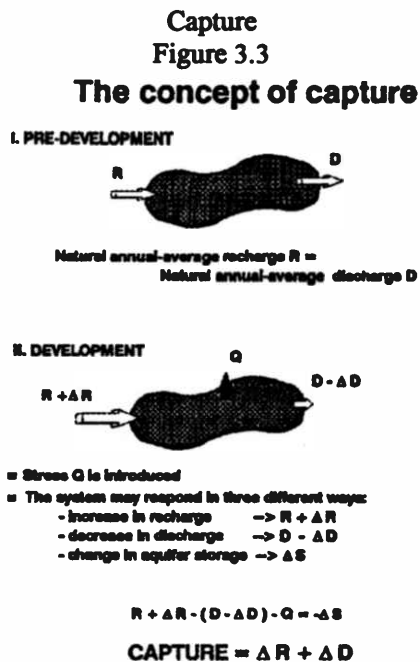
Discharge from pumping wells is a new process imposed on the previously balanced ground-water system, and is balanced by a decrease in aquifer storage, ΔS , and/or some combination of an increase in recharge, $R + \Delta R$, and a decrease in natural discharge, $D - \Delta D$, and Theis' principle requires a new equilibrium condition,

$$(R + \Delta R) - (D - \Delta D) - Q = \Delta S \quad 3-2$$

where Q is the pumping. Combining Equations 3-1 and 3-2 gives,

$$\Delta R + \Delta D - Q = \Delta S \quad 3-3$$

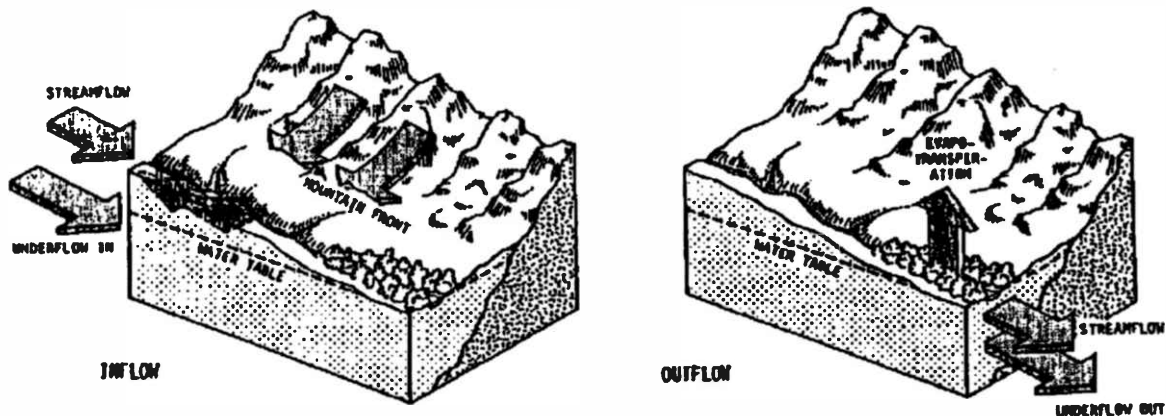
The sum of the induced increase in recharge plus the decrease in discharge, $\Delta R + \Delta D$, is called capture (Bredehoeft *et al*, 1982). A schematic of the capture process is presented in Figure 3.3.



3.2.1 Predevelopment—Steady State

A schematic of a basin in predevelopment steady state conditions is presented in Figure 3.4. Recharge of water into the basin occurs either as ground-water "underflow in" recharging up valley, aerial precipitation, seepage into the aquifer from a stream, or as mountain front recharge. Because the mountain ranges in the Southwest can receive two or three times greater precipitation than the surrounding alluvial basins, mountain front seepage into the aquifer is often the dominant form of recharge. Discharge of water out of the basin occurs as either discharge into a stream (or lake), evapotranspiration into the atmosphere, or as ground water "underflow out" discharging down valley.

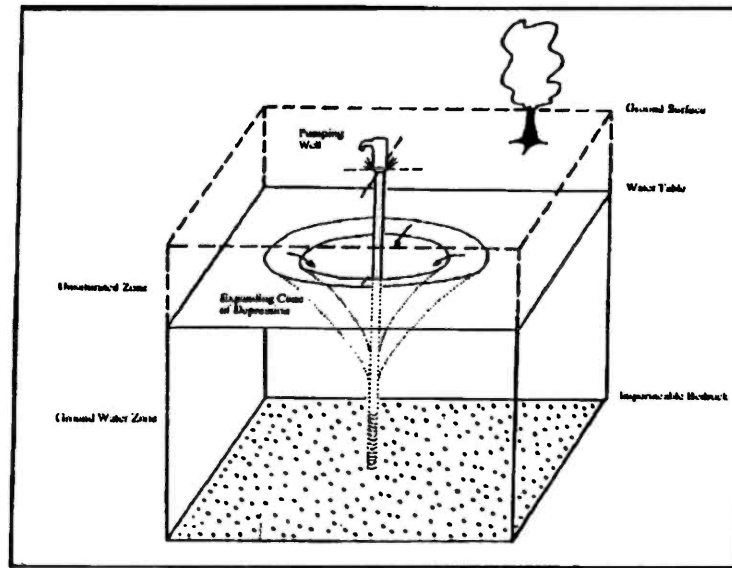
Modes of recharge and discharge for a ground water basin
(Anderson, Freethy and Tucci, 1990)
Figure 3.4



3.2.2 Development

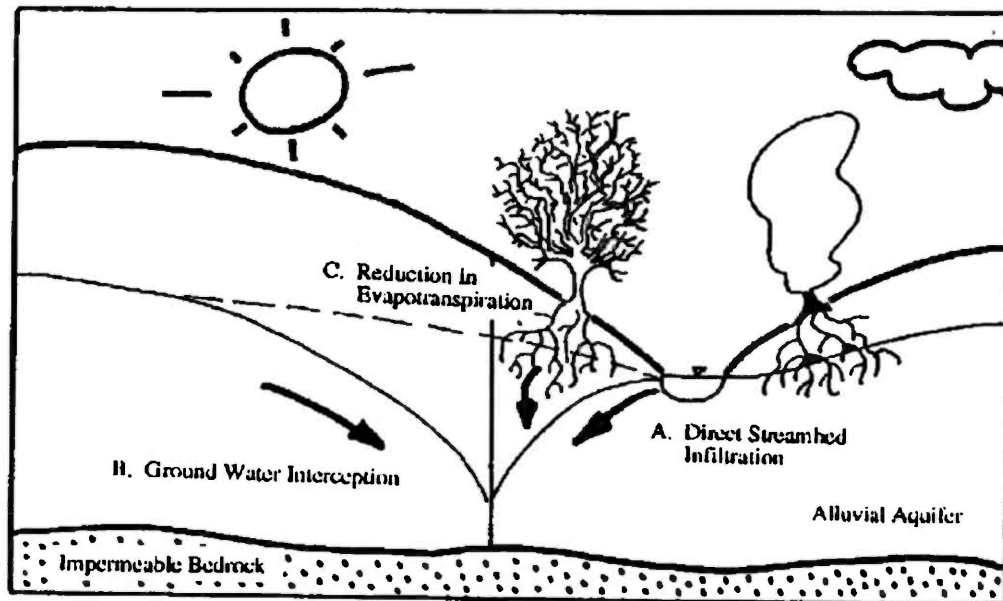
During the initial stages of pumping, most water is withdrawn from storage for two reasons. First, a conical decline of the water table called a cone of depression forms around the well. The cone of depression creates a hydraulic gradient which draws water (by gravitational force) to the well. Second, the lateral expanse of the cone of depression is initially small so that other sources of water (such as a stream) cannot be captured. An expanding cone of depression is illustrated in figure 3.5.

An expanding cone of depression
Figure 3.5



As pumping continues and the cone of depression expands (in depth and width), the growing zone of influence is more likely to intercept other sources of water. The cone of depression will continue to expand as long as it is unable to capture water from other sources. Capture usually occurs as a combination of three processes (Figure 3.6):

Modes of capture.
Figure 3.6



1. infiltration of surface flow directly from the stream channel (direct infiltration stream depletion),
2. interception of subsurface flow before it reaches the stream (interception stream depletion), and
3. a decrease in evapotranspiration due to lowering the ground water table.

When stressed, a system will naturally re-equilibrate toward a new steady state condition. For a ground water basin, the system will re-adjust so that recharge once again equals discharge ($R_{new} = D_{new}$) and water is no longer being pumped from storage. This re-equilibrated steady state will be reached when all pumped water is taken from capture sources. When this occurs, the cone of depression will stabilize; ceasing to grow deeper or wider. However, a new steady state can never be reached if the stress imposed on the system is greater than the potential capture within the system. All capture sources will be exhausted and ground water depletion will continue until the stored water is completely mined or until ground water is no longer economically feasible to pump to the surface.

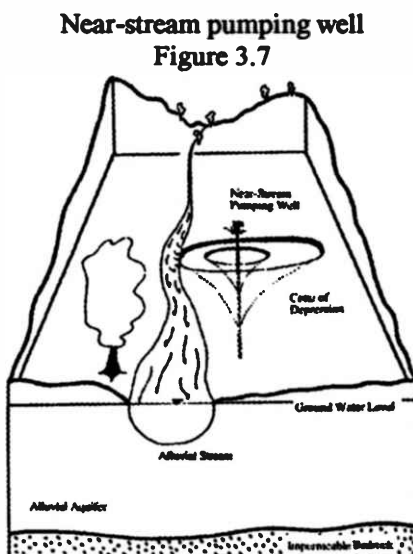
3.2.3 Why is Capture Important?

Capture is the concept which describes the full spatial and temporal impact of ground-water pumping on a riparian system. When water is captured from streams, it is usually described as stream depletion. It is often falsely assumed that stream depletion only occurs when the cone of depression directly intercepts the streambed. As already shown, stream depletion also occurs in the form of interception before the cone of depression even intercepts the stream bed. Had pumping not occurred, this intercepted water would have eventually reached the stream. Depending on the distance to the stream and the properties of the aquifer; this could take days, months, years, even decades. Whether by direct infiltration or by interception; the result is always the same; streamflow is reduced. As seen in the final mode, capture can also occur by dropping the water table below the root zone, thus causing a decrease in stream-side evapotranspiration (this can

either result by a recession or succession of stream-side vegetation) and a subsequent increase of water available for a pumping well.

Finally, a stabilized cone of depression is often assumed to be an indication that no stream depletion is occurring. In fact it is just the opposite! As already demonstrated, a stabilized cone of depression simply indicates that *all* the pumped water is being derived by capture sources; all of which potentially degrade the riparian system.

Comprehensive ground and surface water management in a basin ultimately rests on the possibility of going beyond *single-well* analysis and making capture calculations for the entire stream-aquifer system.



One of the sources of capture--direct infiltration stream depletion--has been studied extensively in the literature. Several field, analytic, and numerical stream depletion methods are described below.

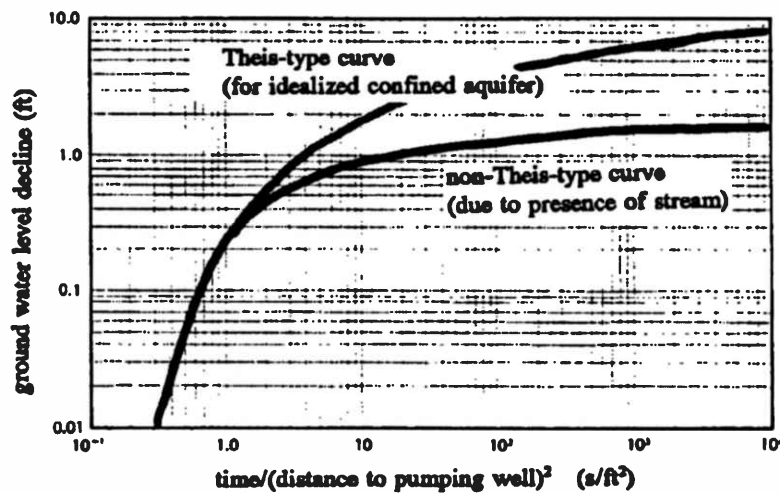
3.3 FIELD TECHNIQUES FOR DETERMINING DIRECT INFILTRATION STREAM DEPLETION

Two field techniques exist for determining direct infiltration stream depletion-- the stream method and the aquifer-test method. The stream method is the most obvious. In

this method, stream depletion due to an individual pumping well can be estimated by taking stream flow measurements upstream and downstream from the pumping well (Figure 3.7). Any loss of stream flow over this reach is assumed to be due to effect of the pumping well. Although conceptually simple, this method is dependant on isolating a single cone of depression in basins which often contain numerous wells which withdrawal water at random pumping times and rates. Also, calculations are complicated by daily and weekly streamflow fluctuations.

The aquifer-test method relies on measuring water drawdown (or water level decline) in the pumping well and/or surrounding observation wells. A pumping well will form an expanding cone of depression which draws water toward the well from the surrounding alluvium. In the case of a near stream well, stream depletion is calculated indirectly by plotting the drawdown curve's deviation from a typical "type curve" (Figure 3.8, Theis, 1935). The "type curve" is the drawdown curve that results in the case that no capture sources exist. In other words, water is being pumped completely from storage. A near-stream well can capture water from the stream so that the drop in the ground water level due to pumping will be less than the "no stream" case.

Deviation from a "Theis type" curve due to the presence of a nearby stream
Figure 3.8



Pump test data can be difficult to interpret. The deviation between curves may be the result of local heterogeneity in the alluvial aquifer (such as a highly permeable gravel bed), leakage from an adjacent confining layer, or a combination of multiple effects. A precise drawdown curve may be difficult to construct. As pointed out by Sophocleous et al. (1988), the method requires precise measurements in the initial seconds and minutes of the aquifer test as well as a minimum of several weeks of measurements to see full stream-aquifer response. The method is also dependent on the existence of observation wells, a luxury not always provided in the field.

Field methods are expensive and time-consuming. They are only reliable under the most ideal data-collection circumstances (ie., an absence of other nearby pumping wells and an absence of recharge from local storms or irrigation events). Besides purely technical consideration, it makes little sense to pump more ground water than necessary in a land of scarce water resources.

Analytical and numerical models have been developed to over-come these limitations. Typically, they are cheaper and less time-consuming. The challenge lies in creating solutions that can accurately model local-scale and regional-scale processes while simultaneously being easy to use on an administrative level.

3.4 ANALYTICAL MODELS FOR DETERMINING DIRECT INFILTRATION STREAM DEPLETION

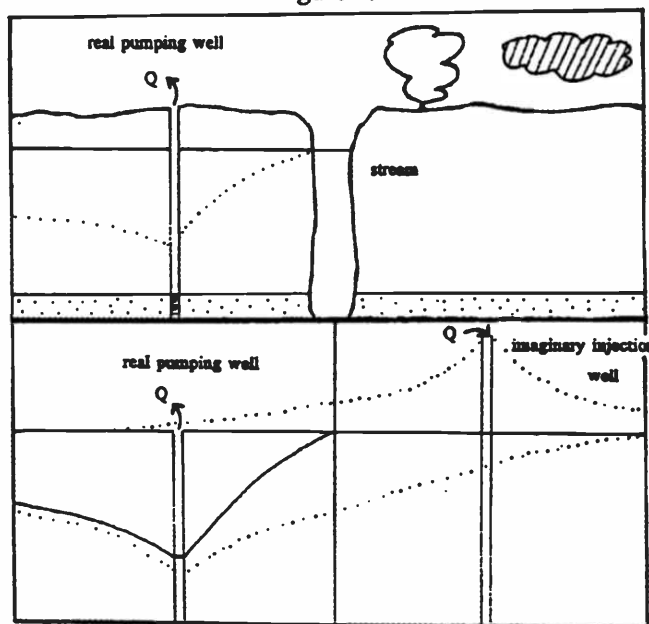
Analytical direct infiltration stream depletion equations have been developed over the past fifty years (Theis, 1941; Boulton, 1941; Kazmann, 1948; Jacobs, 1950; Glover and Balmer, 1954; Glover, 1960; Hantush, 1959, 1965, 1967; Wallace et al, 1990). The intent of their use has ranged from increasing pump-yield to protecting vested surface water rights. In the interest of increasing pump yield, analytical solutions have been used to analyze stream-adjacent alluvium which has a high transmissivity that enables easy movement of stream water to a nearby well. In the interest of protecting senior surface

water claims, analytical solutions have also been developed to quantifying the amount of stream water being depleted by ground water pumping. In more recent times, stream-aquifer models have been developed to optimize comprehensive use of both ground and surface waters within a watershed.

3.4.1 Theis' Analytical Model

Theis (1941) made the premiere contribution when he developed a method for determining the time/quantity effect of a pumping well on a nearby stream. The method was developed shortly after publishing his seminal paper on transient flow to a well (for an idealized aquifer with no nearby stream) in 1935. His 1941 stream depletion equation is an adaptation of his 1935 solution. The stream is accounted for by treating it as a constant head boundary. Image well theory is used to solve the flow equations with a constant head boundary. An imaginary well located twice the distance between the actual pumping well and the stream is used to reproduce the effect of stream seepage to the pumping well (Figure 3.9).

Image well theory to reproduce the effect of a near stream well
Figure 3.9



Theis' stream depletion equation is written as follows:

$$\frac{Q_{stream}}{Q_{well}} = \frac{2}{\pi} \int_0^{\pi/2} e^{-k \sec^2 u} du \quad (5)$$

where,

$$k = 1.87 \frac{a^2 S}{T t} \quad (6)$$

and,

- Q_{stream} = direct stream depletion,
- Q_{well} = total well discharge,
- a = perpendicular distance from the pumping well to the stream,
- T = transmissivity of the aquifer, and
- S = storativity of the aquifer.

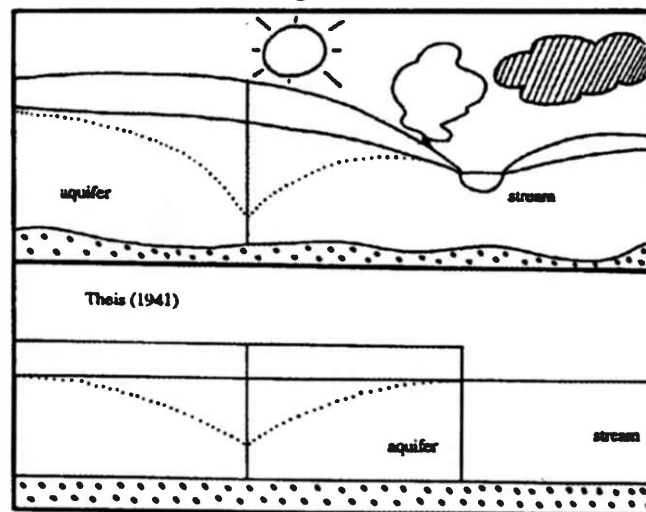
The timing of Theis' equation coincided with the emerging possibility of high-efficiency/low cost pumping; giving junior water right holders the capability of tapping into an abundant ground water supply rather than relying on over-appropriated and often non-existent surface water. Although Theis points out that field measurements can be made to approximate stream depletion; lack of knowledge of the static water level, variations in both natural and cultural recharge, and stream stage variation significantly complicate the process.

Theis' equation is independent of these "field" complications. An inspection of Equation 5 reveals the simplicity of his approach. First, stream depletion is a function of two averaged aquifer properties: transmissivity (an aquifer's ability to transmit water) and storativity (an aquifer's capacity to store or release water per unit decline or rise in water level). Second, the equation is completely independent of stream properties. In other words, the stream is assumed to fully penetrate the aquifer, stream bed resistance (or the existence of a clogging layer) is ignored, and the level of the stream surface does not

decline over time (ie., the stream is supplied with an infinite supply of water). A schematic diagram of Theis' "ideal stream-aquifer system" is shown in figure 3.10. In his equation, Theis assumed :

1. a homogeneous and isotropic aquifer,
2. a straight stream channel,
3. complete hydraulic freedom between the stream channel and the aquifer,
4. that stream stage does not decrease due to ground water pumping,
5. a horizontal water table prior to pumping,
6. that water is released instantaneous from storage,
7. that drawdown is insignificant compared to the saturated thickness of the aquifer,
8. residual drawdown from previous pumping periods can be neglected,
9. the pumping well fully penetrates the aquifer,
10. the stream channel fully penetrates the aquifer, and
11. a semi-infinite aquifer.
12. the streambed is unclogged

Theis's stream-aquifer model
Figure 3.10



As discussed, well discharge can originate from 4 sources: (1) ground water storage, (2) stream water, (3) water on its way to the stream, and (4) water captured from a reduction in evapotranspiration due to the lowering of the water table below the root zone. Theis consciously neglects stream-side vegetation and assumes a horizontal water table. Thus, his equation only accounts for the first two source of water: ground water storage and direct streambed infiltration.

Glover and Balmer (1954) and Glover (1960) developed stream depletion solutions based on similar assumptions used by Theis.

3.4.2. Eliminating Theis' Simplifying Assumptions

Elimination of every simplifying assumption is not possible. Mathematically, assumptions are necessary in order to simplify naturally chaotic systems. Thus, the key in applying any model lies in evaluating the degree in which each assumption is satisfied in the field. A stream which fully penetrates an aquifer is an assumption which is too "far fetched" to ignore. This condition is rarely satisfied in the alluvial valleys of the American Southwest.

As discussed in Appendix-A; Jacobs (1950) and Hantush (1965) developed adaptations to account for partially-penetrating streams. Despite increases in hydrologic accuracy, the solutions are difficult to use on an administrative level since each one relies on "aquifer test" data from both the pumping well and surrounding observation wells.

3.4.3. Advances in Analytical Models

Besides the simplifying assumptions, Theis' equation is limited by its inability to consider the entire picture of stream-aquifer interaction. The effect of multiple pumping wells, a finite supply of water in the stream, irrigation seepage, evapotranspiration loss to the atmosphere, and a non-horizontal water table are not weighted into the solution.

Near-stream irrigation may contribute to an attenuation of streamflow. While part of the applied irrigation water is either consumed by the crop or directly evaporated, extra water is applied to infiltrate into the ground as "return flow" in order to wash away salts which accumulate in the soil. Glover (1960) developed an analytical model to estimate the percentage of applied irrigation water that will eventually discharge into a nearby stream as a function of time. An adaptation of Glover's equation was presented by Brittinger (1964) as follows:

$$P_{MN} = \frac{800}{\pi^2} \left[\sum_{n=1,3,5,\dots}^{\infty} \frac{1}{n^2} e^{\frac{-\alpha n^2 x^2 t_N}{4W^2}} - \sum_{n=1,3,5,\dots}^{\infty} \frac{1}{n^2} e^{\frac{-\alpha n^2 x^2 t_{N-1}}{4W^2}} \right] \quad (7)$$

where,

P_{MN} = % of water reaching the water table during month M , which flows into the river during month N

W = width of the ground water aquifer perpendicular to the river,

α = T/S , and

t_N, t_{N-1} = time accumulated N and $N - 1$ months since month of water application.

Glover (1977) also developed an analytical model to estimate how much each individual stream reach contributes to the total depletion caused by the pumping well. Based on an ideal stream-aquifer system, Glover's equation is expressed as follows:

$$\int_{-x}^{+x} f dx = \frac{2Q}{\pi} \arctan\left(\frac{x}{a}\right) \quad (8)$$

where,

f = flow from the stream per unit length of streambank,

x = length of individual stream reach,

a = distance from the stream to the pumping well.

Centered on the perpendicular distance between the stream and well, 50% of the pumped water is depleted along a distance $2a$ along the stream, 70% of the pumped water

is depleted along a distance $4a$ along the stream, and 90% is depleted along a distance $13a$ along the stream (Sophocleous et al., 1988). The need for such an analysis is somewhat questionable considering that the sum effect of the pumping will be felt everywhere downstream.

3.4.4. Jenkins' Adaptation of Theis' Solution using SDF Analysis

Attempts to increase the hydrologic accuracy of Theis' original solution have resulted in models that are often too difficult to apply. In light of this, Jenkins' (1968a) dimensionless adaptation of Theis' equation has been used most frequently by water administrators. In 1990, Jenkins' adaptation was used to delineate the "50/90 day test" brightline for the Gila River General Adjudication.

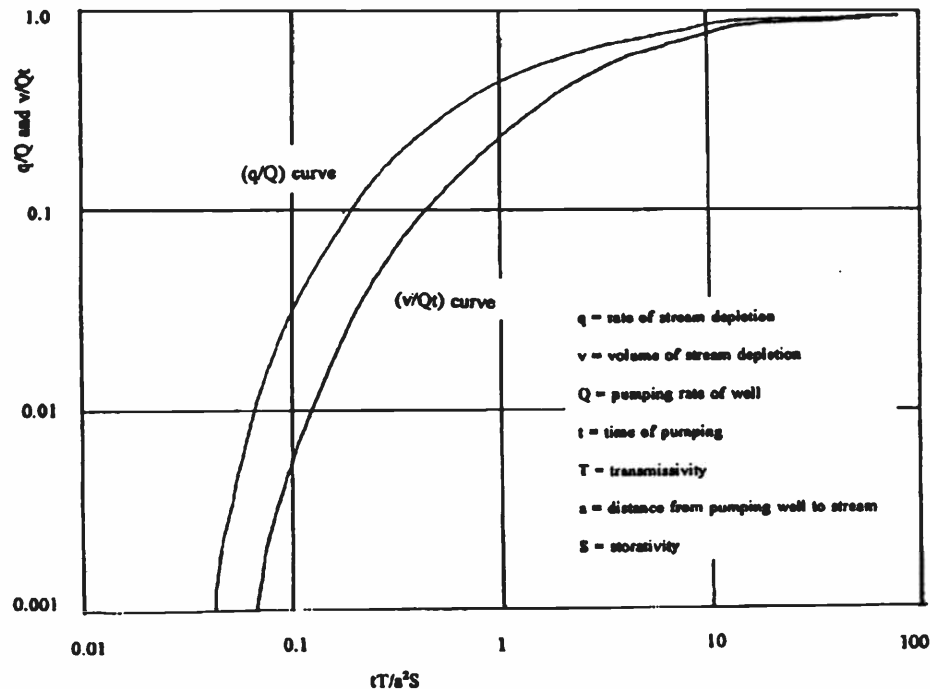
Jenkins did not present any new computations in his solution. Feeling that previous treatments of stream depletion were too complicated for practical use, Jenkins presented a straight-forward solution based on graphs and tables.

Given that q is the stream depletion and Q is pumping from a well, a certain percentage or volume of stream depletion ($\frac{q}{Q}$) can be estimated by simply knowing the time of pumping and a new term called the stream depletion factor, or sdf (Figure 3.11). The sdf is a surrogate aquifer describer which combines aquifer properties of transmissivity, storativity, and the distance from the stream to the well into one term. At any lateral location in the aquifer, the sdf is the time from the beginning of pumping which stream depletion (q) accounts for 28% of the water being withdrawn from the pumping well (Q). When ideal stream-aquifer conditions prevail (as listed earlier), the sdf is expressed as follows:

$$sdf = \frac{a^2 S}{T} \quad (9)$$

where S is the storativity, T is the transmissivity, and a is the distance from the pumping well to the stream.

Cartoon of Jenkins's graphical stream depletion solution
Figure 3.11



Although the sdf is expressed in units of days, it functions similar to a dimensionless parameter. Any location in the near-stream aquifer can be assigned a permanent sdf which is independent of both the pumping time and rate. Once the sdf is calculated, the rate or volume of stream depletion is easily obtained from the sdf curve (Figure 3.11).

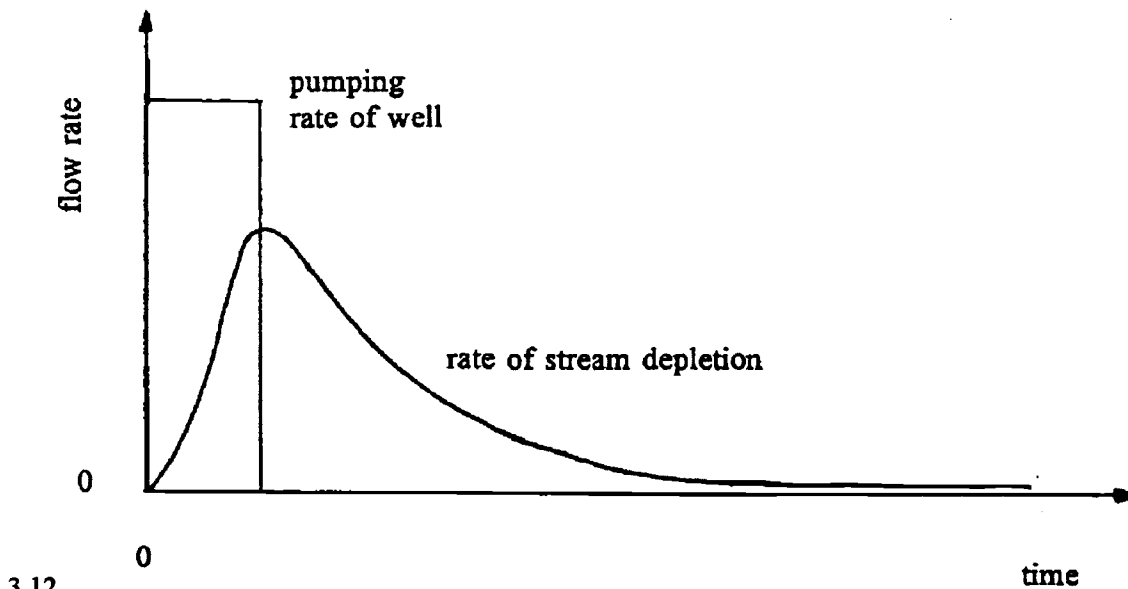
Because the cone of depression will not disappear instantaneously when the well is shut-off, stream depletion continues until the cone of depression completely recedes to pre-pumping conditions (Figure 3.12). Jenkins accounted for this by using image well theory.

3.4.5 Field Comparison to Jenkins's Solution.

Despite its application on an administrative level, Jenkins' method is based on all the simplifying assumptions of the idealized stream-aquifer system. In a field study along the Arkansas River near Great Bend, Kansas; Sophecious and et al. (1988) identified three reasons why Jenkins' and Glover's solutions over-estimated observed stream

depletion. They include (1) the existence of a stream which only partially penetrated the underlying aquifer, (2) storage loss from the opposite bank of the river, (3) and the existence of thin clay layers underlying the stream.

Ground water pumping v. stream depletion
Figure 12



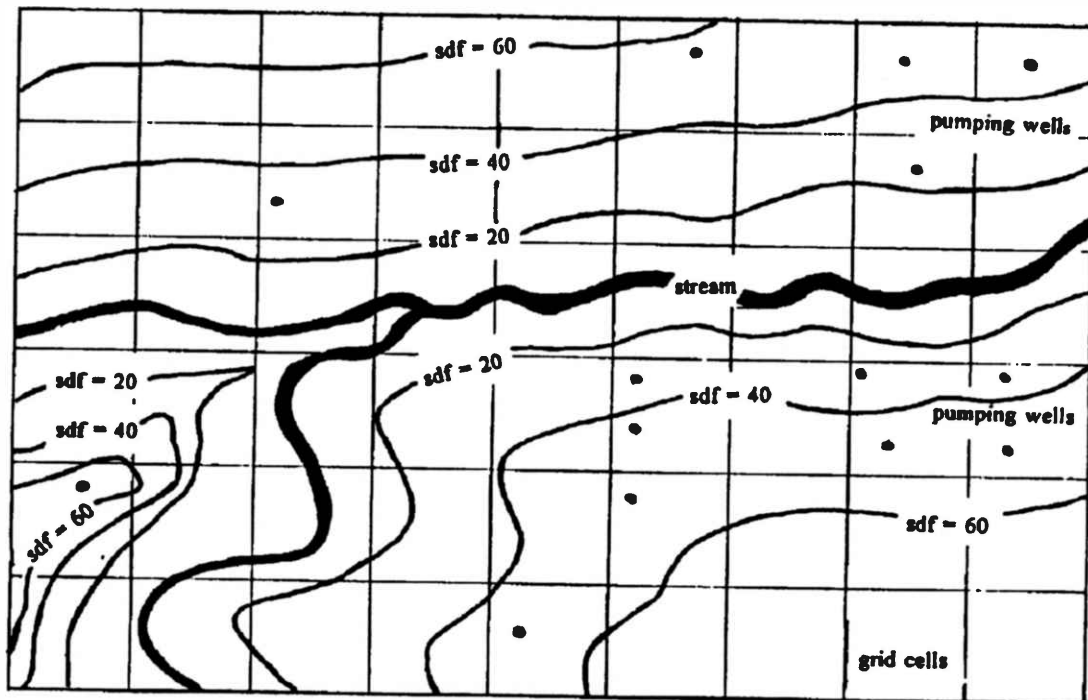
3.4.6 Effective SDF Calculations

Because ideal stream-aquifer conditions rarely occur in the field, Jenkins (1968b) suggested the use of an *effective sdf* to replace the idealized sdf. This *effective sdf* could be adjusted to account for non-idealized conditions such as impermeable boundaries, stream meanders, variations in aquifer properties, and a less permeable streambed. The idealized sdf (calculated as a^2S/T) is simply replaced with an *effective sdf* which represents the time in which stream depletion accounts for 28% of the water withdrawn from the pumping well.

Numeric ground water models can be used to calculate sdf values for each individual well in a stream-aquifer system. As an administrative tool, *effective sdf* values can be contoured in lines of equal sdf away from the stream (Figure 3.13). This technique

was applied successfully by Moulder and Jenkins (1968), Taylor (1971), and Taylor and Lucky (1972,1974) for the Arkansas River between Colorado and Kansas and by Glover (1990) for the Upper Bear Valley in Wyoming.

Plan view of hypothetical basin with contoured sdf lines
Figure 3.13

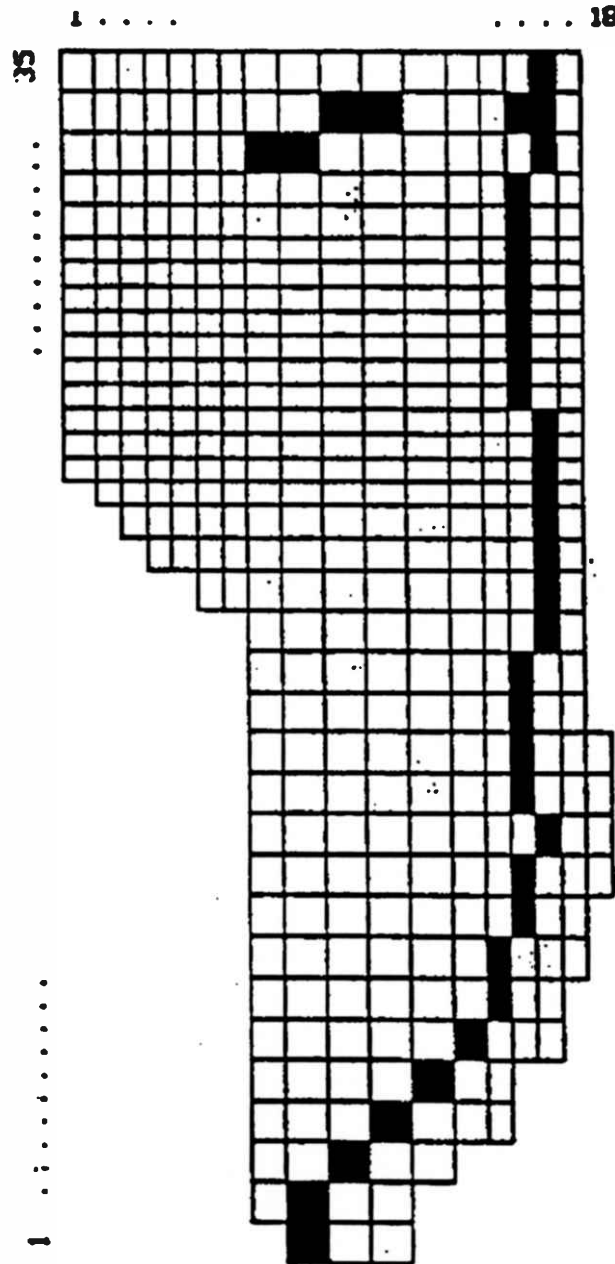


3.5 NUMERIC MODELS

Although the *effective sdf* approach seems to offer a comprehensive system-wide solution, the method is based on a *single* well-by-well analysis. In reality, wells interact and interfere with each other, effect the regional hydraulic properties such as T and S , capture waters through the interception stream depletion, and thus change the sdf contours with time. The numeric models stand alone as the sole tool for addressing the above factors and for making basin-wide capture estimates. By considering basin wide stream-aquifer interaction, numeric models are a valuable tool for addressing both legal and economic questions. For example, when will a pumping well begin to deplete a

certain amount of appropriable stream water? Or, how much water is being pumped by a certain interest group and how does this consumptive use affect other water users? A plan view of a finite difference model grid for the Upper San Pedro Basin, Arizona is shown in Figure 3.14.

Plan-view of a model grid for the Upper San Pedro Valley (Vionnet and Maddock, 1990)
Figure 3.14



Numeric ground water models can closely converge to a real ground water basin. With ample data and accurate calibration, numeric ground water models can account for the following complexities which are neglected in analytical models.

1. a non-horizontal water table,
2. heterogeneous aquifer parameters
3. evapotranspiration loss due to vegetation,
4. streams which partially penetrate an aquifer,
5. reduced streambed permeability,
6. effect of multiple pumping wells,
7. multiple aquifers in a single basin,
8. a finite water supply in a stream,
9. head-dependent hydraulic parameters,
10. partial penetrating wells, and
11. storage depletion that may contribute to a pumping well from the opposite bank of the stream.

Numeric models can be used to distinguish among all three modes of capture: (1) direct streambed infiltration, (2) interception stream depletion, and (3) a reduction in evapotranspiration.

3.5.1 Calculating Capture

Similar to the conceptual explanation of capture provided in the beginning of this chapter, estimating the total capture that has occurred since the beginning of ground water development requires both steady and transient-states runs of the model. The capture calculation is determined in two steps. The first step is to perform a steady-state analysis to give the spatial distributions of R and D . The second step is to perform transient states analyses to give the spatial and temporal distributions of $R + \Delta R$ and $D - \Delta D$. Capture is calculated by subtracting the steady-state values of R from the transient values of

$R + \Delta R$, subtracting the transient value of $D - \Delta D$ from the steady-state value of D , and adding the resulting ΔR and ΔD terms.

Capture can be determined globally for the entire aquifer system or locally over a portion of a capture source.

Table 3-1 illustrates the use of the global (valley wide) water budget calculations for capture calculations for the ground-water flow model of the Upper San Pedro Valley (Vionnet and Maddock, 1992).

Recharge, discharge and capture values (in ft³/sec) for the
Upper San Pedro Valley in southeastern Arizona in 1988
(Vionnet and Maddock, 1992)

Table 3-1

	R	D	$R + \Delta R$	$D - \Delta D$	ΔR	ΔD
Loosing Steam Reaches	2.64		4.52		1.88	
Mountain Front Recharge	17.33		17.33		0.00	
Basin Inflow (from Mexico)	5.54		5.85		0.31	
Gaining Stream Reaches		13.70		9.25		4.45
Evapotranspiration		10.91		7.97		2.94
Basin Outflow (to Benson Sub-Watershed)		0.90		0.90		0.00
Totals	25.51	25.51	27.70	18.12	2.19	7.39

The transient values are for the year 1988. The total pumping rate for all wells in that year was 18.72 ft³/sec, and the loss of storage rate was 9.14 ft³/sec. The total capture, ($\Delta R + \Delta D$), was 9.58 ft³/sec. Note that $9.58 - 18.72 = -9.14$ as required by Equation 3-3.

Capture from 10 reaches of the San Pedro River, Upper San Pedro Valley in
southeastern Arizona in 1988 (Vionnet and Maddock, 1992)

Table 3-2

Reach	Steady State		Transient States		ΔR	ΔD
	Loosing Reach	Gaining Reach	Losing Reach	Gaining Reach		
1		0.621		0.016		0.605
2	0.106		0.462		0.356	
3	0.076		0.719		0.643	
4		0.162	0.680		0.680	0.162
5		0.635	0.540		0.540	0.635
6		0.924	0.351		0.351	0.924
7		0.677		0.210		0.467
8		0.548		0.277		0.271
9		0.164		0.068		0.096
10	0.027		0.430		0.403	

Table 2 illustrates the calculation of a local capture process for a portion of the San Pedro River (Vionnet and Maddock, 1992). Before development, seven of the stream reaches (1, 4, 5, 6, 7, 8 and 9) were gaining and three were losing (2, 3, and 10). By the year 1988, because of ground-water withdrawals, only four of the gaining reaches were still gaining (1, 7, 8, and 9), and they were at a reduced rate. Three of the gaining reaches (4, 5, and 6) became losing reaches, thus incurring both a ΔR and a ΔD component.

3.5.2. Devising Comprehensive Water Management Schemes

Besides calculating capture, numeric models can also be used to optimize conjunctive ground and surface water management within a basin (Maddock, 1974; Morel-Seytoux, 1975, Illangasekare and Morel-Seytoux, 1986; Young et al, 1986; Hantush et al, 1993). Conjunctive management can be achieved in a brute force manner by running multiple simulations in which the pumping rates of individual wells are fluctuated. As an alternative, optimization models such as MODRSP (Maddock and Lacher, 1990) can also be used for conjunctive water management. Using MODRSP, pre-specified constraints can be placed on the system. For example, a maximum allowable drawdown could be specified for riparian vegetation which depends on a specific ground water level in order to survive. Or, a maximum rate of depletion could be specified along a stream in order to maintain a specific amount of in-stream flow. MODRSP will optimize the system based on these pre-specified constraints.

3.5.3. Increased Accuracy at an Increased Price

Spalding and Khaleels' (1991) comparison between analytical and numeric models suggests that an accurately calibrated numeric model is superior to analytical methods of calculating stream depletion. The Theis (1941), Jacob (1950), Glover and Balmer (1954), and Hantush (1965) analytical solutions were all compared to aquifem, a two-dimensional numeric model. In all cases, stream depletion was over-estimated by the analytical

solutions. Theis' solution resulted in 20%, 45%, and 21% over-estimations of stream depletion from the numeric model due to the existence of a partially penetrating stream, streambed resistance, and opposite bank storage withdrawal, respectively. Even though Jacob's and Hantush's solutions were calibrated to correct for partial streambed penetration and streambed resistance, both solutions over-estimated the numeric solution by 21% due to opposite-bank storage withdrawal.

Numeric ground water models have distinct advantages over every other method of calculating stream depletion. They can account for "field complexities" such as a non-horizontal water-table and stream-side vegetation, they can be used to calculate capture (and therefore go beyond single-well analysis), and, once developed, can be used readily and efficiently as an administrative tool. Numeric ground water models do have limitations. Accurate calibration of a ground water models relies heavily on large and accurate data-bases of historical water levels, pumping rates, streamflow, and land-use patterns as well as estimates of aquifer properties. Although large-scale aquifer heterogeneities can be specified on a cell-by-cell basis, individual cells can be quite large. Thus, local-scale heterogeneities (which occur within individual cells) cannot always be accounted for (Glover, 1988)

Numeric ground water models provide the best scientific tool for determining when and how much each well diminishes streamflow. The big question remains: is there any relation between the legal term *subflow* and the hydrologic term capture?

Chapter 4

History of Problem

Summary

Despite strong scientific evidence that ground water pumping diminishes in-stream flow, Arizona continues to adhere to a bifurcated water system in which ground and surface waters are governed under separate legal doctrines. The evolution of water law in the American West in general and the 1931 Southwest Cotton ruling in Arizona shed light on the dichotomous path that Arizona water law has taken. Normally interpreted in a strictly legal context, the historical discussion in Chapter 4 places the issue in a more illuminating economic frame-work.

4.1 INTRODUCTION

To summarize, Arizona is presently in the midst of a general stream adjudication for the Gila River System. As discussed in Chapter 2, a stream adjudication is the judicial process by which appropriable water rights are prioritized (under the law of prior appropriation). In attempt to expedite the adjudication, Judge Goodfarb of the Arizona Superior Court developed the "50 %/ 90 day test" -- a quantitative rule for determining the extent that appropriable water extends into the ground water zone. It was rejected by the court in the 1993 Interlocutory Review; not because of its scientific impreciseness, but rather because of its failure to adhere to previous legal standards established in the 1931 case Maricopa County Municipal Water Conservation District no. One v. Southwest Cotton (or Southwest Cotton).

The logic used by the court in the 1993 Interlocutory Review can be summarized as follows. Initially, the court alludes to the historic antiquity of Arizona's bifurcated water law system.

This bifurcated system of water rights was not unique to Arizona. It was typical of western states until around the turn of the twentieth century. At that time, scientific investigation was revealing that most underground water is hydraulically connected to surface water. As scientific knowledge progressed, most states revised their water laws to provide for unitary management of hydraulically connected underground and surface water. Arizona, however, did not, and continues to adhere to a bifurcated system of water rights, with compelling implications for the general stream adjudication (Interlocutory Review, 1993). (emphasis added)

The compelling implications, which serve to capture Arizona's frustrating attempt to adjudicate the Gila River System, are two-fold. The first implication is legal. A bifurcated water law system implies a line. There is appropriable water and there is non-appropriable water; between the two lies a boundary. This boundary occurs somewhere in the ground water zone. Although the construction of such a line will necessarily be arbitrary (since science recognizes no such boundary), its *degree of arbitrariness* is ultimately constrained by legal criteria that is over six decades old. The second implication is scientific. Because water moves through the ground in obedience to the laws of science instead of the laws of the court, there is no legal stipulation which prevents ground water pumping from diminishing downstream flow.

Although the court admits that powerful arguments exist for adopting a unified water code which recognizes the interconnection of all waters, the court unyieldingly concedes to the perpetuation of its bifurcated system under the contention that Arizona is economically dependent on the present system; thus throwing the issue into the legislative arena and outside the scope of the court.

...Even though Southwest Cotton may be based on an understanding of hydrology less precise than current theories, it would be inappropriate to undo that which has been done in the past.

...

More than six decades have passed since Southwest Cotton was decided. The Arizona legislature has erected statutory frameworks for regulating surface and ground water based on Southwest Cotton.

Arizona's agricultural, industrial, mining, and urban interests have accommodated themselves to those frameworks.

...

We believe, ..., that in this area of law, as much or more than any other, any appropriate change in existing law must come from the legislature (Interlocutory Review, 1993).

It is important to recognize the *unaccountability* of the court's economic assumption. The court is inconvenienced by the fact that the existing legal precedents (which uphold a bifurcated system) support its assumption. Because the bifurcation is apparently advantageous to the various economic interests, the court emphasizes the unchangeability of the law (bound by stare decisis), instead of presenting an economic analysis which supports its assumption. This is not necessarily bad. However, it does reveal how the legislatures unwillingness to confront such a highly-charged issue and the court's refusal to address the problem outside of its rigid, legal framework has resulted in a circle of irresponsibility.

The court's economic impetus for perpetuating a legally-fabricated bifurcation in the face of undeniable scientific evidence that in-stream flow will be reduced is understandable so long as its economic assumption is true. A closer look at the events leading up to and surrounding the 1931 Southwest Cotton ruling rattles, if not completely refutes, this assumption and casts considerable doubt on its infallibility. Properly conceived, the Gila River General Adjudication should not be seen as an obstacle; but rather as a stopping point. Arizona once again finds itself at a critical junction for re-inventing its water policy. If Arizona has faltered in the past, it is now in a position to either re-affirm the same decision it made 60 years ago or re-create a unified policy that legally recognizes the scientific connection between ground and surface waters. Will Arizona make the same decisions it has in the past? If so, will it be able to live with the consequences?

4.2 THE SCIENCE V. LAW MISCONCEPTION

The problem is seen by many as simply a battle between law and science. The schism that has developed between legal hydrology and scientific hydrology is an undeniable factor. It is most readily apparent as a simple terminology gap, a gap that has been growing wider and wider in Arizona since Clesson S. Kinney's 1912 treatise Law of Irrigation, 2nd Edition -- originally a common ground for both law and science. The gap that has developed between law and science between 1912 and today is discussed by Barbara Tellman of the Water Resources Research Center, 1993.

Many of the legal terms used when dealing with groundwater have little scientific basis. Arizona's law, for example, talks about "Water flowing in definite underground channels, underground streams" and "water that passes through or under the surface in a definite channel with ascertainable beds and banks." Such definitions are not generally used by hydrologists.

Examples of how much legal definitions differ from those a scientist can be found in Black's Law Dictionary, a basic reference for lawyers. Water in underground streams is very different from "subterranean waters" which are defined as "waters which lie wholly beneath the surface of the ground, and which either ooze and seep through the subsurface strata without pursuing any defined course or channel, (percolating waters,) or flow in a permanent and regular but invisible course, or lie under the earth in a more or less immovable body, as a subterranean lake."

Black defines "percolating waters" as "those which pass through the ground beneath the surface of the earth without any definite channel, and do not form a part of the body or flow, surface or subterranean, of any watercourse. They may be either rain waters which are slowly infiltrating through the soil or waters seeping through the banks of the bed of a stream, and which have so far left the bed and the other waters as to have lost their character as a part of the flow of that stream." In Arizona, both subterranean and percolating waters are regulated as groundwater, and the underground streams are regulated as surface water. In most other western states, all three types of water are managed as an integrated system (Tellman, 1993).

The disparate evolution of law and science does partially explain the present conundrum where ground and surface waters meet in Arizona. On the one hand, legal knowledge is retrospective. Contemporary court decisions are based on case law that can be decades (even centuries) old. The more often a court ruling is cited over time, the more firmly it becomes imbedded as a legal truth. Thus, familiarity (perpetuated over time through case law) is the foundation of legal knowledge. Science, on the other hand, continually searches for new truths; sometimes even discarding previously held notions. Scientific knowledge, defined by innovation, is more accurate (and sometimes alarmingly different) decades in the future, not decades in the past.

These two separate paradigms of thought, truth by familiarity and truth by innovation, have developed startlingly different conceptions of how ground and surface waters behave. On more than one occasion, the idea that "*knowledge was less precise back in the day when the law was developed*" has been used to logically explain the dichotomous evolution. If lack of knowledge was the root of this dichotomy, lack of knowledge continues to be a problem today. The present conflict has taken decades to develop with issues that are complex and interdisciplinary; requiring a mastery of all to fully grasp its origin, evolution, and future implications. Viewed by themselves, law and science present only a partial, and therefore flawed, picture of the present problem.

The picture is not painted complete until it is placed into its larger economic and historical context. Southwest Cotton is only a small part of the larger doctrine of prior appropriation. Moreover, the doctrine of prior appropriation is an economic doctrine -- law forged by financial expediency. By placing Southwest Cotton in its larger economic context of the prior appropriation doctrine (from its riparian roots to its eventual death and demise in the wake of the Southwest Cotton ruling) the big picture is revealed. By only discussing Southwest Cotton in its legal framework, the court focuses its attention on a half-truth -- legally valid, but ultimately meaningless. No one can refute the law. The real concern is whether the law is answering the right question.

4.3 THE ECONOMICS OF WATER LAW

Water law has a certain oxymoronic connotation to it; neither water or law entirely embracing the other. On the one hand, law has struggled to develop a unique set of rules for governing water -- a resource which is not akin to the traditional rules assigned under property right statutes because of its ability to move, taking on many different forms while still remaining the same water. On the other hand, water has struggled to constantly re-shape the rules which govern it. The key idea is that water (or the economic perception of water) has historically controlled how the resource is legally governed.

*(L)egal rules tend to converge when the issues at stake concern "self-interested behavior that threatens the general welfare." They diverge when the rules either "do not much matter" or "raise issues about which reasonable people *** could disagree." The implicit logic behind [such an] argument is that societies will develop relatively efficient rules over issues that matter dearly. Whatever the rules over insignificant matters, most legal regimes will develop efficient legal rules to govern important issues, and those rules will tend to resemble each other (Sax and others, 1991).*

It is this evolution of water law, constrained and coerced by economic expediency, that ultimately finds meaning in Arizona's attempt to answer the riddle at the river's edge.

Although endless pages have been written on the legal intricacies and subtleties that have evolved into the riparian and appropriation doctrines, the distinction between the two hinges on three central questions; namely:

1. who has a right to the water,
2. where can the water be used, and
3. how much water is the user entitled to?

4.3.1 Riparian Doctrine

The riparian doctrine found wide application east of the Mississippi River, matching well with the economic framework of a generally humid climate. Although

bordering on the tautological, the riparian doctrine guarantees riparian rights -- riparian referring to both riparian land owners and the water course itself. Simply stated,

1. who? only riparian land owners are entitled to use stream water,
2. where? on lands that are riparian to a water course (since water is appurtenant to the land under the doctrine),
3. how much? limited in quantity by the principle of "natural flow" which guarantees every riparian owner the right to natural stream flow, undiminished in quantity and quality.

Although riparianism may suggest an attitude of non-interference for nature, this reverence for a seemingly unsullied wilderness was simply an end result of the economic relevancy of water in a humid climate. Because rainfall was plentiful in the eastern half of the country, property value was not intensely tied to its connection with surface water. Just as law should show a theoretical convergence with economic needs, the riparian doctrine evolved over time: replacing its "natural flow" principle with the doctrine of "reasonable use" in order to meet the growing industrial and municipal demands of stream water. This "reasonable use" principle held that a riparian owner could use stream water to a *degree of reasonableness* judged relative to other riparian owners' use.

4.3.2. Evolution the Law of Prior Appropriation

Although initially adopted in most western states, riparianism proved ill-suited for regions west of the 100th meridian. First and foremost, the aridity of the climate dictated this. Unlike the East which received ample aerial rainfall over its entire region, the West was characterized by a scarcity of region-wide rainfall and an uneven distribution of snowmelt-fed streams that it had. Thus, surface streams were the *sole source* of reliable water in the West for *all* lands, regardless of how far the lands were from the stream or river. Second, riparianism is rooted in quasi-private property tenants where water is held to be appurtenant with the adjacent land. In the West, however, most of the region was

acquired by the federal government from foreign countries; so that settlers and speculators were essentially trespassers on government-owned property (Getches, 1990).

The law of prior appropriation was not hanging up on a legal coat-rack somewhere, ready to be adorned as soon as America outgrew its eastern origins. Rather, the law was sown from scratch; the legal seamstress weaving a coat to fit the lay of the new land west of the 100th meridian. The evolution of the law of prior appropriations occurred locally first, and then later became recognized by territory and state constitutions. The law of prior appropriation became officially recognized by the federal government under the desert land act of 1877 (Sax et al., 1991).

The essence of the appropriation doctrine can be summarized as follows.

1. who? According to the law of prior appropriations, the first person who came to a stream and claimed its water, or a part of it, had priority to use it.
2. where? Under the doctrine, it did not matter at all how far from the river the person lived or how far the person diverted water from its natural course.
3. how much? Nor did it matter if the river was drained dry. All that mattered was that the water, under a "first come, first serve" basis, was put to beneficial use.

In its purest form, the law of prior appropriation operated under only one rule: "first in time, first in right." Water became public property. It was no longer held appurtenant to the land or bound by adjacent land rights. It was public property, however, only to the extent that the resource was used "beneficially" -- or in other words, only to the extent that its use was maximized by individual right holders. Failure to put the water to beneficial use simply resulted in a loss of the water right and a chance for another worthy appropriator to put the water to economic ends. Thus, it was only public property as long as it was used by public individuals for private gain.

The appropriation doctrine was driven by a desire to avoid economic waste -- the worthless flowing of untapped water in the stream. Because of a scarcity of regional precipitation, land in the semi-arid West loses its value if it is denied water; the only

source of which is the stream. While the appropriation doctrine was geared to maximize exploitation, the potential for economic growth was ultimately limited by the finite quantity of water in the stream. Many stream systems quickly became over-appropriated so that during lean years, the junior-most right holders could be left with no water.

If the appropriation doctrine evolved out of the drive to maximize exploitation, it did so under the assumption that the stream was the *sole source* of water. As already mentioned, regional precipitation was sparse and sporadic. Ground water, even if it was known to exist, was not extractable by contemporary methods.

The importance of this assumption in the development of the doctrine can be highlighted by considering the following hypothetical scenario: what if the technology needed to extract ground water was actually available prior to the settling of the West? Would prior appropriation have applied in such a situation? If so, would it have applied only to surface water? One thing is for certain. The relative importance of the stream dwarfs considerably.

4.3.3. Ground-water Development and the Demise of the Appropriation Doctrine

As we now know, surface water is no longer the sole source of water in the West. Technological advances eventually allowed for the efficient extraction of water from the subsurface. The development of the high yield centrifugal pump made it physically possible, the existence of cheap hydro-power made it financially affordable, and advances in well drilling techniques enabled its quick proliferation. Because the appropriation doctrine was originally geared exclusively for surface water, its applicability to this *new source of water* was not immediately appreciated or understood. Ground-water law generally recognized the following, suggesting a crossbreed between the riparian and the appropriation doctrines.

1. who? Similar to riparianism, ground water was seen to be appurtenant to the adjacent land, thus protected by private property rights. In this case, the right holder was the owner of the land above the water.

2. where? Although the efficiency of ground water extraction may have varied from location to location, ground water could be extracted almost anywhere in an alluvial valley, thus nullifying the need to export water from an outside source (such as a stream).

3. how much? Similar to riparianism, the quantity was limited by "reasonable use." However, the degree of reasonableness was only measured relative to other property owners -- or in other words, only to other ground water pumpers.

Although ostensibly reminiscent of riparian tenants, the ground water code reflects the same economic desire to maximize exploitation exercised by the appropriation doctrine. Indeed, the development of ground water in the West seemed to open the door to an infinite supply of water; forever freed from the finite water supply of the stream. Junior appropriators were no longer the helpless victims of sporadic stream flow.

With the development of this *second source* of water, the underlying assumption of the appropriation doctrine began to break down. In its pure form, the doctrine was no longer suited for the West. Just as the riparian doctrine was ill-suited for a different *climatic environment*, the appropriation doctrine (as originally conceived) was ill-suited for the slowly evolving *technological environment* which enabled ground-water pumping. It was a matter of fact that near stream pumping could diminish stream flow; either by direct infiltration from the stream or interception of ground water before it reached the streambed. Put into the broad perspective of the prior appropriation doctrine, many ground water pumpers were junior surface-water holders. Their ability to tap into a reliable reservoir of water effectively gave them priority to the entire water system by a simple flick of a switch. As pumping began to increase many states slowly recognized the interconnectedness of all waters and the inappropriateness of a separate laws for both ground and surface waters. New Mexico and Colorado, for example, quickly adopted more expansive views of the appropriation doctrine, making *all* waters appropriable.

In an interesting turn of historic events, Arizona has maintained a legally bifurcated water system; founded on the benchmark 1931 Southwest Cotton ruling. Having already established the broader context of water law in the West, three important questions should be kept in mind. First, was Southwest Cotton the classic conflict between a downstream senior appropriator and an upstream ground water pumper? Second, how was the court influenced by existing scientific, legal, and economic considerations. Third, how critical was the timing of the decision? Would the same ruling have been made if the case were held a decade later?

4.4 SOUTHWEST COTTON AND THE ORIGIN OF SUBFLOW

John Leshy and James Belanger fully describe the events surrounding the Southwest Cotton ruling in Arizona Law where Ground and Surface Waters Meet (1988). The following discussion attempts to re-unite Southwest Cotton's *spirit* with its *words*. Whereas the intent of the ruling has been lost in the decades which followed its passing, the words of the ruling have been taken out of context to support ideas which Southwest Cotton never even confronted.

4.4.1. Brief History

In 1916, an agriculture company called Southwest Cotton installed several deep water production wells between two ephemeral stream, the Aqua Fria and the New River, near Phoenix. Nine years later, speculation on an upstream dam by a separate company finally started to materialize. In fear that their upstream water source would be cut off by the dam, Southwest Cotton filed suit claiming that their wells were protected by the law of prior appropriation.

Winning the initial case, Southwest Cotton advanced three separate defenses during the appeal. Southwest Cotton claimed that:

1. percolating underground water is appropriable,
2. water in underground channels is appropriable, and
3. *subflow* in the Agua Fria is appropriable.

Each claim was individually analyzed by the court. Claim 1 was rejected based on case law dating back to the territorial constitution in 1864 (with an emphasis on the 1919 state water code). Percolating ground water was never considered to be an appropriable resource in Arizona. As will be discussed later, the exclusion of percolating ground water from the appropriation doctrine can be either interpreted as a direct violation of the territorial and state constitutions or, at the very least, a misinterpretation of them (Leshy and Belanger, 1988). Claim 2 was rejected on the grounds that no concrete evidence substantiated the claim that water withdrawn from the wells moved through definite underground channels. It is important to note that *definite underground channels* is Arizona's equivalent of the human body's appendix. No one is quite sure what a definite underground channel is or what the constitutional creators meant by it. Regardless, it has persisted in Arizona law to this day. Claim 3 was also rejected on the basis that the Agua Fria was an ephemeral stream with no hydraulic connection to ground water. Therefore, the stream could not have a *subflow* component.

In rejecting claim 3, however, the court did define a component of subsurface flow which was indeed appropriable. Termed *subflow*, the court cited Clesson S. Kinney, a Utah water lawyer and not a hydrologist. In his 1912 treatise Law of Irrigation, Kinney defined *subflow* to be:

... "those waters which slowly find their way through the sand and gravel constituting the bed of the stream, or the lands under or immediately adjacent to the stream, and are themselves a part of the subsurface stream" (Interlocutory Review, 1993).

Although Kinney's thesis expounds upon *subflow* in greater detail, the above quote served as the basis for the Southwest Cotton court's perception of *subflow*. It should be noted that even in 1912, let alone 1931 or 1993, Kinney was hardly authoritative.

From its inception, *subflow* was defined qualitatively so that subsequent attempts to quantify it have been stifled by the vagueness of the definition. So while it may be easy to intuitively visualize, the exact extent of *subflow* is cloudy at best. In a continued explanation, the 1931 court suggested three ways in which to quantify the boundary:

1. *subflow* is, in most cases, within or adjacent to the stream,
2. *subflow* cannot be removed without "directly and appreciably" removing streamflow, and
3. *subflow* increases as surface flow increases.

4.4.2. Luck, Scientific Dismissal, Constitutional Misinterpretation, and an Economic Bias

Southwest Cotton became the benchmark case upon which Arizona has perpetuated its bifurcated water law system into the present. While many states were taking steps toward unified water management at this time, Arizona anomalously did just the opposite -- a little out of the uniqueness of the case, a little out of its timing, but mostly out of an economic bias held by the court.

The uniqueness of the case perhaps started the Southwest Cotton ruling off on the wrong foot. The classic water rights dispute in the west usually involved a *downstream, senior, surface water appropriator* filing suit against an *upstream, junior, ground-water pumper* under the claim that the ground water pumper was diminishing in-stream flow. Similar suits throughout the west brought this injustice before other courts. In Colorado and New Mexico, the end result of such a suit was unified ground and surface water management. In Arizona, however, this classic water law dispute never occurred. Southwest Cotton was just the opposite. Not only was the ground water pumper filing suit on the surface water appropriator, the pumper was using its water almost a decade prior to the surface water claim (Leshy and Belanger, 1988).

The significance of this seems to have eluded the court. The court, speaking through Justice Alfred Lockwood, saw the case as

"one of the most important which ha(d) ever come before the court, involving as it does not only property interests of (great) value ... but also a declaration of legal principles which will in all probability determine and govern to a great extent the course of future agricultural development within the arid regions of Arizona. The real question involved is the law applicable to the relative rights to the ownership and use of subterranean waters of the state against those of surface water" (Interlocutory Review, 1993).

The court should have addressed the case for exactly what it was -- namely, a law dispute where appropriable water and property rights meet. The fact that the suit was reversed, however, seems to have largely dictated the outcome of the ruling.

Incredibly, despite the celebrated importance of the case, the court relied only scantily on contemporary scientific knowledge in its decision-making process. Kinney, the same authority that the court cited its *subflow* definition from, also wrote in 1912 that it would only be a matter of time before tributary flow would be considered appropriable (Leshy and Belanger, 1988). Samuel Weil, a contemporary of Kinney, supported the notion that percolating ground water was an inseparable component of surface flow and succinctly stated that "it is a question of fact, not law" (Leshy and Belanger, 1988). Thus, although the court cited a quasi-scientific document, its decision did not reflect an appreciation for available scientific evidence that suggested ground and surface waters are inseparable; evidence that neighboring states were using to adjust their bifurcated systems.

Above and beyond disregarding contemporary scientific knowledge, the ruling seems to have been a violation of constitutional statutes. In a 1887 territorial statute, the Arizona legislature explicitly rejected the riparian doctrine in all forms, stating that it should never apply within the state:

"The common law doctrine of riparian rights, shall not obtain or be any force or effect in this territory" (Leshy and Belanger, 1988).

This prohibition of riparian rights, the doctrine which bound water use to property rights, was adopted by the Arizona state constitution twenty three years later in 1910 (Leshy and Belanger, 1988).

At this point, *timing* becomes especially important. Although riparianism was rejected, subsequent amendments to the water code up to 1928, under the supervision of Arizona's prominent engineer G.E.P. Smith, attempted to spell-out the exact waters that the law of prior appropriation applied to. As shown below, although the statute referred to waters of all sources, ground water is never explicitly mentioned.

"The waters of all sources, flowing in streams, canyons, ravines or other natural channels, or in definite underground channels, whether perennial or intermittent, flood, waste or surplus water, and of lakes, ponds and springs on the surface, belong to the public and are subject to appropriation and beneficial use as provided by this chapter" (Leshy and Belanger, 1988)

Although Smith contended some years later in Ground Water Law in Arizona and Neighboring States (1936) that he conspicuously avoided mention of ground water because "so little was known" about it and immediate priority was given to surface water concerns, the net result of his omission simply dumped the issue of interpreting *waters of all sources* and *definite underground channels* onto the lap of the court. Ruling under the strict legal interpretation that "expressing one excludes the other," Judge Lockwood of the Southwest Cotton court concluded that the *absence* of percolating ground water and the *inclusion* of other sources of water in the code simply implied that ground water was excluded from the appropriation doctrine (Leshy and Belanger, 1988). Thus, the irony is that although riparianism was prohibited in all forms in Arizona, the ambiguity of the language in Arizona's appropriation statutes, whether intentional or accidental, effectively placed ground water under a code of "reasonable use" -- startlingly similar to riparian statutes.

So far, the court has based its decision on ignoring contemporary scientific knowledge and misinterpreting the constitution. First and foremost, however, the ruling was based on economic bias. In the opening statement of importance, Justice Lockwood alludes to the ruling's future impact on "agricultural" development (although "agricultural" is excluded in the same quote as cited in the 1993 Interlocutory Review). At the time of the ruling, ground water use was seen as a speculative venture. Ground water production was in its infancy and high-yield pumps had not yet been developed. C.V. Theis' seminal paper which describes flow to a pumping well would not be published for another four years. In light of this, the 1931 court envisioned surface water utilization as a safer and more economically prudent alternative than ground water pumping.

Because the suit was the exact reverse of the traditional water dispute in the West, it was impossible for the court to include tributary flow as a unified component of stream flow. In doing so, the court would have effectively ruled in favor of ground-water production; a mode of water withdrawal that was considered immensely unfavorable (Leshy and Belanger, 1988). Furthermore, it would have ruled against the financially lucrative construction of the surface water reservoir. In light of this, the Southwest Cotton court devised the following test for *subflow*:

The best test which can be applied to determine whether underground waters are as a matter of fact and law part of the subsurface stream is that there cannot be any abstraction of the water of the underflow without abstracting a corresponding amount from the surface stream, ... (T)he test is always the same: Does drawing off the subsurface water tend to diminish appreciably and directly the flow of the surface stream? If it does, it is subflow, and subject to the same rules of appropriation as the surface stream itself; if it does not, then although it may originally come from the waters of such a stream, it is not, strictly speaking, a part thereof, but is subject to the rules applying to percolating waters (Interlocutory Review, 1993). (emphasis added).

Three points can be made about the test. First, it is a one-way test. There is no mention of protecting "senior" ground-water claims from subsequent surface-water

diversion, thus making it a biased test devised specifically for the Southwest Cotton situation (Leshy and Belanger, 1988). Second, in devising such a biased test, it seems almost certain that Southwest Cotton establishes a high degree of protection for surface water claimants from subsequent ground water pumping. In fact, this did not occur at all. Third, the first sentence implies a drop-for-drop reduction in surface flow, while the second sentence definition appears to be more elastic. Which is it to be?

In the Southwest Cotton decision, the court sought to protect surface water rights; not out of scientific truth or even out of property right justice; but rather, simply out of economic expediency. Interestingly, this expediency would change dramatically within a decade.

4.4.3. Implications over the Past 60 Years

The biggest irony of all is the court's final comment concerning what it perceived would be the future ramifications of the decision.

"It may be said that this (ruling) means an end to all future large (ground water) pumping projects. If these projects are based on the depletion of surface waters, it is far more economical both in money and water, and thus better for the state as a whole, that those surface waters be utilized through surface developments (If the effect) will be to lessen somewhat the number and size of future irrigation projects depending upon pumped water, in our opinion it is more than compensated by the establishment of certainty and security for the vastly more important surface projects now existing, and which will doubtlessly exist in the future" (Leshy and Belanger, 1988). (emphasis added)

The irony is two fold. First, by refusing to legalize the scientifically understood connection between surface water and tributary flow, Southwest Cotton marked the beginning of the end of prior appropriation in Arizona. The implications of the decision were not fully appreciated at the time. If Southwest Cotton gave ground water pumpers the *legal right* to top priority of the entire water system, the introduction of the high-yield pumps, cheap hydro-power electricity, and advances in well construction gave the

pumpers the *ability to carry out this right*. Intending to perpetuate the bifurcated water law system in favor of surface water use, Southwest Cotton ironically did just the opposite; becoming the rule upon which wide-spread and prolific ground water production would occur over the next 60 years.

Why was this possible? Tributary flow was legally recognized under "reasonable use" principles which were very similar in nature to the riparian doctrine. Tributary ground water, so long as it was not determined to be *subflow*, could be pumped continuously regardless of its effect on connected surface water rights.

The second irony is found in the final lines of the court's closing statement (underlined above) -- "(surface water use) will doubtlessly exist in the future." Sixty years later, perennial stream flow has diminished to a fraction of its natural amount. The resource that Southwest Cotton attempted to save has all but disappeared; not despite it, but because of it.

4.4.4. Implications Today and in the Future.

Since the 1940's, a massive proliferation of ground water pumping has occurred in Arizona; ironically and unexpectedly riding on the coat-tails of Southwest Cotton. This was accompanied by growing scientific understanding of the behavior of ground water, surface water, and their interaction. Twenty-two years after the Southwest Cotton ruling, Judge Lockwood realized the short-sightedness of the ruling and desperately urged the court to re-evaluate the issue in *Bristor v. Cheatham* (1952). Although a Superior Court majority voted in favor of making all waters appropriable, the decision was over-turned under appeal in *Bristor II* (1953), largely in response to public disapproval of *Bristor I* (Leshy and Belanger, 1988).

The Gila River General Adjudication has forced Arizona to revisit Southwest Cotton. By refusing to re-evaluate the Southwest Cotton ruling, the court has embraced the same flawed reasoning employed over 60 years ago: namely,

1. ignoring contemporary scientific knowledge that law should reflect the unity of all waters because
2. eminent economic catastrophe will occur if the bifurcated water system is changed.

The reasoning is the same. This time, however, the court is *refusing to make* a decision, fearful of disrupting an economic matter which is better left to the legislature. As discussed throughout, the court and legislature have historically played hot-potato with the issue, resulting in a roller-coaster ride of indecision. In the final adjustment to the state water code in 1928, G.E.P. Smith conspicuously avoided classifying ground water, feeling it to be a matter better handled by the court. During the Southwest Cotton ruling, the court did make a ruling -- based on the economic assumption that surface water use must be protected from speculative extraction of water from the ground (although this intent was never achieved). Today, the same bad decision that the court *made* in 1931 will be perpetuated by simply not making any decision at all; a route that today's court seems quite comfortable with since it explicitly states in the Interlocutory Review (1993) that any changes must be initiated by the legislature.

Once again, the court leans on an economic bias. Hydrologic models can now predict what history has proven over the past six decades; namely, that in-stream surface flow is diminished by ground water pumping. The court is inconvenienced by the fact that its indecision, based ostensibly on legal precedent, coincides with its implicit economic assumption. It should not be forgotten that a similar economic short-sightedness in the Southwest Cotton ruling (1) legitimized unregulated ground water pumping, (2) substantially weakened the efficacy of the doctrine of prior appropriation, and (3) resulted

in a dramatic decrease in perennial surface flow within the state; all of which the ruling explicitly aimed at preventing.

If the court is truly stuck in its legal myopia as it suggests in the 1993 Interlocutory Review, its ability to reach a coherent decision is doubtful. Law is never a good surrogate for fact. Indeed, it is noble to learn from the mistakes we made in the past, but clinging to these mistakes as legal fiats for future decisions seems truly absurd.

There is little question that economic growth has occurred in the midst of massive ground water pumping in the past sixty years; emptying over 85 percent of Arizona's perennial streams and filling the pocketbooks of irrigators, mine companies, municipalities, and industries. Though not necessarily untrue, the court's economic assumption is both too broad and susceptible to future change. The broadness of the decision is high-lighted by the more insightful question: who uses the water and to what economic ends is it used? The Southwest Cotton ruling occurred at a time when agricultural development (using surface water irrigation) was seen as vital to Arizona's economic future. Does this still hold true? Just as agricultural, municipal, industrial, and mining interest groups fiercely compete for water, they ultimately put the water they use to varying economic ends. Finally, the economic perception of water may once again be in transition so that Arizona's remaining perennial streams are becoming the most valuable resource of all. Not only is perennial surface water inflated in price by its pump-diminished scarcity, its preservation ironically contradicts the basic premise of the prior appropriation doctrine: namely, that water flowing untapped in a stream is absolute waste.

Arizona finds itself in the unique position it was over sixty years ago; this time, however, privy to the first-hand effects of scientifically flawed decision-making. Can Arizona learn from the mistakes it made in the past or will it continue to legally adhere to them? Will Arizona be able to live with whatever it chooses sixty years in the future? Most importantly, will the federal government be able to live with Arizona's choice today?

Chapter 5

Law of Problem

Legal Interpretations of *Subflow*
based on legal memoranda filed before the court
on September 24, 1993 and October 4, 1993

Summary

Unfortunately, if it is clear to the Interlocutory Review Court that the "50%/90 day test" is bad law, it is no way clear to them what type of *subflow* solution will make good law. In memoranda submitted before the court on September 24, 1993 and October 4, 1993; law firms which represent each interest group (including mining companies, municipalities, irrigators, Indian tribes, cities, and the federal government) attempt to decode the legal riddle at the river's edge.

5.1 INTRODUCTION

As late as 1988, John Leshy and James Belanger wrote highly of Judge Goodfarb's rule in their law review article Arizona Law where Ground and Surface Waters Meet.

Still, the {"50%/90 day test"} ought fairly to be regarded as a step in the right direction, at least compared to many previous Arizona Court decisions on the subject. It candidly confronts the basic issue and forthrightly tries to deal with it within the constraints a trial court encounters in searching for guidance in appellate decisions that only dimly outline the contours of state law on the subject. In the end, Judge Goodfarb's has created an adequate basis for appellate review and a clear opportunity for higher courts to provide, at long last, the definitive guidance necessary to put Arizona water management on a hydrologically sound basis (Leshy and Belanger, 1988).

To the Interlocutory Review Court, the "50%/90 day test" was failure. However, it is with considerable more ease that they are capable of pointing out errors in the past than they are capable of correcting them in the present. In memoranda submitted to the

Superior Court on September 24 and October 4, 1994; lawyers representing each interest group attempt to decode the legal riddle of *subflow*.

5.2 RESPONDING PARTIES

The following interest groups filed memoranda on September 24, 1993:

1. Certain Groundwater Users (which consists of multiple parties),
2. Cities of Chandler, Glendale, Mesa, and Scottsdale,
3. City of Goodyear,
4. City of Phoenix,
5. City of Tempe,
6. Gila River Indian Tribe,
7. Gila Valley Irrigation District, Cities of Sierra Vista and Benson, Towns of Mammoth and Patagonia,
8. Salt River Project,
9. San Carlos Apache Tribe, the Tonto Apache Tribe, and the Yavapai Apache Tribe, Camp Verde Reservation, and
10. Verde Valley Water Users.

The following groups filed rebuttals to the original memoranda on October 4, 1993,

1. Certain Groundwater Users (which consists of multiple parties),
2. Gila River Indian Tribe,
3. Apache Tribe,
4. Gila Valley Irrigation District and others, and
5. Salt River Project.

along with,

6. State of Arizona, and

7. Magma Copper Company.

The listed interest groups only represent a skeleton of those involved in the adjudication and the fate of *subflow*. If anything is made apparent in the memoranda, it is the diversity of the views concerning *subflow*. The following five areas are analyzed:

- A. where is *subflow*?,
- B. what should be the *process* for categorizing wells which deplete *subflow*?,
- C. what *criteria* should be used in the determination?,
- D. what *technological methods* are available?, and
- E. should *de minimis* wells be included?

5.3 WHERE IS SUBFLOW

Incredibly, there seems to be a general consensus among all parties that the "50/90 rule" was rejected simply as a re-confirmation of Southwest Cotton. Or in other words, even though the court recognizes that ground and surface waters are inter-related and that the principles employed in the 1931 ruling do not accurately reflect hydrologic reality, it is not the court's job to erase what has already been done.

The big question remains: what exactly has already been done? If it is not the role of the court to "refine, revise, correct or improve Southwest Cotton", then how is *subflow* defined in the 1931 ruling. The following points are accepted by most parties:

- 1. *subflow* is a narrow concept,
- 2. *subflow* is found immediately within or adjacent to the streambed,
- 3. *subflow* depends on whether the water is more closely associated with the stream than the surrounding alluvium, and
- 4. *subflow* is physically distinguishable from tributary flow.

Unique views of *subflow* continue to exist, some attempting to expand and some attempting to shrink the *subflow* zone. The City of Goodyear suggests that only wells

located within the *subflow* zone should be included in the adjudication, insinuating that wells located outside the *subflow* region are excluded for all time. The source of this conclusion is both unclear and unsubstantiated by any sort of evidence. It is clearly stated in the Interlocutory Review that wells located outside the *subflow* zone can indeed deplete *subflow*.

However, when taken out of context, certain excerpts from the Interlocutory Review may appear to support other ideas. For example, the Verde Valley Water Users extend the suggestion that only a part of *subflow* is appropriable based on what the Apache Tribe calls a misinterpretation of two passages in the Interlocutory Review, namely:

(w)e decide today whether the court erred in adopting a new test to determine whether the underground water known as subflow is appropriable under ARS Section 45-141

and

even if extraction of groundwater will cause a more-or-less corresponding depletion from flow volume, the extraction is of groundwater, not subflow.

The former passage was misinterpreted as determining whether *subflow* (and not the "50/90 rule") was in error, perhaps suggesting that the concept of *subflow* should be abolished. Taken out of context, the later idea insinuates that all wells pump tributary flow, and are thus exempt from court jurisdiction. Given the entire scope of the Interlocutory Review, these ideas are not supported.

Verde Valley Water Users also present the misguided argument that a mature cotton wood can deplete more surface flow than a domestic well; perhaps suggesting that all trees should be included in the adjudication, undoubtedly as junior water right holders. Such a claim is not as totally outlandish as it might first appear. In Southeastern Colorado Water Conservancy District v. Shelton Farms (1974), Shelton Farms was awarded a water right for clearing phreatophytes along the Arkansas River partly under the defense that the riparian area was virtually devoid of "water loving" vegetation prior to the settlement of

the area due to buffalo grazing of the tree saplings and Native American timber use (Sax et al., 1991).

Salt River Project (SRP) endorses an expansive view of *subflow*. In doing so, Certain Groundwater Users contend that SRP ignores that *subflow* is "within or immediately adjacent to the streambed". Despite as a reason for rejection of the "50%/90 day test" (which was based on Halpenny's original suggestion), SRP insists that the younger alluvium does not extend from ridgeline to ridgeline in all cases and that anything within the younger alluvium may indeed be more closely related to the stream than the distant alluvium. (This point of conflict is discussed more thoroughly in the chapter 6.) SRP also holds the view that *subflow* can exist, on occasion, beneath and adjacent to ephemeral stream reaches; a somewhat contradictory (though possibly true) hypothesis considering that ephemeral washes are usually defined by their lack of hydraulic connection to an underlying aquifer.

In objection to the Gila Valley Irrigation District and others, The Gila River Indian Reservation includes the idea that "*subflow* should err on the side of including wells" as one of the key *subflow* criteria expressed in the 1993 Interlocutory Review. No other party shared this interpretation.

Finally, in suggestion that a specific ruling concerning protection of surface water rights from upstream pumping has never been directly addressed in Arizona, the Gila River Indian Reservation outlines a long list of cases which supposedly support such a protection. In objection, Gila Valley Irrigation District and others contend that the argument has little significance to the issue at hand since it is not the court's intention to erase what has already been done.

If beauty is in the eye of the beholder, it becomes increasingly obvious that *subflow* is in eye (or perhaps 'pocketbook') of the water user.

5.4 WHAT WILL BE THE PROCESS ?

Controversy even surrounds the procedure that will be used to find *subflow*. The City of Phoenix, in an August 1993 brief, captures the dual perspective on how the process should proceed:

(a.) should the court develop a system-wide subflow criteria with a simultaneous or subsequent examination of the variations (if any) which may be necessitated by "differences in geology and hydrology from location to location" and then later apply the criteria to particular wells or (b.) should the court begin with particular wells and develop subflow criteria on a well-by-well analysis?
(emphasis added)

The arguments presented for both procedures are included in Appendix-B.

5.5 WHAT WILL BE THE CRITERIA FOR DETERMINING SUBFLOW AND SUBFLOW DEPLETION?

The system-wide approach receives the most support in the Interlocutory Review. This approach requires two-steps: (a) identifying *subflow* and (b) determining which wells "directly and appreciably" deplete appropriable water (both streamflow and *subflow*).

5.5.1 Identifying Subflow (Geographically)

According to Southwest Cotton, *subflow* is (1) a narrow concept; (2) water that is more closely related to the stream than the surrounding alluvium; (3) water that is within or immediately adjacent to the streambed, (4) and groundwater that is distinct from *tributary flow*. However, since "the present record [meaning Southwest Cotton and the Interlocutory Review] allows neither the trial court nor [the supreme court] to identify a definitive set of criteria", the supreme court has ordered DWR "to take evidence and, by applying the principles contained in this opinion, determine the criteria for separating appropriable *subflow* from groundwater" (Interlocutory Review, 1993). Despite the

courts firm, if not sophistic, embrace of an imaginary legal concept, it readily recognizes that a physically-based determination is essential.

Five potential criteria are generally mentioned in the Interlocutory Review including relative ground water elevation, water table gradient, chemical make-up of the water, flow direction, and volume of water in the adjacent stream reach; none of which are quantified in any fashion. The idea that certain criteria may receive more or less emphasis depending on variation in local geology and hydrology is also mentioned.

SRP contends that topographic, geologic, soil, and water level maps; along with aerial photography, well logs, and vegetative features can all be used to define the *subflow* region, which it refers to as the 'saturation zone'. Gila Valley Irrigation District and others suggest that determining whether a stream is gaining or losing and the speed of streamflow will help delineate what it calls the "line of demarcation". Additional ideas cited by the City of Goodyear including alluvial deposit stratification, lithology of stratigraphic units, geomorphologic description, ground water depth, well depth, pump well depth, well casing, well capacity, perforation interval, annual well volume, and water quality suggest that *subflow* delineation is more complex (and will require considerable more technical analysis) than originally alluded to in the Interlocutory Review.

DWR's November 5, 1993 memoranda which outlines the approach it will use in determining *subflow* reaffirms not only the complex nature of scientifically identifying an imaginary concept but also the confusing constraints concerning the criteria it can or cannot use. DWR seems to have interpreted the court's rejection of the time/volume and younger alluvium approach used in the "50/90 rule" as a ban on using any sort of time analysis or geologic delineation concerning *subflow*. If this is the case, the 'time' disqualification has thrown out every analytical or numeric model at DWR's disposal; furthermore, they seem to have discarded any sort of geologic interpretation as well. What else are they left with? Nothing really, other than water levels. Thus, DWR concludes that:

the force of gravity acting on subsurface waters will provide a workable model of the flow direction, making the delineation of the imaginary line feasible. It ignores geologic and time/volume or rate analysis.

Even if DWR's conclusion is erroneous, the point is made: if the court wants an imaginary line to be painted, it must let the artist use imagination, uncensored.

5.5.2 Which and When Wells Diminish Subflow?

Wells located inside the *subflow* zone will almost always pump appropriable water. Exceptions to this may occur if a highly impermeable clay layer lies between the well and stream. In addition to the vague criteria for identifying *subflow* mentioned above, Southwest Cotton also makes mention of an additional test for determining when a pumping well is depleting appropriable water:

The best test which can be applied to determine whether underground waters are as a matter of fact and law part of the surface stream is that there cannot be any abstraction of the water of the underflow without abstracting a corresponding amount from the surface stream, for the reason that the water from the surface stream must necessarily fill the loose, porous material of its bed to the point of complete saturation before there can be any surface flow...

Not only does [*subflow*] move along the course of the river, but it percolates from its banks from side to side, and the more abundant the surface water the further will it reach in its percolations on each side. But, the test is always the same: Does drawing off the subsurface water tend to diminish appreciably and directly the flow of the surface stream? If it does, it is *subflow*, and subject to the same rules of appropriation as the surface stream itself; if it does not, then, although it may originally come from the waters of such a stream, it is not, strictly speaking, a part thereof, but is subject to the rules applying to percolating waters. (emphasis added)

In a 1936 article Groundwater Law in Arizona and Neighboring States, Arizona hydrologist G.E.P. Smith points out that this test was devised in hope of replacing former criteria such as the existence of "bed and banks" which were difficult to physically identify in the field. However, Smith points out that this new test could only be realistically applied "in the case of a small, steady stream flow, unvarying over many days, with heavy withdrawals from nearby wells ... but when the stream flow is out of proportion to the pumpage or is subject to wide natural fluctuations within a few hours, and especially in the case of Arizona's ephemeral streams, (the test) cannot be applied." The irony is that although the test could easily be accommodated today with numeric ground water models, the Interlocutory Review seems to refute any sort of test which establishes *subflow* to be a particular amount of stream depletion over a given period of time; regardless of the fact that the above test described in Southwest Cotton encouraged such a method.

Wells outside the *subflow* zone can also diminish *subflow*. This is understood by both the court and the majority of involved parties. The real questions at stake are: which ones?, when?, and how much? Based on Southwest Cotton and ideas forwarded in the Interlocutory Review, the developed set of criteria must embody the following four concepts.

- a. Depletion must be "direct". This has been interpreted as meaning distinct from *tributary flow* which indirectly feeds a stream.
- b. Depletion must be "appreciable", or measurable.
- c. Depletion does not correspond to a particular percent of depletion over a particular time (such as was done in the "50%/90 day test").
- d. Depletion does not require a gallon-per-gallon diminishment in order to be included in the adjudication.

5.6 WHAT TECHNICAL METHODS ARE AVAILABLE FOR DELINEATING SUBFLOW?

If none of the involved parties presents a cohesive scheme for implementing a technical solution, this is largely out of anticipation for DWR, the special master, or the court to do so. Even in the case that criteria is developed in an adversarial trial setting, some sort of technical solution will be required.

The technical solutions which are proposed are usually for determining *when* and *how much* a well depletes appropriable water. However, even the identification of the *subflow* region will require the quantification of criteria. For example, if water flows in the general direction of the stream, how significant is this in delineating *subflow*? Also, how does the *subflow* width correspond to flow in the adjacent stream reach?

As discussed, daily streamflow data is a poor indicator of depletion caused by individual near stream wells. A cone of depression intersecting a streambed has generally been agreed to offer the strongest technical proof that "direct" stream depletion is occurring. However, even controversy has arisen here due to SRP's contention that the cone of depression only has to intersect the *subflow* zone in order to be pumping appropriable water (Figure 5.1). This interpretation is supported in the Interlocutory Review when it states that pumping *subflow*

turns on whether the well is pumping water that is more closely associated with the stream than the surrounding alluvium.

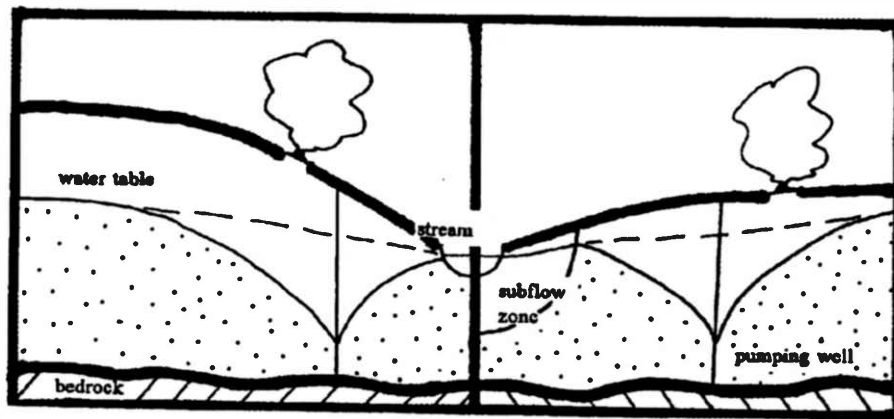
This implies *subflow*. However, Gila Valley Irrigation District and others contend SRP is rewriting the Interlocutory Review with the above interpretation. The streambed stipulation is clearly expressed in the Interlocutory Review as follows:

if the cone of depression of a well has expanded to the point that it intercepts a streambed, it almost certainly will be pumping subflow.

Regardless of minor interpretive differences over subtle, yet no doubt significant, ambiguities in the Interlocutory Review, the drawdown test seems to offer the most

potential to many of the parties, including SRP and City of Tempe, who contend that the test could determine *when* and *to what extent* an intersecting cone of depression depletes streamflow. The Theis drawdown test is considered superior to numerical models and analytic stream depletion equations.

Cones of Depression intersecting the streambed and *subflow* zone
Figure 5.1

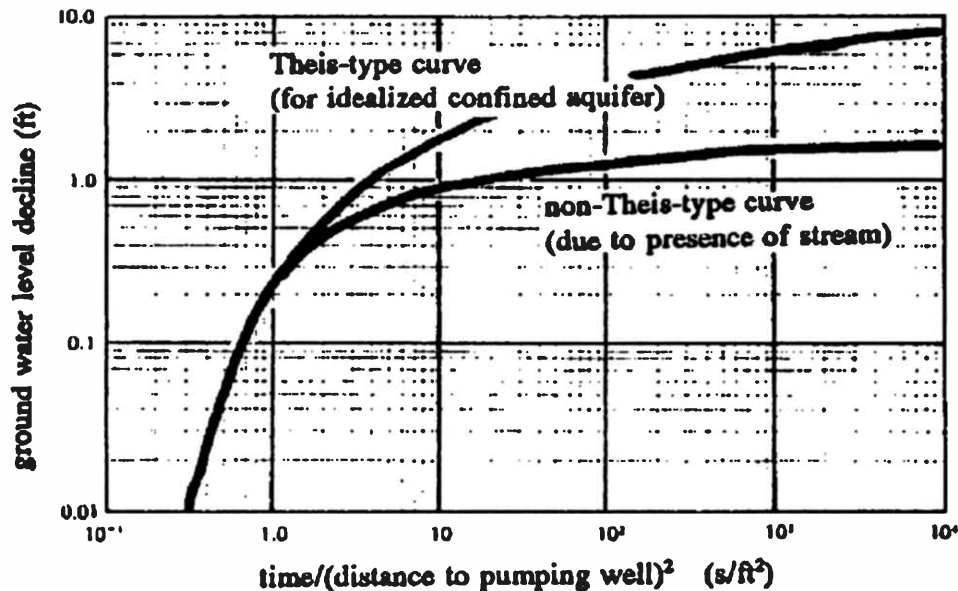


Theis' drawdown solution could be used in two ways, both of which have complications. The first method would be to actually conduct a pump test on representative wells. In this case, stream leakance is a secondary calculation, solved for by using a chart which relates the drawdown curve's deviation from a 'type curve' to a leakance term (Figure 5.2). The problems with this type of test were discussed in chapter 3. SRP's suggestion that "a calculated or observed drawdown in the observed area of at least 0.1 feet should be presumed to pumping at least some *subflow*" seems to be somewhat misguided since seasonal variations in water level are often well over 1 foot. Due to a long history of groundwater pumping in most areas, antecedent water levels are rarely known within 0.1 foot accuracy.

The second method would rely on using Theis' equation under ideal aquifer conditions *without the presence of a stream*. Although stream depletion cannot be estimated in this case, stream-side drawdown can be estimated if aquifer properties are known. However, the absence of the stream would defeat the entire purpose of the test

which is supposed to identify the amount of water depleted from the stream. Defining an arbitrary drawdown (such as 0.1 feet) is at best a duplication of the same logic used in the "50% over 90 days" threshold.

Deviation from the Theis Curve possibly due to stream leakance
Figure 5.2



Chemical methods are also proposed. Gila Valley Irrigation District and others suggest that

(t)here are systems capable of detecting a difference in water chemistry when the stream is intercepted by a cone of depression. These systems can automatically shut down one well and turn on a substitute well whose pumping will not affect the river (at least for a time). Using such a system, a water administrator can switch back and forth between wells so as to avoid interference with streamflow.

The Gila Indian River Reservation expresses considerable doubt on the existence of this system. Even if such a system did exist, it seems quite probable that the water chemistry would be very similar and that even if they were not similar, the chemistry of the surface water would change as it moves through the ground toward a pumping well.

Many respondents seem cognizant that any technical solution will raise other questions that may even be more complicated to solve. For example, even if an arbitrary drawdown threshold is defined, how much does drawdown affect stream seepage depending on streambed factors?, how should wells be handled that are only partially depleting *subflow*?, how about cone of depressions that will intersect the streambed in the future?, and how can multiple wells with intersecting cones of depression be separated?

The City of Phoenix suggests that the technical solutions which are chosen should be based on the following checklist:

1. focus of test,
2. accuracy of test,
3. expense of test,
4. time consumed by test (performance and analysis),
5. data needed to run the test,
6. strengths and weaknesses of test,
7. assumptions of test,
8. consensus of scientific community concerning test,
9. applicability to large geographic area,
10. suitability of test to diverse geologic and hydrologic situations,
11. extent to which test is used throughout the West, and
12. in-house ability of DWR to conduct test.

5.7 DE MINIMIS WELLS -- SHOULD ALL WELLS BE INCLUDED?

A de minimis well is a small pumping well, such as a stock well, which can be considered to have an insignificant impact on the water system. The superior court forwards the idea in the Interlocutory Review that "wells having a de minimis effect on the river system" should be excluded. Exclusion of de minimis wells will not result in a "piecemeal adjudication of water rights or in any other way run afoul of the McCarran

Amendment" but rather will "simplify and accelerate the adjudication by reducing the work involved in preparing the hydrographic survey reports and by reducing the number of contested cases before the special master" (Interlocutory Review, 1993).

SRP suggests that the de minimis standard should be applied to all wells that pump under 1 acre/feet per year, are outside the *subflow* zone, and do not have a cone of depression that intersect the *subflow* zone. Many parties contend that the de minimis issue should not be addressed in the upcoming evidentiary hearings. However, completion of the hydrographic survey reports is largely dependant on some sort of de minimis resolution.

Above and beyond completing the HSR, the Apache Tribe's contention that it is too soon to exclude any wells from the adjudication casts the long shadow of federally reserved water rights across the entire *subflow* standstill. Indeed, the Apache Tribe seems already resigned to the notion that any sort of criteria adopted at the state level will not protect their federally reserved right; not because they are 'omniscient' as is suggested by Gila Valley Irrigation District and others, but because *subflow* (whether narrow or expansive, geologically mapped, or mathematically derived) does not exist, except upon the pages it is written.

Chapter 6

Proposed Solutions to Problem

Hydrologic Interpretations
proposed in technical reports filed before the court
for the January 1994 evidentiary hearings

Summary

The proposed solutions forwarded in the January 1994 evidentiary hearings form the foundation of evidence for Judge Goodfarb's eventual subflow ruling. Because the Arizona supreme court only provided vague hints of criteria that may serve as good indicators for determining *subflow*, the usefulness of these solutions must be judged on a combination of tests; such as (1) are existing legal precedents satisfied, (2) are the solutions based on fixed, natural characteristics, and (3) can the methods be implemented readily and cost-effectively? In the end, there is no perfect solution that will satisfy each test, there is only a best solution -- and undoubtedly a compromise. Capture (the hydrologist's conceptualization) and *subflow* (the legal conceptualization) do share some common ground in an expansive view of *subflow*.

6.1 INTRODUCTION

Although many passages in the court's recent ruling (Interlocutory Review, July 1993) give further insight into the *subflow* solution it seeks, the crux of the opinion is captured in the following excerpt.

We believe the Southwest Cotton court drew a line between subflow as part of the stream and water in the surrounding alluvium that is either discharging into the stream or being discharged by the stream. That line is relatively close to the stream bed, with variations depending on the volume of stream flow and other variables. Thus, if a well is drawing water from the bed of a stream, or from the area immediately adjacent to a stream, and that water is more closely related to the stream than

the surrounding alluvium, as determined by appropriate criteria, the well is directly depleting the stream (Interlocutory Review, 1993). (emphasis added)

The above excerpt serves as a microcosm of the problems encountered by the hydrologist, the court, and the administrator in finding a suitable solution. The hydrologist is stymied by the recent ruling's reliance on Southwest Cotton -- a ruling which offers little prospect of unifying ground and surface waters. The court, on the other hand, is troubled over Southwest Cotton from a legal perspective. If not completely perplexed by the confusing legacy left by the 1931 ruling, the court has struggled because of the inexact wording such as "bed of the stream" and "immediately adjacent to" used to describe the region where *subflow* exists. Finally, the administrator is confronted with the difficult task of using "appropriate criteria" to delineating a boundary that is hydrologically non-existent and legally ambiguous. Although the court does provide vague hints of criteria that may serve as good indicators, the proposed solutions seem to be based on the following three tests:

1. does the method satisfy legal precedents,
2. is the chosen boundary based on fixed, natural characteristics, and
3. can the method be implemented readily and cost effectively?

Technical solutions for finding *subflow* were submitted by the following groups:

1. Arizona Department of Water Resources,
2. Arizona Office of Attorney General (presented by Don Young),
3. Errol L. Montgomery and Associates, Inc. (representing Certain Ground Water Users),
4. Gookin Engineers (representing Gila River Indian Community and Silas Kisto),
5. Leonard Rice Consulting Water Engineers (representing Salt River Project),
6. South Pass Resources, Inc. (representing the Cities of Chandler, Glendale, Mesa, and Scottsdale),

7. Southwest Ground-Water Consultants (representing Gila Valley Irrigation District and Town of Mammoth),
8. Stetson Engineers Inc. (representing the United States Government), and
9. The Nature Conservancy (presented by Tom Maddock)

In the end, there is *no one perfect solution* that will completely satisfy each test; rather, there is only a *best* solution -- and undoubtedly a compromise. Conspicuously, hydrologic accuracy is not included in the list of tests. Although some may contend that hydrologic accuracy is implicitly hidden in the decision-making-process, its failure to be felt as an over-riding issue foreshadows the ultimate fate of the ground water which feeds Arizona's streams. Legal doctrines can change, artificial boundaries can be drawn at will, and short-sighted economic analysis can make easy and non-comprehensive solutions seem alluring; however, the laws which control subsurface and surface-water flow (which are inseparable) will not change -- inevitably jeopardizing the effectiveness of the entire adjudication and the future of in-stream flow in Arizona.

6.2 SUBFLOW AS A "WIDE CONCEPT"

Similar to a sheriff's bravado just prior to an outlaw's arrival into town, DWR opens its report with a hydrologist's condemnation of the evils of Arizona's bifurcated water law system -- the root of the entire problem. DWR states that the determination of whether certain water is governed by the ground water code or the surface water code is impossible since "neither law nor hydrology" provides a fixed dividing-line between the two (DWR, 1993).

DWR's initial inclination towards hydrologic accuracy is fleeting, however; quickly conforming to the new law of the land -- which is, to "assist in finding a means to uphold the letter and spirit of the Arizona Supreme Court's recent opinion on the definition of *subflow* while at the same time applying sound principles of hydrology" (DWR, 1993). Although *application of sound hydrologic principles* would question the relevance of a

non-moving *subflow* boundary for the adjudication, DWR trades in its hat and badge for a magnifying glass and a law book and aptly states in the critical mode of legal scrutiny:

Responsibility for imprecision in the identification of subflow has often been attributed to Arizona's bifurcated system of water law. In DWR's view, however, the difficult problems associated with the identification of subflow arise primarily because the legislature and courts have not specified the necessary arbitrary factors which define its existence (DWR, 1993).

If not a complete forfeiture to legal parochialism, DWR's stance is not surprising in light of the court's recent rejection of the time/volume "50%/90 day test" -- a method that DWR considered technically superior, with modification, to all other methods. In the end, however, DWR cannot totally hide the cynicism that lurks underneath its nicely enamored legal facade when it states that it is "extremely difficult to draw a fixed cultural line through a dynamic, natural system," but the bifurcated water law system demands that a line be drawn (DWR, 1993).

6.2.1. The Modified Flow Net Method

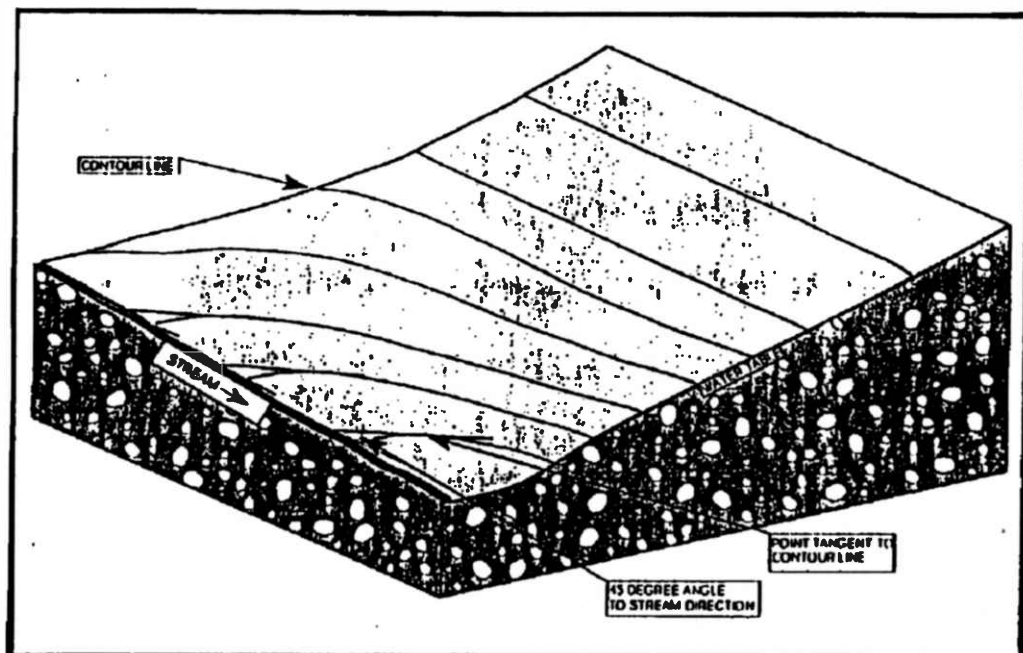
DWR briefly discusses an entire list of methods (including time/volume, geologic, and geographic analysis) that may offer reasonable solutions in the absence of existing legal precedents. True to its November 1993 preliminary report (already discussed in chapter 5), DWR proposes the approach that rides on the coat-tails of the method which "seeks the least controversial path through the various provisions in the [recent] court ruling" (DWR, 1993), namely:

The force of gravity acting on subsurface waters will provide a workable model of the flow direction, making the delineation of the imaginary line feasible. It ignores geologic and time/volume or rate analysis (DWR, 1993).

Thus, by the *very strictest interpretation* of Southwest Cotton and the Interlocutory Review, DWR developed a gravity-based method which it refers to as the

Modified Flow Net Approach¹ to define the lateral extent of the *subflow* zone. The method avoids all points that are in the least bit controversial in either court ruling. Furthermore, the Modified Flow Net Approach is modeled from the central test of the Interlocutory Review -- namely, is the subterranean water "more closely associated with the stream than the surrounding alluvium" or, in other words, is the subterranean water flowing in the same general direction as the stream?

Conceptualization of DWR's Modified Flow Net Approach for determining the lateral extent of *subflow* in a gaining stream reach (DWR, 1993)
Figure 6.1



The Modified Flow Net Approach is divided into a 3-step procedure:

1. Does a hydraulic connection exist between the stream and the underlying aquifer? This requires (a) the existence of a perennial or intermittent stream reach and (b) ground water elevations that are equivalent to the stream stage.
2. Is the subterranean water more "closely associated with the stream than the surrounding alluvium (?)." This requires 3 separate steps.

¹The DWR has mis-named their analysis. As seen by Figures 6.1 and 6.3 the Modified Flow Net Method is now way or form a flow net. More properly, it is a Flow Field or Velocity Field Method.

- a. What is the direction of stream flow? In most cases, the direction of stream flow will have to be "smoothed" to compensate for channel meandering throughout the modern floodplain.
 - b. What is the flow direction of the subterranean water? Existing wells will be used to contour the static ground water levels.
 - c. What is the chemical composition of the subterranean water? Although this is difficult to do, chemical composition can be used as a secondary test to check the validity of the flow direction test.
3. The final step is to delineate the *subflow* zone (which DWR has re-named the *accounting surface*) by determining the lateral extent in which water moves more *with* the stream than *to or from* it. The accounting surface will be constructed by simple geometry based on the point that a line drawn *45 degrees* from the direction of stream flow becomes tangent with the ground water contour lines (Figure 6.1).

6.2.1.1 Drawbacks of the Modified Flow Net approach

By firmly embracing a very strict legal interpretation, DWR readily admits that the Modified Flow Net Method is not without short-comings. First, ground water levels are susceptible to significant natural and cultural changes. Seasonal and yearly fluctuations are quite common. The effects of past and present pumping wells also have dramatically affected the shape and elevation of the water table in some regions. In this case, DWR proposes that since it is not possible to restore water levels to their undeveloped state, only the *present* condition of the water table is applicable for determining *subflow*. Second, construction of the line is not dependent or defined by any fixed boundary. For example, in some cases the boundary may extend beyond the outer edge of the younger alluvium (which is expressly ruled against in the Interlocutory Review) while in other instances the boundary encroaches within the confines of the modern floodplain. In this later case, DWR proposes to extend the boundary to the outer limit of the modern floodplain. Third, the method fails to put a definitive end to the entire issue. Fluctuations

in the water table necessitate a continual change in the *subflow* boundary. This will leave the adjudication open indefinitely. Finally, implementation of the method for the San Pedro Basin alone will take between 12 to 20 months to complete, over twice as long as every other proposed method.

6.2.1.2 Thoughts of other parties

With the exceptions of Leonard Rice Consulting (representing Salt River Project) who hold the opinion that the line drawn by the Modified Flow Net Approach will correlate to their line, and The Nature Conservancy who want subflow defined as wide as possible to protect the stream from capture processes²; most of the other parties are critical of DWR's chosen methodology.

Montgomery and Associates (representing Certain Ground Water Users) suggests a flow path technique in the much more narrow context that subsurface flow must be parallel to stream flow in order to be "more closely associated with the stream than the surrounding alluvium."

South Pass Resources (representing Chandler, Glendale, Mesa, and Scottsdale) forwards the idea that flow direction alone cannot be the sole criteria. Underflow in the basin fill may also flow parallel to the stream; however, it is separate and distinct from *subflow*.

Stetson Engineers (representing the United States Government) and Southwest Ground-Water Consultants (representing Gila River Irrigation District and Town of Mammoth) both suggest that the Modified Flow Net Approach is vague and open to wide speculation. Stetson Engineers point to the following weaknesses of any flow net method:

1. even with sufficient data, contour drawing is arbitrary and approximate,
2. contours do not change abruptly, thus drawing a distinct line will be an

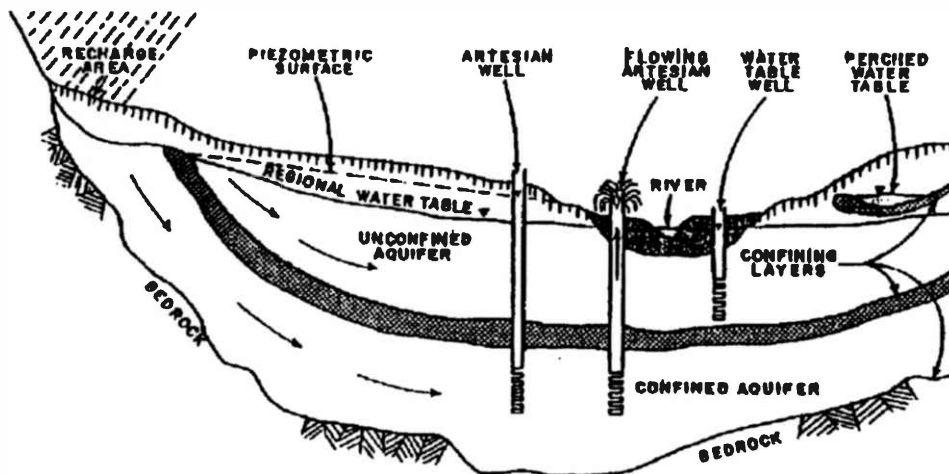
²The Nature Conservancy (TNC) suggested the same methodology and called it the *Ground-water Flow Field Method*. The TNC also suggested three other methodologies (see a later section)

arbitrary process,

3. all water levels will have to be made contemporaneously,
4. subsurface flow in the basin fill can move parallel to the stream, and
5. the method fails to find a lower limit.

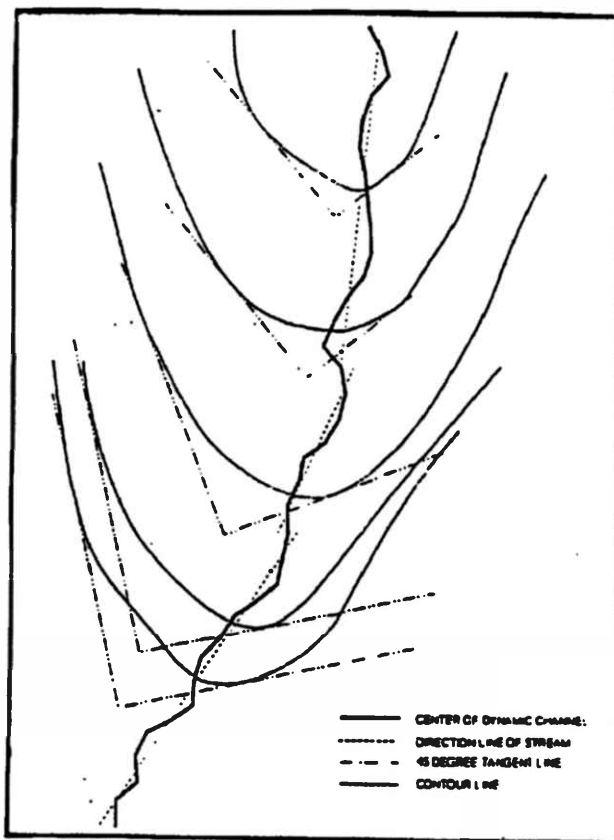
Southwest Ground-Water Consultants suggest that although flow direction may indeed be one criteria to be used for determining *subflow*, it would have to be augmented with geologic and hydrogeologic data. Although site-specific examples of the Modified Flow Net Approach are included in its report, DWR stresses that the examples are only preliminary trials to show how the method may be implemented. For its real application, water elevation would have to be collected contemporaneously (in time) in order to accurately map the *subflow* zone. Also, water level elevations alone are insufficient for determining flow direction since adjacent wells may be perforated in entirely different (or multiple) geologic formations (Figure 6.2). In light of this, an accurate delineation could not be made until the perforation interval of each well is known. The effect of ground water pumping on the downstream-most water level contour in Figure 6.3 highlights the subjective and temporary nature of the test.

Wells with different perforation intervals (HSR, 1993)
Figure 6.2



Preliminary application of the Modified Flow Net Approach to a stream reach near Palominas (DWR, 1993)

Figure 6.3



6.2.1.3. DWR's final words

The true intent of Modified Flow Net Approach remains unclear. On the one hand, DWR advocates the methodology for its strict adherence to the principles iterated by Southwest Cotton and the Interlocutory Review. On the other hand, however, DWR is painfully remindful of the severe short-comings of the proposed technique. In the end, DWR shows little repentance for the court's denial of geologic and time/volume analysis. DWR concludes by stating that it still sees the younger alluvium as most closely meeting Southwest Cotton's definition of *subflow* while additionally maintaining that a time/volume technique would yield the most accurate solution. Thus, the Modified Flow Net Approach is DWR's third choice; or more simply -- winner by default.

DWR points out that not only can "any position ... be supported with select phrases within the [recent court] opinion," but conversely, "it is [also] difficult to ascertain any one definition that fits all the technical criteria offered" (DWR, 1993). In this regard, the Modified Flow Net Approach is the least controversial of any other method. Any chosen method, however, will "involve some exercise of judgment" since determining whether a well "is more closely associated with the stream than the surrounding alluvium" or that a well "is directly and appreciably" affecting a stream are imprecise criteria that are open to interpretation (DWR, 1993). Or in other words:

A physical basis to identify the boundaries of the subterranean component of streams in the alluvial valley does not exist. Consequently, any method devised to describe the extent of a discrete hydrologic entity that does not exist must of necessity incorporate an arbitrary factor which adequately defines the boundary (DWR, 1993).

6.2.2 Younger Alluvium Approach

From a purely scientific perspective, DWR acknowledges that the younger alluvium contains ground water that is closely associated with the stream

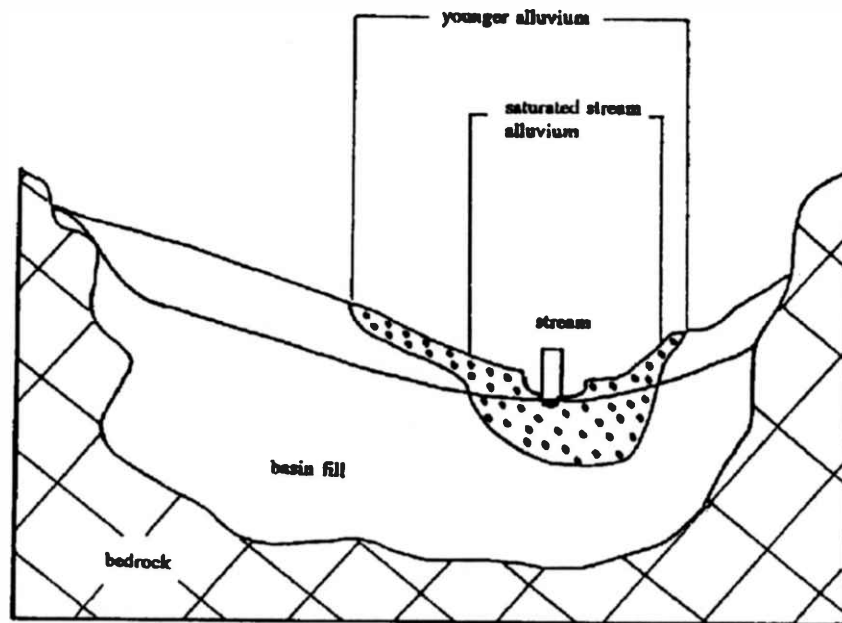
The younger alluvium, in DWR's opinion, is the hydrogeologic feature which most closely represents the subterranean water course of the alluvial valley streams. It is a geologic unit of mostly sand and gravel that was deposited by the stream in recent geologic time, and as such, it is more closely associated with the stream history than the history of the tributary aquifer (DWR, 1993).

From an administrative perspective, DWR also points to several advantages of this method including:

1. relatively easy delineation of *subflow* with reliable techniques,
2. independence from past or future ground water development,
3. basis on observed rather than calculated factors,
4. an end to the adjudication since the boundary will not change with time, and
5. easy implementation within 3 months.

Cartoon of younger alluvium and saturated stream alluvium (cross-sectional view)

Figure 6.4



From a legal standpoint, however, the method is a "controversial path" that DWR avoids. The exact basis for the court's condemnation of the younger alluvium is confusing in itself.

We believe that the trial court's approach is inconsistent with Southwest Cotton. The trial court instructed DWR to apply the 50%/90 day test to all wells located in or near the younger alluvium.

The record shows, however, that in a given area the younger alluvium may stretch from ridge line to ridge line so that all wells in the valley would be in or near the younger alluvium. To say that all of an alluvial valley's wells may be pumping subflow is at odds with Southwest Cotton's statement that subflow is found within or immediately adjacent the streambed (Interlocutory Review, 1993).

(emphasis added)

The validity of the above passage can be questioned in two ways. First, DWR and Gookin Engineers (representing the Gila River Indian Reservation) both point out that the ridge line to ridge line occurrence of the younger alluvium rarely occurs, thus making the court's rejection of the younger alluvium a misleading and unfounded argument. DWR feels that the court may have been confused in its distinction between *younger alluvium*

and the *alluvial valley* since both are used almost interchangeably in the above passage. Second, DWR suggests that the younger alluvium test does not automatically classify all wells within it as depleting *subflow*. This would only be the case where there is a hydraulic connection between the stream and the underlying aquifer (DWR, 1993).

The court's disfavor of the younger alluvium approach seems to be based scientifically on its misunderstanding of the younger alluvium and legally on its interpretation of Southwest Cotton that *subflow* is a "narrow concept." Regardless of how narrow "narrow" is or how Southwest Cotton was actually interpreted to reach this conclusion, the younger alluvium is indeed a "narrow concept" when considered in the big picture of the alluvial basin (see Figure 6.5). Despite the questionable stance of the court, a latter passage in the Interlocutory Review rejects the use of the younger alluvium as a criteria entirely.

Southwest Cotton's concept of subflow added marginally to the statutory definition of water subject to appropriation, but we do not propose to rewrite statute further by broadening the concept of subflow. We believe the trial court's 50%/90 day rule expands the clear words of A.R.S. @ 45-141 (A) to include not only the waters flowing in streams but potentially waters pumped anywhere in the younger alluvium (Interlocutory Review, 1993). (emphasis added)

6.2.2.1 Scientific support for the younger alluvium approach

In defiance of the Interlocutory Review, Stetson Engineers, Gookin Engineers, Leonard Rice Consulting and The Nature Conservancy all support the younger alluvium approach.

Stetson Engineers suggests that the scientific literature of the San Pedro Basin defines the floodplain alluvium in a similar fashion that the court defines *subflow*. Putnam et al. (1988) definition of the floodplain alluvium, which is:

A portion of the surface flow percolates downward into the floodplain alluvium, where it generally flows parallel to the course of the river, although much more slowly than the stream flow is surprising similar to Southwest Cotton which defines *subflow* as

"those waters which slowly find their way through the sand and gravel constituting the bed of the stream, or the lands under or immediately adjacent to the stream, and are themselves a part of the surface stream" (Interlocutory Review, 1993).

Furthermore, the aquifer characteristics of the floodplain alluvium offer practical and appropriate criteria for *subflow* delineation. Besides being geologically unique and stratigraphically above the basin fill aquifer, the floodplain alluvium is easily characterized by its:

1. greater permeability,
2. subsurface flow vector that is nearly parallel to the stream,
3. close proximity to the stream,
4. role as the main provider and recipient of stream recharge and discharge, and
5. surface expression as the inner valley.

Gookin Engineers presents an abbreviated argument which similarly suggests that the floodplain alluvium meets many of the court established criteria. Steve Weatherspoon, attorney to The Nature Conservancy, summed up the arguments by stating

[I]t is clear from all the evidence that the only reasonably acceptable geologic unit by which subflow may be defined is the Holocene³ alluvium by whatever name referred. (Post-hearing Memorandum, 1994)

6.2.2.2 The historical argument -- Kinney's treatise and the recession of the ice age

Although legal research can provide little insight into the recent court's "out-right" rejection of the younger alluvium method, Leonard Rice Consulting presents historically-

³The term holocene alluvium was used to describe the floodplain alluvium in some testimony.

based arguments that shed light on both the scientific and legal contention that the younger alluvium would provide a suitable boundary for *subflow*.

Scientifically, Leonard Rice Consulting recapitulates the idea that the saturated portion of the younger alluvium, referred to as the saturated stream alluvium (Figure 6.4), is readily discernible and provides the only rational and non-arbitrary boundary between the stream and the surrounding alluvium. In other words, it is a physically fixed boundary. Furthermore, it will be easy to delineate using drilling, aerial photography, topographic maps, seismic data, water table maps, phreatophyte presence, and field mapping. This is nothing new. However, in citing Anderson (1985), Leonard Rice Consulting emphasizes that the *history* of the saturated stream alluvium is more closely related to the *history of the stream* than the *history of the surrounding alluvium*.

Geologists recognize that Saturated Stream Alluvium was deposited during and after the wetter period in Arizona associated with the Pleistocene Ice Age. As a result of increased precipitation at the close of the Tertiary Period, streams enlarged and eroded channels into the older Basin Fill sediments. These channels were the bed and banks of the streams at the time. As the Ice Age waned and precipitation levels decreased, the stream were not able to carry the sand and gravel eroded from the surrounding area. This material was deposited in the eroded channel and is known today to geologists as Quaternary Alluvium or Recent Alluvium to denote its age of deposition. In this report this unit is called the Saturated Stream Alluvium (Leonard Rice Consulting, 1993). (emphasis added)

Legally, Leonard Rice Consulting suggests that the saturated stream alluvium approach is supported by both the recent court ruling:

water that "is more closely associated with the stream than the surrounding alluvium" (Interlocutory Review, 1993)

and Southwest Cotton:

"those waters which slowly find their way through the sand and gravel constituting the bed of the stream, or the lands under or immediately adjacent to the stream, and are themselves part of the stream" (Interlocutory Review, 1993).

Similar to Southwest Cotton's definition of *subflow*, the saturated stream alluvium has both a bed and banks.

Leonard Rice Consulting also looks back into history to investigate the basis for Southwest Cotton itself -- the 1912 treatise of Clesson S. Kinney entitled The Law of Irrigation and Water Rights, Second Edition. In his text, Kinney separated ground water into three distinct classes: (1) diffused percolation not tributary to any definite surface or underground body of water, (2) percolating waters tributary to the surface, and (3) subterranean water courses. Kinney further subdivided the final category into *known* and *unknown* courses. Known courses were even further divided into underground courses that were *independent* of a surface stream and those that were *dependent* on a surface stream. This final sub-category (*known subterranean water courses which are dependent on a surface stream*) is where *subflow* exists. Leonard Rice Consulting investigated the section of Kinney's treatise where he discusses this sub-category and included a portion of it in their report.

"The second class of "defined and known" subterranean or underground streams or watercourses, under our classification, are the known and dependent subterranean water courses. These waters are dependent for their supply upon the surface streams, or are the "underflow," "sub-surface flow," "subflow," or "undercurrent," as they are at times called, of surface streams. These waters may be defined as those which slowly find their way through the soil, sand, and gravel constituting the beds of streams, or the lands under and adjacent to the surface streams, and are themselves a part of the surface streams. Those who are acquainted with the water courses in the arid portion of our country know that some of the most important and well-defined beds, channels, banks, and currents of water at least a portion of the year, and there is at all times what is known as the underflow, and they are in every respect natural water courses, to which legal rights may attach. At certain periods of the year water flows on the surface in a well-defined course, and there is at all times what is known as the underflow. This is the broad and deep subterranean volume of water which slowly flows through the sand and gravel underlying the most, if not all, of the streams which traverse the country adjacent to

the mountain systems of the arid region. These underground streams are probably much greater in volume in some cases than the water upon the surface, and are, as far as rights of appropriation or riparian rights are concerned, but a valuable portion of the well-defined surface stream. In fact, it is a common expression used in the West that during part of the season certain streams "flow upside down", that is to say, the rocks and gravel are on top and the water flowing underneath. There is considerable truth in this statement, for at times during the dry season the surfaces of many of them are entirely dry, while underneath their dry surfaces may be found flowing of subterranean water" (Kinney, 1912). (emphasis added)

Albeit the language of the 70 year old treatise is different, Leonard Rice Consulting contends that Kinney's "known dependent subterranean Water Courses" is identical to the saturated stream alluvium.

The Southwest Cotton court adopted much of the ideas elucidated upon by Kinney, including " a channel, consisting of well defined bed and banks and a current of water." However, one of Kinney's main passages that was interpreted by Southwest Cotton does offer a point of extreme confusion.

"These waters, in order to constitute the underground flow of surface streams, must be connected with the stream and strictly confined to the river bottom and moving underground, as was stated in the California case, "in connection with it, and a course within a space reasonably well defined". In other words, the water must be within the bed or the surface stream itself. Otherwise such underground waters must be classified with percolating waters, hereinafter discussed" (Leonard Rice Consulting, 1993). (emphasis added)

Leonard Rice Consulting concludes that Kinney was either in error or that he simply used the wrong terminology. "If Kinney equated 'river bottom' and 'bed of the surface stream' with the bottom of the sand and gravel channels he described [in the previous passage] then there is no error but only confusing terminology" (Leonard Rice Consulting, 1993).

In any event, Southwest Cotton draws heavily from this confusing passage in Kinney's treatise when it states the *subflow* "may be defined as those waters which slowly find their way through the sand and gravel constituting the bed of the stream or the lands under or immediately adjacent to the stream." It also interesting to note that the word immediately (as used by Southwest Cotton in the above passage) is not included in Kinney's original description and was a point of contention during the 1931 court case (Interlocutory Review, 1993). Thus, the recent court's "narrow concept" interpretation of *subflow* is a dubious, though no doubt legitimate, legal precedent.

Regardless of whether Kinney was actually describing the saturated stream alluvium in his treatise, inclusion of his antiquated description starkly uncovers the court's and legislature's failure to keep pace with an issue of unavoidable consequence in a land of little water. In fact, the history of water law in Arizona is so convoluted that Leonard Rice Consulting mistakenly suggests that Southwest Cotton set out to protect ground water users when in fact, the spirit of Southwest Cotton was to do just the opposite.

6.2.3 Other Suggested "Wide Concepts"

The Nature Conservancy suggested four possible "wide" techniques, the first two--Ground-water Flow Field and the Younger Alluvium--have been described earlier in the Modified Flow Net Method section (6.2.1) and Younger Alluvium section (6.2.2), respectively. The other two are: Riparian Habitat, and Water Level Comparisons.

6.2.3.1 Riparian habitat

The Nature Conservancy advocated

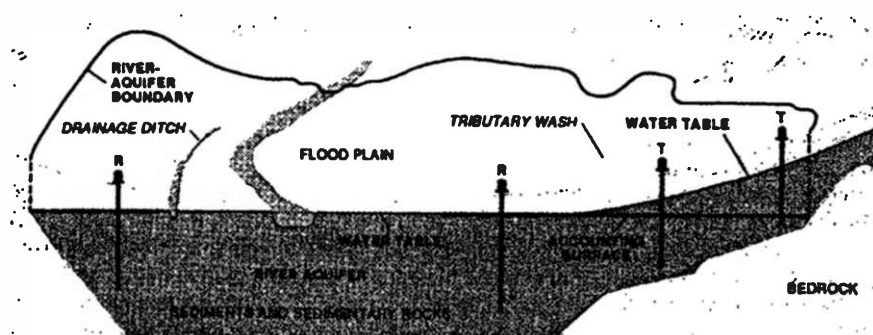
Given that a riparian habitat exists in the vicinity of a stream, the historic outer boundaries of such a habitat would constitute the boundaries of subflow, and any well within those boundaries would be pumping subflow.

Because the Arizona Department of Game and Fish has recently completed riparian mapping, the boundaries of the riparian areas, and therefore *subflow* could be determined from these maps. The problem is, however, that a large portion of the riparian habitats in the Gila has already been disrupted. This methodology would then reflect exclusively current conditions, and if used, the original extent of the riparian area would have to be established.

6.2.3.2 *Water level comparisons*

A methodology developed by the U.S. Geological Survey and the Bureau of Reclamation (Wilson and Owen-Joyce, 1994) is used to identify those wells that yield water that originated from a river. They have applied their technique to the lower Colorado River. An accounting surface is defined as the water table that would exist if the only source of water to the aquifer is the river (Figure 6.5). It runs laterally from bedrock to bedrock. Any aquifer below the accounting surface is called a river aquifer. Any well within the floodplain, no matter what its depth, is assumed to pump the river aquifer and to pump *subflow*. Wells that perforate the aquifer outside the lateral limits of the floodplain with a static (nonpumping) water level at or below the accounting surface are presumed to pump the river aquifer and to pump *subflow*. Wells with static levels above the accounting surface are presumed to be pumping *tributary ground water*.

Schematic cross-section of the river aquifer and accounting surface
(Wilson and Owen-Joyce, 1994)
Figure 6.5

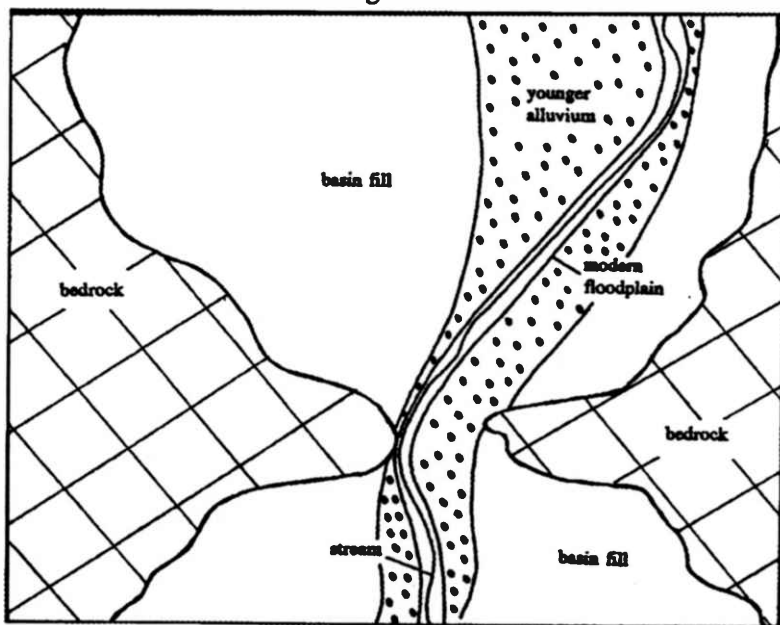


As with any other methodology, implementing the water level method may pose problems. Even though a well has a water level above the stream stage, it could be intercepting stream flow.

6.3 SUBFLOW AS A "NARROW CONCEPT"

Many consider the younger alluvium approach to be an expansive view of *subflow*. Southwest Ground-Water Consultants (representing Gila Valley Irrigation District) suggests that although the deposition of the younger alluvium is closely associated with the history of the stream, the younger alluvium does not correspond to the *present state* of the stream or its *subflow*. Furthermore, the younger alluvium cannot be associated with a *definite* geologic age. It is more desirable to replace words such as "younger" or "recent" with precise geologic terms. In light of this, the *subflow* region should be confined to the recent channel that has formed in the past 8,000 years -- identified by Southwest Ground-Water Consultants as the Holocene Channel (Figure 6.6).

Narrow interpretation -- modern floodplain
Figure 6.6



In an even narrower interpretation of the *subflow* boundary, Montgomery and Associates identifies the following criteria for *subflow* identification, *all of which* must be satisfied for *subflow* to exist. *Subflow* must have :

1. a location immediately adjacent to a perennial or intermittent stream,
2. an occurrence laterally and vertically within the modern floodplain alluvium (excluding area beyond bedrock outcrops),
3. subsurface flow parallel to stream flow,
4. a direct response of subsurface waters to stream stage fluctuation, and
5. similar chemistry to the surface stream.

In response of the Interlocutory Review's mandate that "*subflow* is a narrow concept", the Office of the Attorney General presents an informal argument that the *subflow* boundary should be defined by the 10-year flood (the storm event that has a 10% chance of occurring each year).

Despite the apparent mandate of the recent court ruling for a "narrow" interpretation of *subflow* that is *within and only a part of* the younger alluvium, Leonard Rice Consulting suggests that any boundary established between the outer edge of the saturated stream alluvium and the stream channel cannot be defined using "appropriate criteria." In other words, there is not a fixed hydrogeologic boundary within this region. The modern floodplain is subject to constant geomorphic processes. Arroyo incision and filling-in processes characterize the history of the entire younger alluvium. Finally, all narrow interpretations of *subflow* use the bottom of the younger alluvium as the vertical extent of *subflow*. Leonard Rice Consulting considers it illogical to use the "bed" and not the "banks" of the younger alluvium for identifying *subflow*.

Montgomery and Associates suggestion that *subflow* should be parallel to the surface stream is a criteria that is rarely, if ever, met at the ground and surface water interface. Even in purely natural (or undeveloped) conditions; gaining streams, losing

streams, and bank storage processes all contain a component of flow that moves to or from the stream channel. Furthermore, the infrequent occurrence of wells very close to the stream would necessitate either wide-spread well digging or highly subjective interpretation of water levels from wells located farther away from the stream.

6.4 TIME/ VOLUME APPROACH

If the court is indecisive on what it meant by phrases such as "appropriate criteria," "narrow concept," and "bed of the stream;" the recent ruling directly and unambiguously refutes the "50%/ 90 day test" and any other so-called time/volume analysis. Initially, the Interlocutory Review suggests the type of stream depletion which is considered appropriate.

Thus, if a well is drawing water from the bed of a stream, or from the area immediately adjacent to a stream, and that water is more closely related to the stream than to the surrounding alluvium, as determined by appropriated criteria, the well is directly depleting the stream. If the extent of depletion is measurable and direct, it is appreciable (Interlocutory Review, 1993). (emphasis added) "Direct" is interpreted as meaning immediately, thus ruling out depletion effects that occur over time such as the interception of ground water that would eventually feed the stream. Furthermore,

Southwest Cotton...did not purport to identify subflow in terms of an acceptable amount of stream depletion in a given period of time (Interlocutory Review, 1993).

Aside from the existing legal precedent of Southwest Cotton, the ruling also points out the artificial nature of the time/volume approach.

Furthermore, the actual time and volume elements adopted by the trial court are essentially arbitrary.

Despite the courts direct rejection of the "50%/90 day test" in its recent ruling, DWR continues to advocate the accuracy of a time/volume type approach. If the court would decide that time was a relevant factor for the determination, DWR leaves little

doubt that it would endorse either of two time/volume alternatives. The first alternative would be similar to the "50%/90 day test", namely, a specified rate of stream depletion could be used to delineate *subflow*. In the second alternative, a specified volume of stream depletion could be assigned over a specified time interval; a pumping well depleting over this threshold would be included in the adjudication.

DWR does not deny that either alternative would be artificial and arbitrary to an extent. However, any test will involve a certain degree of arbitrary judgment. In this manner, the Modified Flow Net Approach is not unlike the "50%/90 day test" and perhaps could be called the "45 degree/ *n* day test", (*n* depending on how often water level measurements are made to verify the *subflow* boundary). If it has been said that the Modified Flow Net Approach hints on the main test cited in the recent court ruling: is the subterranean water "more closely associated with the stream than the surrounding alluvium"; then time/volume (or cone of depression) analysis directly matches Southwest Cotton's central test for determining *subflow*:

"The best test which can be applied to determine whether underground waters are as a matter of fact and law part of the surface stream is that there cannot be any abstraction of the water of the underflow without abstracting a corresponding amount from the surface stream, for the reason that the water from the surface stream must necessarily fill the loose, porous material of its bed to the point of complete saturation before there can be any surface flow .

*Not only does [subflow] move along the course of the river, but it percolates from its banks from side to side, and the more abundant the surface water the further will it reach in its percolations on each side. But, considered as strictly a part of the stream, the test is always the same: Does the drawing off the subsurface water tend to diminish appreciably and directly the flow of the surface stream? If it does, it is *subflow*, and subject to the same rules of appropriation as the surface stream itself; if it does not, then, although it may originally come from the waters of such stream, it is not, strictly speaking, a part thereof, but is subject to the rules applying to percolating waters"*
(Interlocutory Review, 1993). (emphasis added)

In this context, Southwest Cotton's definition of *subflow* is not dependent on a physically fixed boundary. Rather, *subflow* only exists if stream water is being "diminish(ed) appreciably and directly" by a pumping well. *Subflow*, like capture, can only exist when a stress is placed on a ground water system. Using this logic, the time/volume approach is the only reasonable solution technique -- with a ground water model being the best tool for the determination (such as was discussed with the San Pedro Basin in chapter 3).

Also, it is important to put Southwest Cotton in historical context. It has alluded many that Southwest Cotton never attempted to defend unlimited ground water pumping at the sake of downstream surface water claims. As shown earlier, the *spirit* (or intent) of Southwest Cotton was to protect surface water use. Within a decade of its passing, changing technology stripped away its *spirit* and left only its words which have been used ever since to condone massive and unregulated ground water development.

Finally, it would be completely preposterous for the Southwest Cotton Court to suggest a time/volume framework for determining *subflow*. The 1931 ruling was made a decade before Theis introduced the time/volume approach for determining stream depletion due to a nearby pumping well. The time-dependent (and delayed) effects of ground water pumping on a nearby stream simply were not known. It would have been omniscient for the court to suggest such a criteria.

6.4.1 . *The Interlocutory Review.*

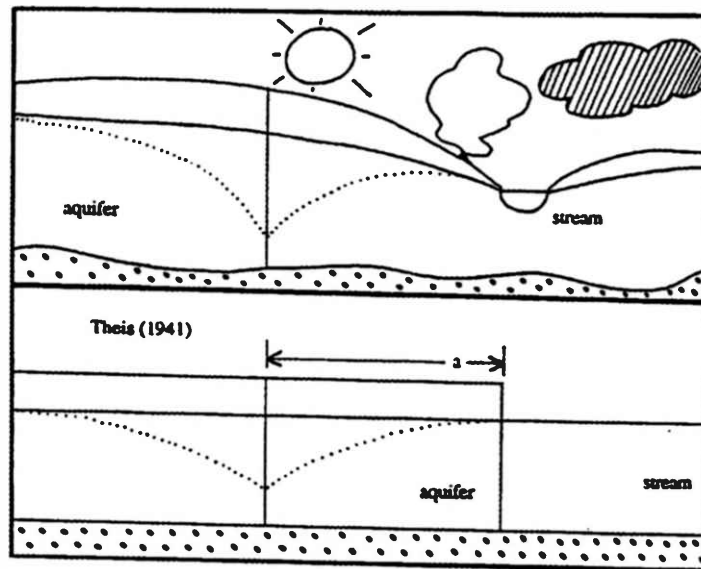
Although the recent court ruling rejects the time/volume approach for defining the actual physical extent of the *subflow* zone (Figure 6.7), the ruling indirectly (and ironically) suggests that it will be the main criteria for determining depletion outside the *subflow* zone.

Stream Depletion] is not an all-or-nothing proposition. For example, if the cone of depression of a well has expanded to the point that it intercepts a stream bed, it almost certainly will be pumping

subflow. At the same time however, it may be drawing water from the surrounding alluvium. Thus, part of its production may be appropriable subflow and part of it may not. Even though only a part of its production is appropriable water, that well should be included in the general adjudication (Interlocutory Review, 1993).

Theis' time/volume model for calculating stream depletion from a nearby pumping well

Figure 6.7



$$\frac{Q_{stream}}{Q_{well}} = \frac{2}{\pi} \int_0^{\frac{\pi}{2}} e^{-k \sec^2 u} du, \text{ where } k = 1.87 \frac{a^2 S}{T t}$$

The suggestion that an expanding cone of depression can be used to determine the amount of depletion implies the use of a time/volume approach, no other method is available.

6.4.2. DWR's View

Given the unambiguous wording in the Interlocutory Review, DWR's suggestion that wells located *outside* the *subflow* zone are exempt from the adjudication ironically defies its self proclaimed *strict interpretation* of the court ruling. However, DWR stance is understandable from an administrative perspective. Undoubtedly, the step of

determining *which and when* wells outside the *subflow* zone deplete appropriable water will be both controversial and time-consuming. In fact, the existence of such a test throws into question the actual need for a physically-defined *subflow* zone. Why not just use this test for all the wells? On the one hand, if an expansive *subflow* zone is adopted, there is little need for a time/volume test. On the other hand, if a time/volume test is used, there is little need to declare an artificial *subflow* zone. One or the other, not both.

Montgomery and Associates also proposes the exclusion of wells (for all time) outside of the *subflow* zone; which, accompanied with its extremely narrow interpretation of the *subflow* boundary, seems to suggest that virtually no wells should fall within the jurisdiction of the adjudication.

6.4.3 Procedure for Including Wells Outside the Subflow Zone

If wells outside the *subflow* zone are going to be included in the adjudication, what should be the procedure for doing so? While Stetson Engineers, Office of the Attorney General, South Pass Resources, and Southwest Ground-Water Consultants all recognize that wells outside the designated zone should be included, only Leonard Rice Consulting presents a detailed procedure for making the determination. After defining the saturated stream alluvium as the *subflow* zone, Leonard Rice Consulting's suggested procedure (Table 6.1) highlights the added complexity involved in this step.

Interestingly, Rice Consulting's method fails to define an actual volume of stream depletion. Instead, a drawdown threshold (of 0.1 foot) is specified at the *subflow* boundary. Again, the arbitrariness of such a threshold is very similar to the artificial nature of the rejected "50%/90 day test". South Pass Resources suggests that the volume of *subflow* can be estimated if the porosity of the *subflow* zone is known. Estimates of *subflow* depletion can then be calculated for the portion of the cone of depression that intercepts the *subflow* zone. Furthermore, if the cone of depression intercepts the opposite stream bank, *subflow* no longer exists. If not a completely ridiculous

proposition, the suggestion does pointedly aim at the importance of defining a fixed *subflow* boundary. However, since *subflow* is an legally fabricated concept, it is largely impossible to define a *fixed subflow boundary* that can actually be hydrologically protected from subsequent ground water pumping.

Leonard Rice Consulting's Procedure for Wells Outside the *Subflow* Zone
Table 6.1

1. Identify the saturated stream alluvium.
2. Exclude all wells outside the *subflow* zone which have a de minimis withdraw rate (as specified by Salt River Project -- 1 acre-foot/year).
3. Identify wells perforated in the saturated stream alluvium. These are automatically included in the adjudication.
4. Delineate the thickness and hydraulic conductivity of any confining layers (based on driller's logs). This will be important for determining if confined wells should be included in the adjudication.
5. Divide wells outside the *subflow* zone into either artesian or unconfined groups.
6. Determine the transmissivity and storativity (or specific yield) of the basin fill.
7. Use Theis' equation for unconfined wells to determine the drawdown at the *subflow* boundary. Given the pumping rate of the well, the time of pumping, well distance from the *subflow* boundary, lateral distance to bedrock, and the transmissivity and storativity of the aquifer; a computer program could be readily developed to do the drawdown calculation. Since drawdown will be the threshold criteria, only basin fill properties will be used in the method.
8. For the more complex case of confined conditions, a modified version of Theis' equation (such as Newman and Witherspoon or Hantush's methods) will be used.
9. Averaging techniques will be applied to wells which do not pump at constant rates. Also, irrigation "return flow" will be subtracted from the total pumped depletion of *subflow*.

6.5 HYDROLOGIC REALITY AND THE RELEVANCE OF TIME

The ultimate message of the recent court ruling is an insidiously subtle denial of protecting appropriable downstream water rights and in-stream flow requirements. On the one hand, the recent court ruling vocalizes a fundamental understanding of the scientific key to controlling stream depletion. The court states that:

(t)hose who argue that the 50%/90 day rule is too narrow suggest that Southwest Cotton's test is very broad. They argue that pumping underground water from a tributary aquifer causes direct stream depletion, either by intercepting water that otherwise would reach the stream or by de-watering an area, thereby inducing water to flow from the stream to fill the void. ... These parties contend that any well pumping from a tributary aquifer is pumping subflow if it causes any measurable stream depletion in a period of one or more decades. Viewed outside the context in which the Southwest Cotton test was formulated, that interpretation is plausible (Interlocutory Review, 1993).

The above passage indirectly describes *capture* -- the key concept to protecting in-stream flows. However, the court finishes the above passage with the following:

Viewed in context, however, it clearly is too expansive for both geographical and time standpoints (Interlocutory Review, 1993).

Thus, Southwest Cotton, and not the protection of downstream water rights, is what *subflow* is based on. Any connection between *subflow* and protecting in-stream flow is purely coincidental. In its recent ruling the court stated that:

it would be a senseless waste to use a flawed presumption for identifying wells pumping subflow" (Interlocutory Review, 1993).

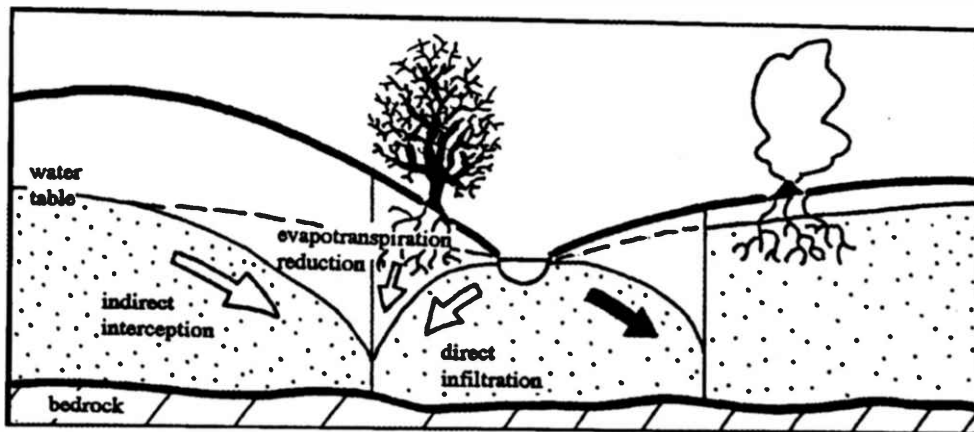
The court implies "senseless", however, only as far as it does not comport to Southwest Cotton, whereas protection of downstream water rights and in-stream flow requirements have little relevance at all. Ironically, Southwest Cotton is the *flawed presumption* and perhaps the above quote would more appropriately embody the hydrologic reason that the "50%/ 90 day test" failed if it were reworded as:

...it would be a senseless waste to use a flawed legal precedent such as Southwest Cotton for identifying wells pumping capture.

Only one mode of capture (out of three) is legally recognized, namely -- direct infiltration away from the stream (or *subflow* zone, Figure 6.8). As discussed in chapter 3, interception of water that would have naturally reached the stream and reduction in evapotranspiration due to water table decline are also occurring, regardless of their legal

un-recognition; ultimately resulting in a commensurate degradation of the riparian system. Even the one legally-recognized mode of stream depletion has been scrutinized. Montgomery and Associates suggests that only a part of direct depletion should be included since the total amount of water taken from the stream is not necessarily pumped to the surface (but instead fills the void left by the cone of depression) and thus should not be entirely included in the adjudication.

Cartoon showing depleted *subflow* to be only a part of total capture
Figure 6.8



In the end, the effectiveness of a *subflow* zone at anything other than re-affirming the words in Southwest Cotton may stigmatize the entire purpose of the adjudication. In a voice that hints at both humor and desperation, the Office of the Attorney General comments on the irrelevance of the line's placement -- "(i)t doesn't matter where they put the *subflow* line so long as they put it *somewhere*" since stream depletion calculations (if done accurately) have nothing to do with its placement. Furthermore, since it is undesirable to wait for individual cones of depression to intersect the *subflow* boundary (unless it is desirable to keep the adjudication open indefinitely), a computer model could be used to assess the impact of a pumping well into the predictable future. Of course, South Pass Resources contends that the use of models (to investigate basin fill wells) has already been refuted by the court.

There seem to be far more *subflow setbacks* than there are *subflow solutions* and undoubtedly it is all too easy to lay bombastic blame on Arizona's persistent adherence to an archaic water law system. In the end, the *best* solution is neither a starry-eyed stroll down the primrose path of legal parochialism nor is it a systematic shut-off of every well in the Gila River system. Rather, capture (the hydrologist's conceptualization) and *subflow* (the legal conceptualization), as contradictory as they appear to be, do share "common ground" in an expansive view of the *subflow* zone. While being far from a perfect solution, an expansive view of *subflow* seems to offer the best collective solution -- scientifically, legally, and administratively. Capture processes will continue, though at a slower rate. Ground water pumping will also continue, though in a more restrictive environment. In the end, the legal and scientific *subflow* squabbles seem to have effectively eclipsed the much larger picture at hand, namely -- a finality to the adjudication.

Chapter 7: Fate of Problem

Summary

On the one hand, determining the extent of *subflow* is only a small part of the on-going Gila River General Adjudication. On the other hand, it is the link which connects Arizona law to its past and future. Not only does it hold the historical key to understanding how Arizona's archaic bifurcated water law system has been perpetuated into the present, it also offers the opportunity to confront this past so that the future goals of the adjudication can be met.

7.1 SEARCHING FOR SUBFLOW

Five years after the Southwest Cotton ruling, Arizona engineer G.E.P. Smith wrote:

There is an unfortunate aspect connected with litigation over trivial quantities of water, besides the high cost of the litigants. If the evolution of groundwater law in all its details is to come about through court decisions, it is better that cases concerning important water supplies should be before the court, so that there may be as a background a knowledge of the groundwater regimen in broad phases and both sides of the case may be thoroughly presented. In important cases, if the details of the picture are not known, it is feasible to make expenditures in the field to ascertain physical conditions. Trivial cases end as they begin, wrapped in surmise (Smith, 1936).

Although Southwest Cotton may not have involved trivial quantities of water at the time, Chapter 4 examined how the ruling had become *trivialized* within a decade of its passing, partly due to the poor decision-making of the Southwest Cotton court but mostly due to the changing technological environment that enabled massive ground water pumping shortly after its passing. The inappropriateness of the Southwest Cotton ruling for the situation Arizona faces today cannot be understated; especially in light of the fact

that the ruling never even confronted the classic water dispute of the West: namely, a *senior surface water claim* being depleted by *upstream junior ground water pumping*. Given the logic employed by the Southwest Cotton court back in 1931, such a reversal would have undoubtedly resulted in a different ruling.

The importance of this is highlighted by comparing Southwest Cotton to the Proctor v. Pima Farms Company (1926) ruling which occurred just 5 years prior to Southwest Cotton and 7 years after the enactment of Arizona's 1919 water code. This timing was especially important. Not only was it the first case to deal with the *extent of appropriable water* under the new code, it was the ruling that should have served as a precedent for Southwest Cotton. In Pima Farms, the court supported an *expansive* view of appropriable ground water. The case, however, was unique from Southwest Cotton in two very important ways: (1) both parties agreed at the onset of the trial that the water they were pumping near the Santa Cruz river was a "known independent subterranean stream" and (2) neither party was relying directly on surface water diversion. The irony is that because both parties accepted the notion (without question) that the underground stream indeed existed, the court was not required to indulge its time in a futile search for the "bed and banks" of the underground channel; nor was the court inclined to since neither litigant was diverting surface water -- the form of water that was considered economically desirable to ground water at the time. They simply assumed that the appropriable ground water existed. On the other hand, Southwest Cotton did just the opposite. It used the absence of ascertainable "bed and banks" to suggest that the ground water in question was not appropriable. The key point is that the "bed and banks" were never found in either case, yet Proctor v. Pima Farms and Southwest Cotton each came up with exact opposite rulings concerning its existence. Arizona has continued the search during the Gila River General Adjudication, spending over five years on this frustrating endeavor alone. At times, it seemed that the closest Arizona would ever come to finding

the "bed and banks" of appropriable ground water would be in the minds of the Proctor v. Pima Farms Company litigants, and they died with the secret many years ago.

Because the Gila River system comprises the southern two-thirds of Arizona, the Gila River General Adjudication does not involve *trivial quantities* of water -- making it an ideal forum for resolving the issue of *subflow*. Undoubtedly, the process has resulted in a voluminous investigation of both hydrogeology and water law and involved a large financial commitment by many concerned with its outcome.

7.2 FINDING SUBFLOW: JUDGE GOODFARB'S NEW SUBFLOW RULING

Judge Goodfarb officially found *subflow* on June 30, 1994. In what many considered to be an expansive interpretation (perhaps reminiscent of the Proctor v. Pima Farms decision), Judge Goodfarb ruled that *subflow* is defined by the "saturated floodplain Holocene alluvium" -- a very close adaptation of the "saturated stream alluvium" discussed in Chapter 6. More specifically, the new *subflow* zone is defined by the following criteria (which are listed in the conclusion of his ruling, Goodfarb, 1994):

1. *A "subflow" zone is adjacent and beneath a perennial or intermittent stream and not an ephemeral stream.*
2. *There must be a hydraulic connection to the stream from the saturated "subflow" zone.*
3. *Even though there may be a hydraulic connection between the stream and its floodplain alluvium to an adjacent tributary aquifer or basin-fill aquifer, neither of the latter two or any part of them may be part of the "subflow" zone.*
4. *That part of the floodplain alluvium which qualifies as a "subflow," beneath and adjacent to the stream, must be that part of the geologic unit where the flow direction, the water level elevations, the gradations of the water level elevations and the chemical composition of the water in that particular reach of the stream are substantially the same as the water level, elevation and gradient of the stream.*
5. *That part of the floodplain alluvium which qualifies as a "subflow" zone must also be where the pressure of side recharge from adjacent tributary aquifer or basin fill is so reduced that it has no significant effect on the flow direction of the floodplain alluvium (i.e., a 200-foot setback from connecting tributary aquifers and a 100-foot setback from the basin-fill deposits).*
6. *Riparian vegetation may be useful in marking the lateral limits of the "subflow" zone particularly where there is observable seasonal and/or diurnal variations in stream flow caused by transpiration.*

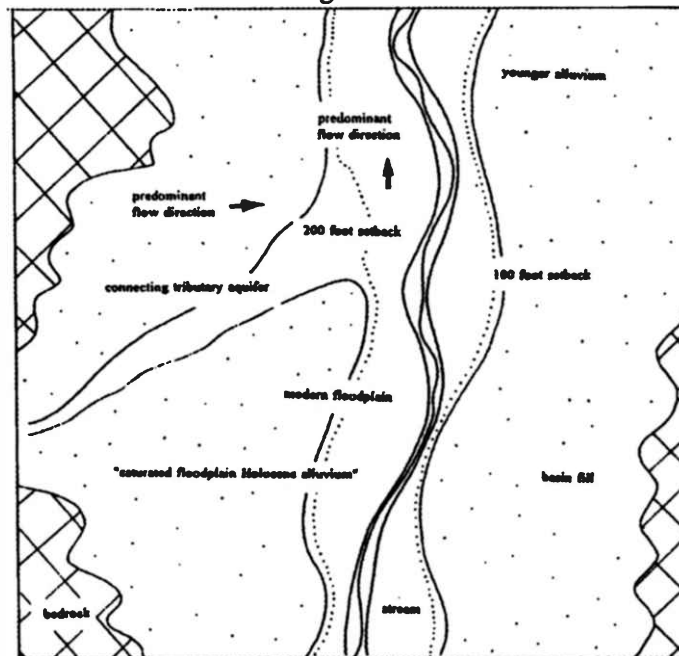
However, riparian vegetation on alluvium of a tributary aquifer or basin fill cannot extend the limits of the "subflow" zone outside of the lateral limits of the saturated floodplain Holocene alluvium.

7. All wells located in the lateral limits of the "subflow" zone are subject to the jurisdiction of this adjudication no matter how deep or where these perforations are located. However, if the well owners prove that perforations are below an impervious formation which preclude "drawdown" from the floodplain alluvium, then that well will be treated as outside the "subflow" zone.

8. No well located outside the lateral limits of the "subflow" zone will be included in the jurisdiction of the adjudication unless the "cone of depression" caused by its pumping has now extended to a point where it reaches an adjacent "subflow" zone, and by continual pumping will cause a loss of such "subflow" as to affect the quantity of the stream.

A cartoon of the "saturated floodplain Holocene alluvium" is shown in figure 7.1

Cartoon of "saturated floodplain Holocene alluvium"
Figure 7.1



Because the 1993 Interlocutory Review suggested that *subflow* is a "narrow concept," Judge Goodfarb's expansive outlook of the *subflow* zone surprised many. An even bigger surprise, however, is the fact the new line is almost identical to the old "50%/90 day" line. If one recalls from Chapter 2, the "50%/90 day test" was devised to meet Halpenny's original recommendation that wells in the younger alluvium are likely to be depleting stream water and thus should be included in the adjudication.

7.2.1 The Process: Ends v. Means

If the ends is the same, the means of arriving at this ends is a dramatic departure from the "50%/90 day test." In the opening of the new ruling, Judge Goodfarb cautions the reader to anticipate a lengthy ruling. True to his word, he meticulously documents the entire 1994 evidentiary hearing and then proceeds with a step-by-step analysis of each proposed *subflow* solution. His desire to include all the evidence used in his decision-making-process is explained in the opening statement of the conclusion.

The issues here are geologically, hydrologically and factually complex. While the courts often deal with complex issues, reviewing appellate courts sometimes are unable to glean from the briefs little more than a summary of the complex evidentiary background and the scientific principles which led to the trial court's decision. To overcome this limitation in this proceeding, this Court believes it has a duty to provide as much detail as it can to explain the factual decisions made, the scientific principles relied on, as well as to provide copies of many of the exhibits considered.

In contrast, Judge Goodfarb points out that the "50%/90 day test" ruling was virtually devoid of an evidentiary record explaining how the decision was made, despite the fact that evidentiary hearings in 1987 were held specifically for this reason. More importantly, however, the 1987 evidentiary hearings naively focused on the general relationship between ground and surface waters, never once even considering the legal concept of *subflow* and its applicability to the adjudication. So when certain well owners challenged the "50%/90 day test" on the basis that their wells were not pumping *subflow* and therefore should not be included in the adjudication, it was inevitable that the "50%/90 day" ruling would fail. Not only did it lack an evidentiary record, it never even considered the significance of the legal precedents defining *subflow*.

If the "50%/90 day test" failed because of its misguided attempt to fit science into law, Judge Goodfarb was cautious not to make the same mistake twice. In the new decision he does just the opposite; carefully adapting the *law to fit into science* in a two-step process.

His first step requires the surgical removal of a false statement from the 1993 Interlocutory Review. As discussed in Chapter 6, the statement:

(t)he record shows, however, that in a given area the younger alluvium may stretch from ridgeline to ridgeline so that all wells in the valley would be in or near the younger alluvium (Interlocutory Review, 1993)

was especially problematic because it seemed to rule out any method relying on the younger alluvium based on a statement that was both incorrect and completely unsubstantiated. Judge Goodfarb uses testimony from the 1994 evidentiary hearings to convincingly challenge and then refute the statement.

After this removal, Judge Goodfarb's second step is simply to massage the law to fit into science. He uses testimony in the 1994 evidentiary hearings to support each aspect of his argument. Before embarking on his step-by-step analysis of each *subflow* solution, he carefully explains the logic he will use as follows:

The only logical and rational way the "Southwest Cotton" and [Interlocutory Review] theories [of] subflow can be made consistent with the scientific principles testified [in the evidentiary hearings] is to turn to the tests ... where the Supreme Court urged of flow direction, elevation, gradient, and chemical composition.

...

If we add to those tests the concept that if a "subflow" zone can be differentiated from adjacent geologic units such as tributary aquifers and the basin-fill aquifer which discharges into it or receive discharge from it, a set of principles can be developed to define "subflow" and still be consistent with "Southwest Cotton" and science.

In other words, he was looking to simplifying the process by identifying a distinct geologic unit which meets all the tests mentioned for finding *subflow* (in Southwest Cotton and the 1993 Interlocutory Review) as opposed to attempting to find *subflow* by using any single test. Judge Goodfarb determines that the "saturated floodplain Holocene alluvium" is the only such geologic zone. It is the only distinct and stable zone which can

comport to a series of tests based on water level, gradient, flow direction, and chemical composition.

7.2.2. Wells Outside The Subflow Zone

In accordance to the views stated in the 1993 Interlocutory Review, Judge Goodfarb re-affirms the position that wells located outside the *subflow* zone can be included in the adjudication. He rules that stream depletion begins when the cone of depression intercepts the *subflow* zone, even though it may be "some time before the hydraulic gradient at the river is reversed, and it may be many years before a particle travels from the stream to the well." He summarizes his ruling on wells located outside of the *subflow* zone in the eighth and final point of the conclusion.

8. No well located outside the lateral limits of the "subflow" zone will be included in the jurisdiction of the adjudication unless the "cone of depression" caused by its pumping has now extended to a point where it reaches an adjacent "subflow" zone, and by continual pumping will cause a loss of such "subflow" as to affect the quantity of the stream. (emphasis added)

Other than mentioning that Salt River Project's proposed 0.1 foot drawdown criteria would be difficult to implement and that there is a general consensus that technical methods do exist for determining the extent of individual cones of depression, Judge Goodfarb leaves it up to the Arizona Department of Water Resources to determine a reliable and cost-effective method.

While it was mentioned earlier that the end result of the new *subflow* boundary was essentially the same as the old "50%/90 day " line, the inclusion of a cone of depression test potentially expands the reach of *subflow* to any well in the alluvial valley. Also, while it certainly adds accuracy, it does so by an increase in complexity. Defining the geographic extent of *subflow* is extremely easier than determining *when and how much* wells outside the zone deplete appropriable water.

7.3 DO OTHER ALTERNATIVES EXIST?

As discussed at the end of Chapter 6 (which was written several months prior to the ruling), it was mentioned that capture and *subflow* do share common ground in an expansive view of *subflow*. Judge Goodfarb's "saturated floodplain Holocene alluvium" *subflow* method is appealing for three reasons. Legally, it comports to precedents established in Southwest Cotton and re-iterated in the 1993 Interlocutory Review. Scientifically, it defines an expansive *subflow* zone which even includes some wells located outside of the younger alluvium, thus retarding capture processes and protecting in-stream rights. Administratively, the *subflow* zone is relatively easy to define (although difficulty may be encountered in implementing a cone of depression test for wells outside the *subflow* zone).

Judge Goodfarb has not discovered the unique solution of *subflow*. Other *subflow* solutions can be found by emphasizing different legal passages and scientific methods. For example, another effective solution -- legally, scientifically, and administratively -- may be in the use of numeric ground water models.

From a legal perspective, the primary test described in Southwest Cotton:

"The best test which can be applied to determine whether underground waters are as a matter of fact and law part of the surface stream is that there cannot be any abstraction of the water of the underflow without abstracting a corresponding amount from the surface stream (T)he test is always the same: Does the drawing off the subsurface water tend to diminish appreciably and directly the flow of the surface stream? If it does, it is subflow ..." (Interlocutory Review, 1993),

can only be performed with a ground water model. Although no tool was available to make this measurement in 1931, the development of ground water models has made this both a practical and accurate test today. Additionally, the test offers a unique solution. Ground water models are the only tool capable of conducting such a test and unlike other vague criteria mentioned in Southwest Cotton and the Interlocutory Review (such as "bed and banks," "narrow interpretation," and "more closely associated with the stream than the

surrounding alluvium"), the test clearly spells-out the extent of appropriable waters. The test makes absolutely no mention of a geographic zone -- all that the test hinges on is whether a ground water withdrawal will result in a corresponding diminishment of surface flow.

Scientifically, this test is appealing because it touches on the key concept of capture. Whereas the "saturated floodplain Holocene alluvium" defines *subflow* to be a *physical entity* rooted in time, the test describes *subflow* to be a process which changes over time. In fact, the existence of the test seems to trivialize any need at all for a geographical *subflow* zone since the process has absolutely nothing to do with an artificially-drawn legal line.

Administratively, the use of ground water models can facilitate a reliable estimate of *when and how much* each well (or group of wells) depletes appropriable water. The only point of ambiguity in the test revolves around the precise meaning of *appreciably* and *directly* in:

Does the drawing off the subsurface water tend to diminish appreciably and directly the flow of the surface stream? (emphasis added)

As already discussed in the preceding chapters, these two words have been used to support the argument that only direct infiltration from the stream constitutes appropriable water; thus leaving out both the indirect interception of water that would have eventually fed the stream (over time) and a reduction in stream-side evapotranspiration (which degrades the surrounding riparian habitat). The beauty of using ground water models is that this ambiguity is largely irrelevant. Ground-water models can differentiate between all three forms of *capture* (direct infiltration, indirect interception, and reduced evapotranspiration). Even if it is determined that only direct infiltration is appropriable, it can be separately calculated for while simultaneously observing the effect of total capture on the system -- a calculation that will undoubtedly be invaluable for protecting federally reserved claims, regardless of the fate of Arizona's bifurcated water law system.

Although it is undeniably true that "law is never a good surrogate for fact," it is with considerable more ease that we recognize the existence of *bad law* than we are capable of changing it. Judge Goodfarb has succeeded in both recognizing and changing bad law. The use of ground water models can, if used properly, help re-unite even further the divergent paths that Arizona law and science have taken at the river's edge.

7.4 GOALS OF THE ADJUDICATION

The same bifocals that Arizona has been prescribed in order to clearly see *subflow* may have blurred the larger focus of the adjudication. As discussed in chapter 2, the Gila River General Adjudication can be defined by three *prioritized* objectives. The long range goal is:

(1) to quantify federally reserved Indian water rights within the Gila River system.

Although it certainly is not in the interest of the state to relinquish semi-precious water to Indian tribes, it is also not desirable to perpetuate the "uncertainty" associated with un-quantified Indian claims -- claims that the federal government is resolute on settling itself if the state decides to take no action. The McCarran Amendment does give the states a "first shot" at quantifying the claims. However, the amendment explicitly states that federal water rights cannot be singled out by themselves. They can only be quantified as part of a general stream adjudication. So in order to quantify federally reserved Indian water rights, Arizona was essentially required to enact the Gila River General adjudication; the purpose of which is:

(2) to prioritize all appropriable waters in the Gila River system (including all federally reserved rights).

Although the state may run the adjudication, the McCarran Amendment limits the state to a *comprehensive* adjudication -- meaning that federal claims are still protected under federal statutes (such as Cappaert v. US) which recognize the hydrologic reality that downstream federal surface water claims should be protected from subsequent ground-

water pumping (Leshy and Belanger, 1988). Arizona's bifurcated water law system recognizes no such connectedness. Instead, the extent of state appropriable water is defined by an artificially-fabricated legal line, beyond which waters are considered non-appropriable -- or governed under private property statutes. Thus, in order for Arizona to prioritize all appropriable waters within the Gila River system, it became necessary:

(3) to identify the extent that appropriable water extends into the ground water zone.

The key point is that the placement of the *subflow* zone (no matter how narrow or how expansive) should, in principle, only apply to state-established water claims and should have absolutely no effect on federally-protected surface water claims. In order to meet this requirement while simultaneously keeping its bifurcated water code intact, Arizona adopted a two-tiered adjudication in which:

(a) federal statutes will apply to sub-areas which contain any federal claims, and

(b) state statutes will apply to sub-areas which contain only state claims.

In reality, the efficacy of the two-tiered system seems hopelessly dependent on the hydrologic fiction that water will somehow obey artificially drawn lines. It really does not matter where any of these lines are drawn (whether between appropriable and non-appropriable waters or between federal and non-federal sub-areas) since pumping anywhere in the alluvial valley may potentially diminish in-stream flow.

The beauty of Judge Goodfarb's "saturated floodplain Holocene alluvium" *subflow* ruling is that it avoids this fate. It satisfies both state and federal laws. During the *subflow*-process, this dual requirement seemed destined to fail -- foreshadowing the eventual intervention of the federal government. Judge Goodfarb makes no mention of this ulterior motive in his ruling. Ostensibly, he roots his decision purely in state-established legal precedent. However, the rejection of the "50%/90 day test" may have taught Judge Goodfarb to view the adjudication from a broader perspective. Just as bad decisions (such as the "50%/90 day test") can be challenged on the state level, subsequent bad decisions can also be challenged on the federal level. The "saturated floodplain

Holocene alluvium" *subflow* solution, whether intentionally or coincidentally, seems to successfully avoid both scenarios.

On the level of the court, Judge Goodfarb's ruling seems to be appeal-proof. By assigning a relatively expansive boundary, the "saturated floodplain Holocene alluvium" indirectly comports to federal statutes which recognize that downstream surface water rights should be protected from subsequent upstream pumping. By rooting his decision in state-established legal precedents, it will be difficult for state water users to de-validate the new *subflow* ruling. However, two questions remain. First, if the issue is appeal-proof on the level of the court, will the issue finally find its way to the state legislature? Second, in the 8th and final point of his decision, Judge Goodfarb seems to suggest that only wells with cones of depressions which have "now extended to a point where (they have reached) an adjacent '*subflow* zone'" should be included in the adjudication. Does this mean that wells that do so in the future will not be included?

7.5 QUEST FOR A FINALITY

If the Indian suits of the mid-1970s sparked the need for an adjudication, the winds of uncertainty concerning un-quantified tribal water rights have fueled the blaze. The reason for this uncertainty is that tribal water rights are exempt from the traditional tenant of the law of prior appropriation which states that a non-use of a water right (toward a beneficial purpose) implies a forfeiture of that right. Furthermore, the Winters Doctrine of 1908 holds that when the federal government established a reservation, it did so with the implicit intent of guaranteeing the tribe with enough resources (including water) to fulfill the purposes of the reservation. Up until 1963, the exact quantity of water this entailed remained unspecified, and, given the political environment up until that time, largely neglected. However, in the 1963 Arizona v. California Supreme Court ruling, federally reserved Indian water rights became officially quantified under a "Practically Irrigable Acreage" (PIA) methodology which, in essence, awarded the Indian tribes of the West

with enough water to irrigate all Irrigable land on their reservations. Non-Indian interest-groups' displeasure with the PIA standard is not surprising, considering the sizable chunk of a dwindling resource that it is now obliged to relinquish to Western tribes. Under an appeal filed by several Western states, the court narrowly upheld the PIA standard of quantification in a 4-4 split decision in 1989.

The past three decades have marked a conspicuous change in water management in the West. Tribal litigation, backed by federal force and finance, has required all Western states, including Arizona, to both relinquish water and re-think how its remaining water should be managed. Though litigation can potentially award a seemingly bountiful supply of water to the tribes, courtroom-wrought decrees most often yield an abundance of hypothetical "paper water", as opposed to "wet water." Because tribes tend to lack both the infrastructure and financial resources needed to convert the paper prize into wet currency, litigation is more efficiently used as a bargaining chip for reaching *negotiated* agreements with non-Indians. Negotiated agreements usually result in a reduction of PIA-awarded "paper water" in return for both "wet water" and financial support to develop water projects. In return, non-Indians hopefully end the uncertainty that lingers with unquantified tribal water rights.

In the new West, there has also been a gradual shift from large-scale water reclamation to less-grandiose water preservation. It has become increasingly more apparent that *high consumption/low production* uses of water are poorly suited for a semi-arid land of finite water resources. The end result of the Gila River General Adjudication will most likely be some sort of negotiated agreement. The quantification of federally reserved Indian water rights, assuming that it is accurately done, will provide the tribes with a bargaining chip at the *Gila River system bargaining table*. All parties at the table should keep two key questions in mind: (1) how much water does each party use? and (2) to what economic ends is it put? Relevant economic questions will be tantamount to equitable distribution and efficient use of the resource among all users; including: what

will be the future of irrigated agriculture in the state? and how can water markets benefit Indians and non-Indians alike?

The real question may be *how final* is final? The Supreme Court's recent divided decision on the PIA standard was certainly not a strong re-affirmation -- perhaps suggestive that a slight change in the court could result in a conspicuously different ruling. Although the split decision did not ostensible change anything, it may have invoked a sense of urgency for litigating tribes. In other words, if the tribes truly want to get the water, perhaps it is best to finalize their water claims now while the *uncertainty* is still great and the non-Indians are still willing to bargain.

The same finality that ends *non-Indian uncertainty* may only be the beginning of even greater *Indian uncertainty*. Undoubtedly, a finality will flood tribal fields with both water and self-responsibility; a fate which, perhaps after all was the whole idea behind the Winter's Doctrine to begin with.

For more about tribal water rights in the West, refer to Indian Water in the New West (1993) edited by Thomas R. McGuire, William B. Lord, and Mary G. Wallace and Indian Water Rights: Negotiating the Future by Elizabeth Checchio and Bonnie G. Colby.

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Appendix A

Science of Problem

Analytical Solutions which Account for Streams which on Partially Penetrates an Aquifer

Elimination of every simplifying assumption is not possible. Mathematically, assumptions are necessary in order to simplify naturally chaotic systems. Thus, the key in applying any simplified model lies in evaluating the degree in which each assumption is satisfied in the field. Some assumptions are too "far-fetched" to ignore. A stream which fully penetrates an aquifer is such an assumption. This condition is rarely satisfied in the alluvial valleys of the American Southwest.

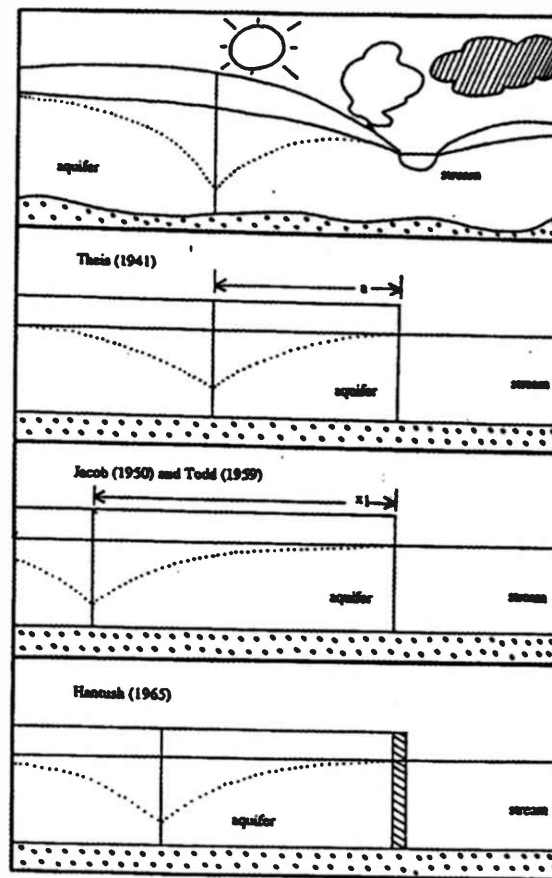
Jacob (1950) developed analytical solutions to compensate for this by artificially extending the distance between the stream and the well. As shown in Figure A.1, the actual field distance " α " between the pumping well and the stream was replaced with an extended effective distance " x ." The effective distance was determined empirically with aquifer test (or pump test) data from observation wells for each individual pumping well employing methods described by Kazmann (1948) and Hantush (1959). In order to determine the effective distance, the well must be pumped and water level measurements must be taken in the pumping well and observation wells over time. As shown in figure A.1, the depth of the stream does not change. It still fully penetrates the underlying aquifer.

Hantush (1965) found that the addition of an effective distance could result in significant stream depletion miscalculations. As already explained in Theis' original model, the pumping well will discharge water from two possible sources: ground water storage and direct streambed infiltration. By increasing the distance between the stream and the well, the aquifer is artificially "stretched", resulting in an increase of ground water storage.

Thus, the model of Jacob *over-estimates* ground water storage and *under-estimates* direct streambed infiltration.

As shown in Figure A.1, Hantush accounted for this miscalculation by adding a semi-pervious layer between the stream and the aquifer and reducing the effective distance. Once again, the stream still fully penetrates the aquifer. However, the addition of the vertical, semi-permeable layer acts as a clogging layer between the stream and the aquifer so that the effective distance can be shortened, subsequently resulting in a closer approximation of real conditions.

Model conceptualizations of a stream-aquifer system
Figure A.1



In 1965, Hantush added to the solution so that the same vertical, semi-permeable layer could account for both partial penetration of the stream and for streambed resistance.

The permeability of the streambed can oftentimes be an order of magnitude less than the permeability of the aquifer.

Despite an increase in hydrologic accuracy, the solutions presented by Jacob, Todd, and Hantush are difficult to implement on an administrative level. The solutions are dependent on pump test analysis for each pumping well that require tedious and time-consuming data collection from multiple observation wells.

Appendix B

Law of Problem

Process for Determining Wells which Deplete Appropriable Water

Although the system-wide approach for finding subflow received the most support in the Interlocutory Review, the well-by-well analysis suggested by some water users highlights the conflict between water users.

B.1 WELL-BY-WELL ANALYSIS

Slight variations of the well-by-well analysis are argued by Certain Groundwater Users (CGU), Verde Valley Water Users, and Gila Valley Irrigation District and others.

CGU point out that a system-wide technical test has already failed and that a continued reliance on artificial lines formulated by DWR will drag the adjudication along indefinitely. The court-ordered right for claimants to file "objections" seems to be the trump card of this argument, and rightly so. The Rules for the Proceedings before the Special Master (1992) states that

any claimant may file with the court or the master written objections to the report or any part of the report (meaning the HSR) ... those parts of the report with respect to which written objections have been timely filed shall not be admitted into evidence until such time as each claimant who has filed written objections ... shall have had a fair and reasonable opportunity to contest the validity of admissibility of the parts of the report to which his objections were directed.

From this perspective, the HSRs' (1990, 1992) are rendered useless since, in a well-by-well trial setting, they stand to be changed after each court ruling. Thus, the court should determine the criteria itself by picking adversarial cases and trying them. Although it may take several trials, the court will be ensured a record for identifying *subflow*; a

record that could eventually, hypothetically, be used as a predictive tool. Thus, the well-by-well analysis is purely a legal approach that would be handled in a courtroom setting.

How about the evidentiary hearings? If everything is handled in the court, there is no need for general hearings. How about the DWR? CGU contends that DWR has, and always should be, nothing more than a technical advisor to the court and should not be responsible for developing any technical methods. In order to expedite the entire process, DWR could continue to collect data (and catalog it) while the adversarial trials simultaneously proceed. Finally, it can only be assumed that res judica ("what is done cannot be undone") will apply to issues already litigated between parties.

Gila Valley Irrigation district (GVID) and others agree with CGU that no more evidentiary hearings are needed, another system-wide technical test will be inappropriate, and the HSR should just be a compilation of data. They also agree with CGU that the supreme court entrusted the development of "system wide guidelines" to the court and special master of the adjudication. However, it will be DWR's responsibility to enforce and enact the "guidelines" on a site-by-site basis.

As in any sort of legal arena, 'wording' become an object of both scrutiny and controversy. The Apache tribe repeatedly objects that "guidelines" will result in a chaotic adjudication and that the court must develop a "definitive set of criteria." According to GVID, the Apache Tribes' insistence that the court must develop definitive criteria is a misinterpretation of the Interlocutory Review passage which states that "the present record allows neither the trial court nor us to identify a *definitive set of criteria*." Furthermore, GVID suggests it is impossible to develop anything but a general set of criteria that can be used by DWR and the special master in specific court cases on a site-by-site basis. Only after the full range of geologic and hydrologic cases have been tried will any sort of definitive set of criteria be developed.

B.2 SYSTEM-WIDE APPROACH

The system-wide approach is based on pre-determining a set of criteria that can then be used to classify all wells with the intent of avoiding litigation in a courtroom setting as much as possible.

Salt River Project (SRP) not only disagrees with CGU's assumption that a system-wide technical test and the HSRs' were both rendered inoperative by the Interlocutory Review, they contend it is DWR's statutory obligation to make and enact the criteria. Even though the "50/90 rule" failed, the process was upheld. Furthermore, since use of a flawed test will "exacerbate an already lengthy and costly process", any objections are premature until a new HSR is submitted since it will be the HSR that the objections must be filed against.

SRP and other parties also contend that DWR's new criteria will provide clear and convincing evidence that a well is (or is not) pumping *subflow*; with the burden of refuting the presumption placed on the well owner. CGU points out this is not the court's intent as stated in the Interlocutory Review as follows:

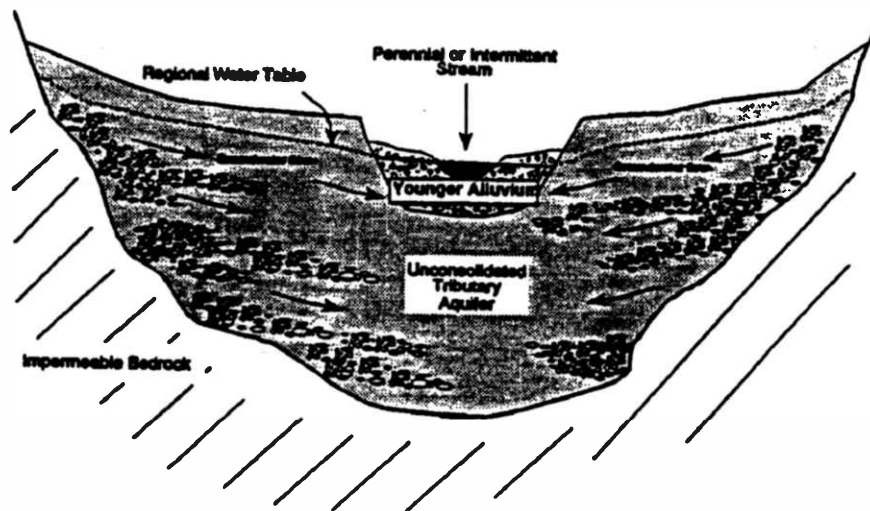
if DWR uses the proper test and relies on appropriate criteria for determining whether a well meets the test, its determination that a well is pumping subflow constitutes clear and convincing evidence.

The existence of *subflow* must be proved on "clear and convincing evidence", however, the same does not apply to *tributary flow*. In other words, innocent until proven *subflow*.

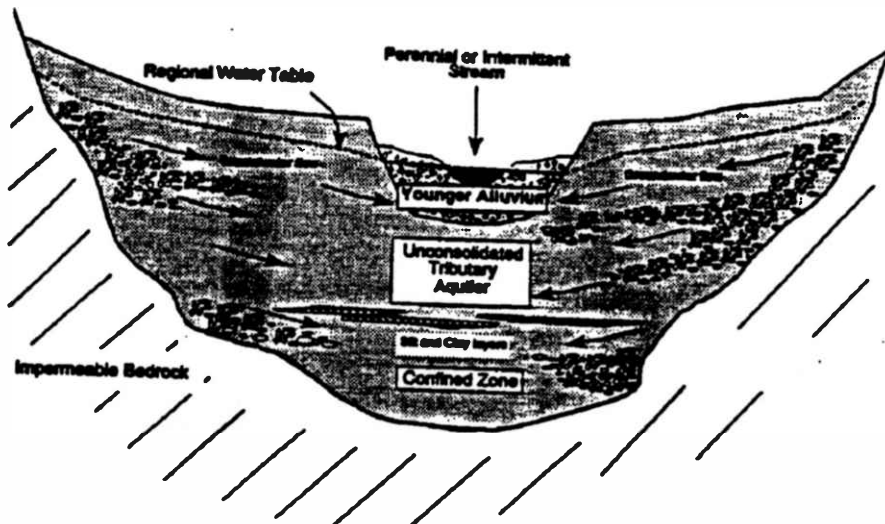
The system-wide approach is broken down into two steps: (a) identifying *subflow* and (b) determining which wells are "directly and appreciably" depleting appropriable water (both streamflow and *subflow*). SRP contends that the "definitive set of criteria" will transcend local geologic and hydrologic variations by giving "different criteria more or less emphasis". Indeed, this idea parallels the path taken by DWR in its November 5, 1993 briefing in which it outlined four unique physical environments in which different criteria will be given more or less emphasis: including, (1) alluvial valley streams, (2) alluvial

valley streams with confined zones, (3) bedrock canyon streams, and (4) mountain front streams (Figures B.1- B.4).

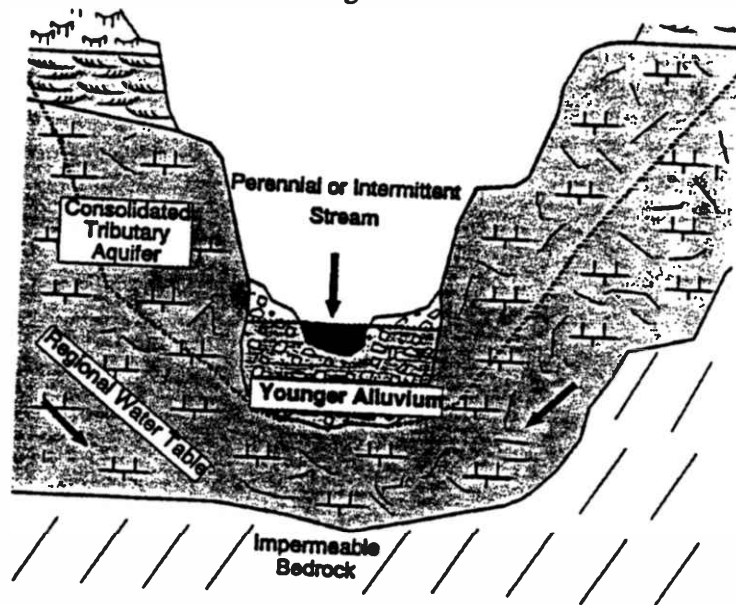
alluvial valley stream
Figure B.1



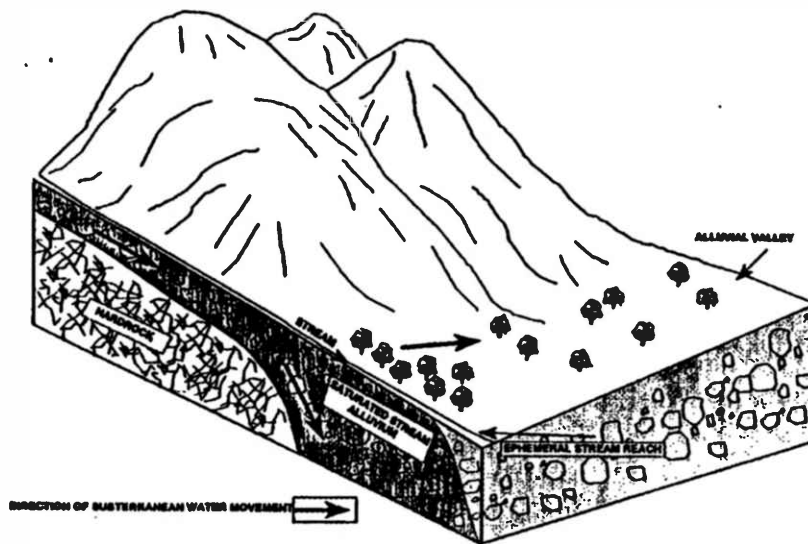
alluvial valley stream with confining layer
Figure B.2



bedrock canyon
Figure B.3



mountain-front stream
Figure B.4



In the system wide approach, DWR will run the show. They will determine the criteria, how to apply the criteria, and ultimately classify all wells in the Gila Watershed. However, evidentiary hearings are necessary before all else: partly to flesh out legal ambiguities inherent in both Southwest Cotton and the Interlocutory Review, and partly to cross-examine, modify, and verify the method developed and adopted by DWR.

However, doubts still exist among many regarding the institutional and physical resources available within DWR to undertake such a monumental task.

A final controversy surrounds the SRP's inclusion of representative wells in its September 24, 1993 briefing's appendices (as shown in table B.1). SRP contends that the representative wells (all of which are contained in the San Pedro Basin) could be used by DWR to develop the "definitive set of criteria" necessary for determining the *subflow* region. Magma Copper Company argues that the wells are predominantly domestic wells owned by claimants who are "elderly, retired or lack the resources" necessary to defend their claim. In light of this, the court should try "one or more major water users" who have the economic means and motivation to defend themselves in court. Gila Valley Irrigation District and others argue that the inclusion of a Benson well (which is over 1 mile from the San Pedro River) violates the narrow concept invoked in Southwest Cotton and, furthermore, has little relevance on the outcome of the *subflow* boundary delineation. Lastly, the general argument persists that any sort of analysis should be conducted across the entire Gila River Watershed, both in the interest of hydrologic accuracy and alleviating unnecessary economic burden on a subset of those involved in the adjudication.

**Representative San Pedro Wells
(As submitted by Salt River Project)
Table B.1**

The wells listed below were selected as representative of the range of geologic formations, pumping cycles, proximity to streams, hydrologic conditions, and amounts of pumping that exists in the San Pedro watershed. "DWR Case No." refers to the wells described on pages 57-67 of DWR's "Gila River system: Groundwater-Surface Water Interaction Study" (September 1987).

- I. Floodplain Aquifer
 - A. Seasonal Pumping
 - 1. Lower basin
 - a. DWR Case No 1 or more wells in WFR 114-1-CCD-1; or one or more wells in WFR 114-4-BDA-1
 - 2. Middle basin
 - a. DWR Case No. 5 (WFR 112-17-88)
 - 3. Upper Basin
 - a. One or more wells in WFR 111-23-DDA-4
 - B. Continuous Pumping, Lower Basin
 - 1. One or more wells in WFR 114-4-35
- II. Basin Fill Aquifer
 - A. Seasonal Pumping, Upper Basin
 - 1. DWR Case No. 10 (WFR 111-23-DAD-6)
 - 2. One or more wells in WFR 111-24-CCB-2
 - 3. The well in WFR 111-23-DDA-6
 - 4. The well in WFR 111-23-DDA-16
 - 5. The well in WFR 111-23-DDA-23
 - 6. The well in WFR 111-23-DDA-25
 - B. Continuous Pumping, Upper Basin
 - 1. DWR Case No. 7 (WFR 111-23-33) and/or other wells in the Sierra Vista area (e.g., DWR Case Nos.8 &9)
- III. Other Situations
 - A. Upper Aravaipa Creek
 - 1. Wells in WFR 115-6-CCA-1
 - 2. DWR Case No. 3 (115-10-BA-1)
 - B. Confined Alluvial Aquifers
 - 1. DWR Case No. 4 (WFR 113-88-22)
 - 2. DWR Case No. 11 (SFR 112-17-39)