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EVOLVING PERSPECTIVES IN WATER RESOURCES

PROCEEDINGS OF THE
SEVENTH ANNUAL SYMPOSIUM

ARIZONA HYDROLOGICAL SOCIETY

SEPTEMBER 22-23, 1994
SCOTTSDALE, ARIZONA

ARIZONA HYDROLOGICAL SOCIETY ANNUAL SYMPOSIUM

September 22-23, 1994

Additional Papers

Session 1B: Observations and Opinions Surrounding the Paradigm Effect in the Environmental Management Industry

Matt Stinchfield, Zenitech Corporation

Session 2C: High Resolution Stratographic Interpretation Made Possible by Rotasonic Continuous Coring Method

Douglas G. Wolfe, ASL Hydrologic & Environmental Services

OBSERVATIONS AND OPINIONS SURROUNDING THE PARADIGM EFFECT IN THE ENVIRONMENTAL MANAGEMENT INDUSTRY†

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ABSTRACT

Within the past forty years, the term *paradigm* has evolved from meaning a pattern within a system to a broad term encompassing the components and trends of entire systems. Paradigm shift occurs when one system of heuristics, or rules, gives way to a new outlook. Paradigms are most likely to shift about the time the practitioners of the previous paradigm recognize that certain problems can't be solved without new rules, practices, language, or beliefs.

After about twenty-five years of intense problem solving in the hazardous waste management industry, a large variety of assessment and restoration projects still defy understanding. Domination of the field by engineers has led to a certain type of problem solving. Natural scientists and persons from outside the industry are now stepping up to try their systems against these tough problems. Among the most promising is the so called *observational method.* Regulatory bodies appear to be moving from command and control to solutions based on *partnering* with citizens, corporate America, and political subdivisions. Even some legal representatives are promoting *proaction* and direct agency discussions, rather than fostering contention and shielding recalcitrance.

In the industrial safety and health fields, new approaches are being developed to increase personal and public safety, while working with fewer resources in a context of greater regulation. Risk managers are moving from risk tolerance and risk assessment to programs of risk prevention and minimization.

Corporations of the nineties are operated with fewer managers, while many are becoming fully vested in team management. Companies are beginning to value workers' personal contributions, rather than demand conformance with preconceived pathways. A premium is being placed on sincere partnerships between service providers, clients, and control bodies.

Overall, the industries responsible for assessing, controlling, and reducing the risks of exposure of hazardous substances and injuries to people and their environment are transitioning into a new, common paradigm. This shift is still controversial; many industry experts refute that these

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† Based on paper originally published in *Emerging Trends in Environmental, Safety and Health Management*, presented at **Creating Solutions for Tomorrow's Challenges**, Albuquerque, New Mexico, March 8-10, 1994.

changes are occurring. Many corporate directors and agencies see such new approaches as risky, trendy, or downright ludicrous. But for those who can read and appreciate these subtle industry changes, a higher level of problem solving, personal success, and environmental protection is the reward.

INTRODUCTION

A *paradigm (paŕ·ə·dīm)*, as I understand it, is a collection of boundary rules, terminology, practices, and beliefs that are employed in understanding and describing any particular phenomenon. Joel Barker, a noted futurist and one of the many "business success evangelists" practicing today defines paradigm as a system of rules that allow one to be successful. Meanwhile, Webster's states that a paradigm is a "model" or a "pattern." (The word originally meant the complete series of declensions of a verb.) Last and not least, Thomas Kuhn, the science historian credited with reviving popular use of the word in his book entitled *The Structure of Scientific Revolution*, describes paradigms as an element of a system of scientific understanding that bounds, and may limit, the acceptance of information into the system.

You may have noted that these definitions are rather diverse; some relate to whole systems and others simply to elements of systems. I attribute these differences to two factors. First, the term has undergone a redefining process as the principles which Kuhn laid out have been almost summarily applied to areas outside of science. Second, the word paradigm seems to cause confusion in many people since its use is so interpretive. The latter is of great concern nowadays, as the paradigm moniker is getting used quite a bit by those not fully understanding it.

A currently accepted paradigm constitutes the popular opinion of experts in a particular discipline at some point in time. Paradigms can be composed of any mix of political, economic, social, scientific, religious, philosophical, artistic, or cultural terms. Right now, the paradigm for cosmologists studying the origins of the universe tend to focus around the big bang theory, red shift, an expanding universe, and so on. Meanwhile, religions based in creationism describe the origins of the universe in their own paradigm: one of a period of darkness, an omnipotent being, and often, people and the world being created out of mud or other basic materials. These are both legitimate paradigms. Each has its own terms, boundaries, and beliefs.

Paradigm Shift

Paradigm shift is the term used to describe a radical transitioning between the accepted way of understanding, defining, and explaining a subject to a sometimes very different belief system. Paradigm shift can occur within an individual's psyche or in a group of practitioners of a particular paradigm. However, paradigm shift is most dramatic when it impacts and entire industry, population, or nation.

An example of paradigm shift that began within an individual can be found if we look at Albert Einstein's history. When Einstein entered the nuclear physics scene around 1916, the prevailing belief, based on centuries of thought and experimentation, was that every motion through space could be exactly predicted using Newtonian physics. The cat jumps off the piano. We know

how much it weighs and how hard it jumped and in what vector, so we can predict exactly when and where it will land. Contemporaries of Einstein, Niels Bohr and Werner Heisenberg thought that this paradigm would not work on the atomic scale. They claimed that it would be impossible to exactly predict the location and time of a subatomic event. (This was the beginning of quantum mechanics as we know it today.) This belief was in direct contraction to centuries of empirical data. A young Einstein couldn't believe that any action that God knew couldn't be discovered by man. He refuted these new theories with a now famous quote: "God doesn't play dice" (sic). At this point in his life, Einstein's paradigm would not allow him to grasp something outside of his experience and training.

Well, you may know the rest of this story. Einstein ultimately came to understand what Bohr, Heisenberg, Edward Teller, and others were discovering. He shifted his paradigm to a new philosophy, one where probability, chance, chaos, and wave-like particles (or particle-like waves) were the norm. He ended up contributing vastly to the new paradigm of quantum mechanics: a paradigm most nuclear physicists operate within to this day. This single individual underwent paradigm shift, and, due to his significance in history, ended up contributing to the shift of the entire human race.

There are many, many examples of paradigms and paradigm shift in the world around us. A commonly cited example is the two paradigms of Japanese industry. In the 1970's many people would have described Japanese products as cheap, unreliable ripoffs; to some degree this was true. But twenty years later we see the world's electronics and automobile markets dominated by reliable, durable, stylish products from Japan. The language, beliefs, expectations, and boundaries used to define Japanese manufactured goods has changed radically in a very short segment of history.

When Does Paradigm Shift Occur?

Paradigms tend to shift when a new set of problems come along that are not adequately addressed by the accepted rules and beliefs. Normally, a few visionary problem solvers begin to see new ways of approaching stubborn problems. These visionaries, whom Barker calls "paradigm pioneers," may come from with the specialty area, or from the outside. (This is what I call the puzzle phenomenon: you can stare at a puzzle for a long time without finding a single piece, while someone just walking up makes several quick fits.)

It is often difficult to accept the new ideas when they are first made known. New paradigm rules often act in direct contradiction to the existing paradigm! It is easy to dismiss these ideas as ridiculous, a cheap marketing ploy, or simply naive. Adopting the new paradigm normally requires some proven success to lower the risk enough for non-adventurous persons to come aboard.

Why would anyone take the risk of venturing into a new paradigm when there is a working paradigm which is explaining most of the problems present in a particular discipline? First, there is the lure of success. Paradigm pioneers are seeking to solve previously unsolvable problems. Most hope to achieve personal and professional rewards, while some seem entirely altruistic. Secondly, particularly in fields related to the human condition (medicine, safety,

hazardous waste management, human rights, etc.), new paradigms hope to better the quality and length of life. Thirdly, paradigms shift because they have to. That is to say, paradigms are sometimes dependent on other paradigms. Related paradigms often shift in concert. It is my belief that the dramatic changes taking place in the workplace environment, gender roles, and discrimination policies paradigms are clearly linked to the changes in hazardous waste management and institutional safety paradigms.

HAZARDOUS WASTE MANAGEMENT PARADIGMS

The very first hazardous waste management paradigm was that there was no hazardous waste management at all. (We won't really count that one.) The first real paradigm was applied from the beginning of chemical industry to the time when we realized that we should begin cleaning up the messes that were fouling the air, water, soil, organisms, and food products. Earth's capacity to dilute, dissolve, and digest our pollutants was beginning to show stress.

Hazardous Waste Remediation (Engineering) Paradigm, ca. 1970 - 2000

The next paradigm, the one that most people probably believe they are in today, is the remediation paradigm. As the word implies, remediation refers to efforts taken after the fact. This is a basic tenet of this paradigm - discover problems, then find a remedy. (The future paradigms will be based less on reaction and more on anticipation.) In the United States this paradigm really appeared in the early 1970's with the advent of the Clean Air Act and the Clean Water Act. Rather suddenly, some visionary civil, chemical, and mechanical engineers began using their problem solving skills in a new way. They began to shift from the design of new production facilities (mines, refineries, chemical manufacturing) to the control of emissions from these sites. This represented the first time in history when people might no longer rely on dilution, dispersion, and natural biochemical/geochemical processes to deal with waste. The engineers who made early moves into this new paradigm were solving problems left and right: wastewater treatment plants, hazardous waste landfill design, atmospheric scrubbers, and so on. Many of these firms grew substantially in this time frame, many are still big today.

The principle players in this new industry were: 1) the new regulators, 2) the newly regulated community, 3) their experts, and 4) the public. Each of these four groups have possessed certain characteristics which express the type of communication, internal organization, and position of importance they placed or found themselves in. Table 1 shows some examples of these characteristics.

Table 1

CHARACTERISTICS OF THE CURRENT
HAZARDOUS WASTE MANAGEMENT PARADIGM

Participant	Communication	Organization	Position
Industries	divisive	military hierarchy	superior, incumbent, provide products and services that America needs
Consultants			
Engineers	stuffy	military hierarchy	superior, educated, makes promises about success
Scientists	sympathetic	team based	inferior, not allowed into high level problem solving
Laboratory	mechanized	military hierarchy or team based	straightforward subcontractor, not allowed into high level problem solving
Lawyers	antagonistic	team based	superior, educated, won't promise anything
Agencies	command and control	military hierarchy	superior, Congressional mandates back actions
Public	grass roots	no organization or loose association	inferior, unsure of what they could accomplish

Hazardous Waste Remediation (Observational Method) Paradigm, ca. 1990 - Beyond

It is my belief that we are now entering a point in time in the environmental and safety management arenas that the new paradigm is being sufficiently evidenced. Examples of this will constitute the rest of this article.

After about twenty-five years of intense problem solving in the hazardous waste management industry, a large variety of assessment and restoration projects still defy understanding. Domination of the field by engineers has led to a certain type of problem solving. Natural scientists and persons from outside the industry are now stepping up to try their systems against these tough problems. Among the most promising is the so called *observational method.* Regulatory bodies appear to be moving from command and control to solutions based on *partnering* with citizens, corporate America, and political subdivisions. Even some legal representatives are promoting *proaction* and direct agency discussions, rather than fostering contention and shielding recalcitrance.

The new paradigm many of us find ourselves learning right now is one where the disparate parties shown in Table 1 come together as a diverse problem solving coalition with common communication, organizations, and positions. Refer to Table 2. This is not to imply that these parties see eye to eye! To the contrary, their positions may be more controversial and extreme than ever. What will be common between them, however, is their ability to work within the context of diversity to accomplish solidarity.

Table 2

CHARACTERISTICS OF THE NEXT (AND OPTIMISTIC) HAZARDOUS WASTE MANAGEMENT PARADIGM

Participant	Communication	Organization	Position
All parties	diplomatic	team	all participants have stake in outcome, avoid promises, promote fairness

The groups in Table 1 are tired of an ineffective system of problem solving. It costs everyone more time, more money, and more allowances for aspirin when problems aren't solved readily. Industry is frustrated with the level and style of regulation. Agencies tire of legal browbeating by big dollar law firms. Scientists will no longer simply generate data without being allowed into the process of problem solving. And the public has won enough battles over land use, natural resources damages, and the like that they are to be taken more seriously than ever before.

In the industrial safety and health fields, new approaches are being developed to increase personal and public safety, while working with fewer resources in a context of greater regulation. Risk managers are moving from risk tolerance and risk assessment to programs of risk prevention and minimization.

Corporations of the nineties are operated with fewer managers, while many are becoming fully vested in team management. Companies are beginning to value workers' personal contributions, rather than demand conformance with preconceived pathways. A premium is being placed on sincere partnerships between service providers, clients, and control bodies.

SUMMARY

Overall, the industries responsible for assessing, controlling, and reducing the risks of exposure of hazardous substances and injuries to people and their environment are transitioning into a new, common paradigm. This shift is still controversial; many industry experts refute that these changes are occurring. Many corporate directors and agencies see such new approaches as risky, trendy, or downright ludicrous. But for those who can read and appreciate these subtle industry changes, a higher level of problem solving, personal success, and environmental protection is the reward.

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DATA SUFFICIENCY PROBLEM # 1
Chrome Artistry Initial Site Sampling Event

STATEMENT OF PROBLEM

Your project manager has sent you, sight unseen, to a chrome plating facility to conduct near surface soil sampling to assess whether or not chromium levels exceed the Arizona HBGL of 1700 mg/kg, in the unsaturated zone.

You know the following:

- You have $ 3500 to characterize the site (your PM said that equals 10 samples),
- You have less than two days at this distant site allowed,
- Chromium is the only contaminant of concern,
- If action levels are exceeded, remediation will follow shortly,
- Contaminated soil requires stabilization under the Land Ban, and
- The client is EXTREMELY cost conscious.

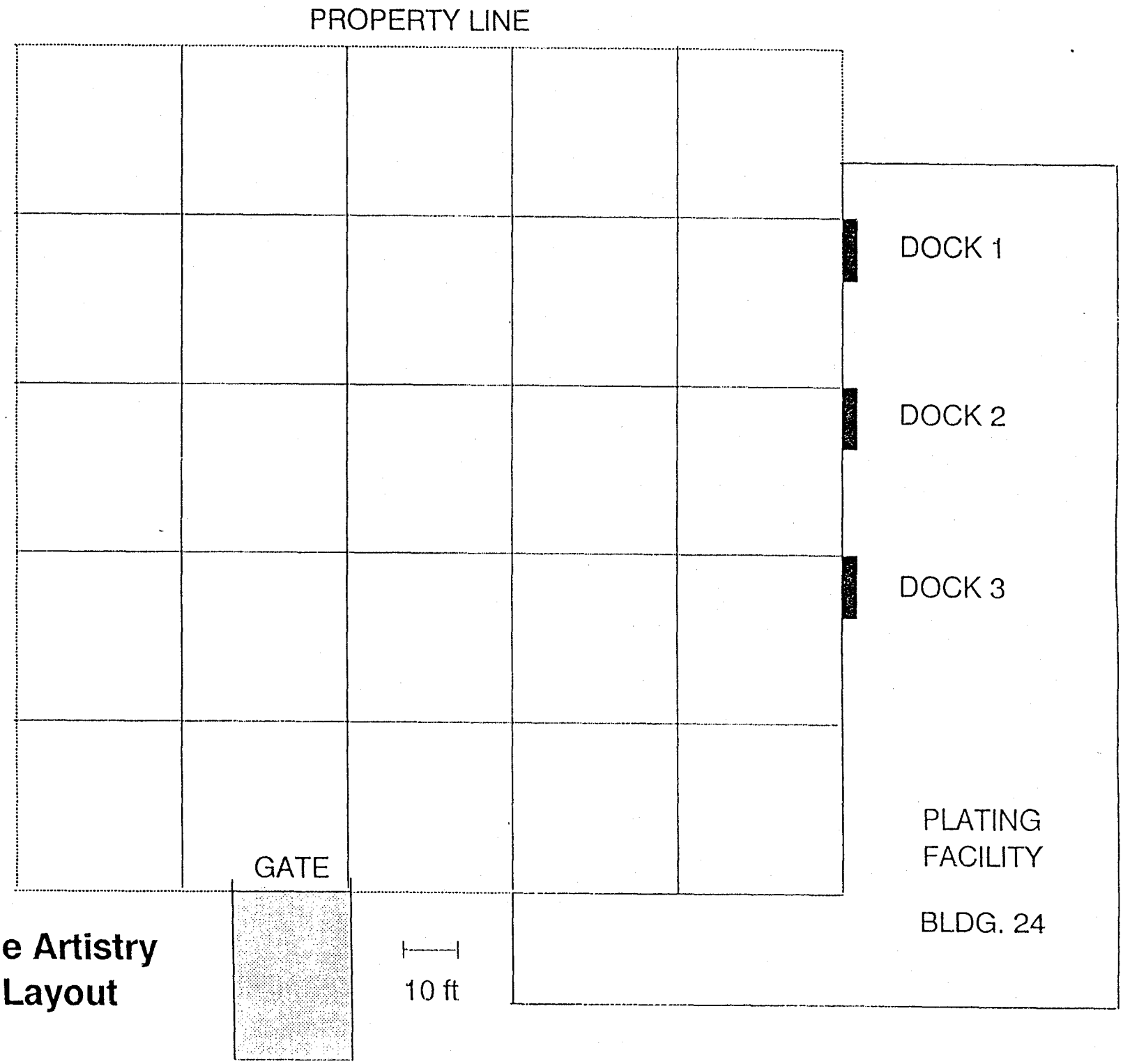
You do not know the following:

- Site topography,
- History of discharges, if any, and
- Soil type, alkalinity, etc.

Your assignment:

- Develop a sampling plan which includes the locations of samples,
- Obtain results for the grids sampled,
- Estimate volume of contaminated soil based on 1 ft depth, and
- Perform flawlessly, save the client big bucks, and get a big promotion.

Since your project manger is on vacation in Bali, you cannot ask any further questions of her.



Chrome Artistry
Site Layout

DATA SUFFICIENCY PROBLEM # 2
Cookie's Motor Muffin and Fuel Depot

STATEMENT OF PROBLEM

A site assessment has turned up the fact that Cookie's Motor Muffin and Fuel Depot once possessed an underground fuel tank(s) which leaked and was removed. Nobody knows where the tank(s) were located. Is groundwater (at 25 ft) impacted?

You know the following:

- You have enough budgeted to drill 100 linear ft with a HSA drill rig,
- You have one day on site with mobile lab,
- BTEXs are the contaminants of concern, and
- The client is EXTREMELY cost conscious.

You do not know the following:

- Site topography,
- History of discharges, if any,
- Location of former tank(s), and
- Subsurface pedology, geology.

Your assignment:

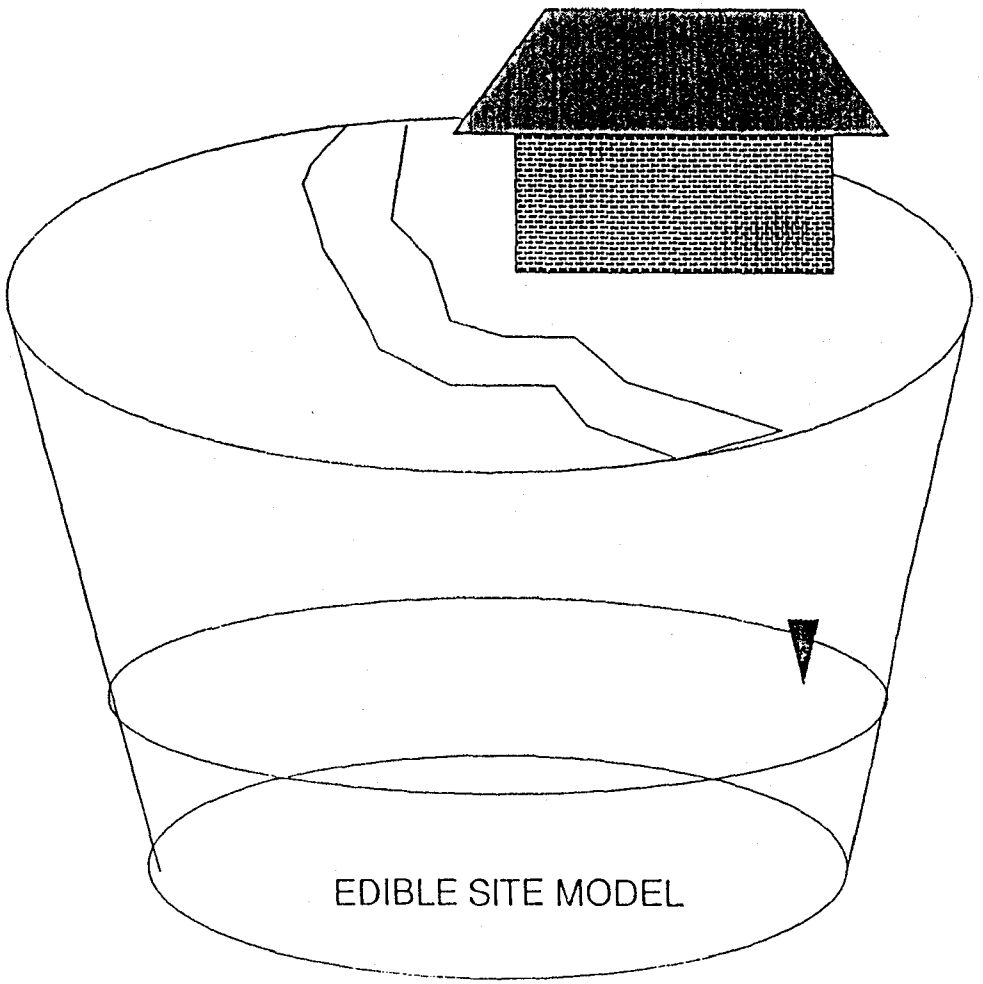
- Develop a sampling plan which includes the locations of samples,
- Auger the site, log holes, and analyze samples,
- Construct fence diagram of the subsurface,
- Plot groundwater flow and contaminated region, and
- Perform flawlessly, save the client big bucks, and get a big promotion.

After you have analyzed the site, as well as possible considering the budget, disect the site carefully to see how close you were.

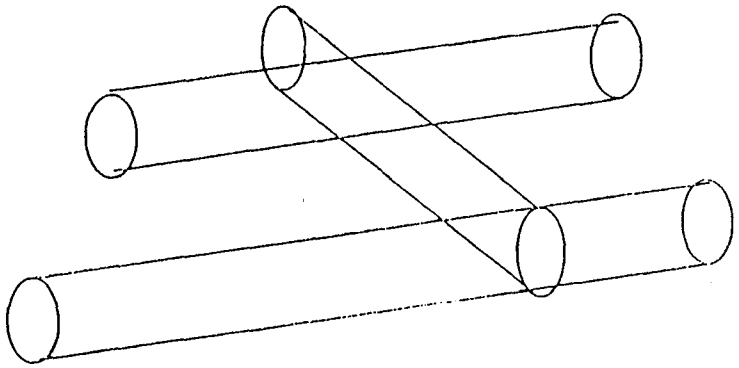
COOKIE'S MOTOR MUFFIN AND FUEL DEPOT

KEY

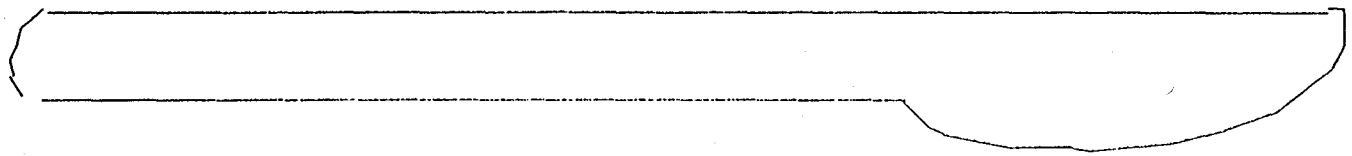
YELLOW CAKE = VADOSE ZONE
BLUE CAKE = SATURATED ZONE
RED CAKE = CONTAMINATION
NUTS, CHIPS = AUGER REFUSAL



3 TRANSPARENT AUGER FLIGHTS



SITE DISECTING TOOL



HIGH RESOLUTION STRATIGRAPHIC INTERPRETATION MADE POSSIBLE BY ROTASONIC CONTINUOUS CORING METHOD[1]

Douglas G. Wolfe[2]

STATEMENT OF THE PROBLEM

"*It will often seem that the geologic processes have maliciously conspired to maximize the interpretive and analytical difficulties*" (Freeze and Cherry, 1979).

Site characterization and remediation is generally ineffective where there is limited understanding of subsurface variability or contaminant distribution. The movement and partitioning of contaminants, in groundwater, and interstitial vapor is ultimately a product of multiple physical forces. Ideally all of these physical forces could be mathematically modeled. However, sediment/soil/rock (matrix) variability expressed at scales ranging from microscopic to regional can produce complexity beyond the practical application of quantitative methods. Order-of-magnitude variability in sediment grain-size or textural variability, intergrain diagenetic cementation, degree of compaction, thermal history, rock-fluid interactions and numerous other factors strongly influence sediment matrix parameters.

For several reasons, most shallow subsurface exploration programs do not apply techniques capable of resolving such fine-scale lithologic variation. Currently, applied drilling techniques do not recover relatively undisturbed samples from cemented soils, coarse-grained sediments (cobbles), or bedrock. Rotary and percussion drilling methods can penetrate most lithologies, but recovered sediments may be too disturbed for accurate sediment description or laboratory analysis.

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[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] Douglas G. Wolfe is Principal Environmental Scientist, ASL Hydrologic & Environmental Services, Phoenix, Arizona.

The procedure for conducting multi-disciplinary, fine-scale interpretation of sediments and rocks has been generally referred to as High Resolution Stratigraphy (HIRES). The purpose of this presentation is not to teach HIRES, which is explained in more detail elsewhere (Kauffman, et al., 1991), or to describe the mechanics of the Rotasonic drill rig, which will be demonstrated later at this conference, but to promote the benefits of combining the Rotasonic rig with the HIRES approach. In our experience, the Rotasonic drilling method provides a high level of sample recovery, at a reasonable cost, with additional advantages including speed, precision, and a safer working environment.

HIRES: WHAT TO LOOK FOR

HIRES is applied through careful sediment description and recognition of important marker beds with particular attention to the bounding surfaces between sediment packages. Criteria used for the recognition of marker beds are generally chosen based on the depositional setting but may include:

Disconformity Surfaces or surfaces of erosion between stratigraphic units. These erosional or sediment bypass surfaces, paradoxically characterized by the absence of deposited sediments, may influence the migration of fluids. Cementation and secondary porosity development, hard-grounds, gravel lags, burrow or tree root networks, and undulating or tilted migration pathways are most commonly present near the disconformity surface.

Event Beds including altered volcanic ash deposits (bentonites), charcoal layers (fossil forest fire deposits), mass flow deposits (turbidities, flood deposits), impact deposits, and geochemical events (isotopic anomalies, organic carbon spikes, diagenetic events) and mass mortality horizons (in fossil-bearing strata) provide evidence of time-synchronous depositional events that may be regionally or globally correlatable. Distinctive ash units can be used as reference stratum to discern the variability between exploratory borings. Uncertainty regarding the correlation between particular marker beds can be resolved through geochemical fingerprinting or graphic correlation using multiple marker beds. Alternately, bentonite ash may influence the migration of contaminants by providing a low permeability zone between two coarser-grained units.

Biostratigraphy, although rarely applicable within the Salt River Valley, may be an important tool for recognition of relationships between individual stratigraphic units within older stratigraphic sequences. Mesozoic and Paleozoic sedimentary rocks cover roughly one third of the State of Arizona and

many of these units are locally important aquifers. Identification of individual sandstone units within the several thousand-foot-thick Cretaceous Dakota Sandstone and Mancos Shale deposits of the Colorado Plateau is accomplished through recognition of significant fossil species and marker bentonites (Molenaar, et al., in preparation). Even within the Salt River Valley, recognition of Pleistocene and older terrace deposits was assisted by the discovery of ice-age mammal fossils (Wellendorf, et al., 1986). Fossil pollen and other microfossils can be used in the identification of terrestrial facies.

Magnetostratigraphy, Radiometric age dating and Geochemical fingerprinting (including carbon isotopic analysis of peat, fossils or other organic carbon remains), and other geochemical analyses can be used to discriminate between strata and aquifers of similar appearance and position. Geochemical marker horizons may be particularly useful for correlation between adjacent sedimentary facies.

In summary, recognition of even a single isochronous or regionally correlatable marker bed provides a baseline for identifying overlying and underlying strata or recognizing facies changes, erosional events, or non-conformable diagenetic phenomena.

THE POWER OF HIRES

Although the procedure has been applied in multiple settings, the interpretive power of HIRES was best demonstrated through application of the method to several of the most important questions in Earth Science:

Tectonics and Sedimentation

Our understanding of plate tectonics demonstrates that lithospheric plates and crustal fragments may be moved great distances at hydrogeologically significant time-scales. Most sedimentary basins are formed and filled, uplifted or subducted according to tectonic framework. The understanding of tectonic process has been enhanced by high-resolution techniques ranging from magnetostratigraphic interpretation of oceanic basalts to the fine-scale dating of uplifted terrace deposits along active margins. Quantitation of long-term sedimentation rates is now possible for individual sedimentary basins throughout much of the geologic record.

In Arizona, fault influenced depositional fabric is common and should be considered when interpreting the stratigraphy of sites located along uplifted regions (Brown and Pool, 1989). Similarly, the location of earth fissures in Arizona, though related to groundwater withdrawal, may ultimately be related to differential sediment compaction over the location of pre-existing mountain-front structures (Carpenter, 1993). Detection of fault-influenced stratigraphy requires a HIRES approach.

Eustasy and Sedimentation

Recently documented global sea-level curves demonstrate almost continual rising and falling of global oceans (eustasy) and concurrent ecologic, atmospheric, and depositional effects (Haq, 1988 and references therein). Development of the Global Eustatic Sea-level Curve was dependant on HIRES techniques, particularly through integrated macro- and microbiostratigraphy, radiometric age dating of "event" beds (especially widespread volcanic ash deposits) and geochemical event horizons, and identification of almost worldwide surfaces of disconformity. Even with the advent of sophisticated remote sensing techniques, discovery and production of fossil fuels still relies heavily on HIRES.

Climate, Geochemistry, and Sedimentation

Discovery of significant global geochemical and climatic cycles could only be accomplished and refined through HIRES. Detection of centimeter-scale variations in sediment geochemistry, for instance, lead to the hypothesis of a bolide-related cause for the extinction of the dinosaurs and other former animal groups. Concurrent detection of massive changes in global geochemistry and reorientation of oceanic water-mass structure led not only to the conclusion that the terminal Cretaceous event was quite sudden, but to recognition of additional mass extinction events, global geochemical and climatic revolutions and scenarios regarding the possibility of nuclear winter or global warming.

The fact that mass extinction events coincide with documented shifts in global atmospheric and oceanic geochemistry is well established even if the initiating mechanisms are not well understood. More practically, however, documentation of these of these events provides recognizable markers that can be used to establish the sedimentary record.

Documentation of the global effect of changes in oceanic structure, the El Nino event for instance, demonstrates that seemingly minor changes in sea-surface

temperatures can lead to massive reorientation of regional temperatures and precipitation patterns. The occurrence of high-intensity, low-frequency precipitation events in Arizona is related to global oceanic, atmospheric and geochemical phenomena.

Clearly the need to apply any stratigraphic technique depends on the problem to be solved. The practitioner rarely knows in advance which stratigraphic component will be the most significant marker bed or contaminant pathway. It is incumbent upon the practitioner to be sufficiently familiar with applicable techniques to recognize correlation opportunities when available. First, however, the practitioner must collect data of sufficient quality and quantity to apply HIRES. The Rotasonic Continuous Coring Method can provide the high-quality data required by HIRES.

ROTASONIC CONTINUOUS CORING: WHAT TO USE

The Rotasonic drill uses "high frequency mechanical oscillations developed in the drill head to transmit resonant vibrations and rotary power . . . to the drill bit" (Dustman, et al., 1992). Soil samples are collected with an inner core barrel driven ahead of an outer casing. The core barrel is then extracted from the boring and the sample material extruded into a special clear plastic sample sleeve or trays for description and sample collection.

Although hollow-stem auger/split-spoon sampling techniques can collect high quality, fine-scale sediment samples by continuous sampling in "ideal" sediments, only the "Rotasonic" drill can collect continuous, high quality samples from unconsolidated sediments, coarse-grained deposits (including cobbles), and bedrock. In addition, Rotasonic drilling offers the following advantages:

1. Collected core samples are approximately 4 or 6 inches (depending on the core barrel) in diameter. These larger-diameter sediment samples allow recognition of sediment features including ripple-marks, lamination and crossbedding, interfingering and gradational facies, and larger sedimentary clasts. In coarser-grained deposits, sufficient matrix material is collected between gravel- and cobble-sized particles to provide sufficient material for laboratory analysis and to better describe the stratigraphic unit. In cemented units the larger-diameter sample makes it easier to discriminate between potentially continuous cemented horizons and scattered concretionary nodules.

2. Collected cores are quickly extruded into plastic sample socks or trays that can be stored for later reference. Stratigraphic variations that may not seem significant upon first examination may take on added importance following additional study. Cores collected with the Rotasonic are generally of sufficient quality even after sampling so that cores from adjacent borings can be re-examined to define persistent marker beds.

3. Air and fluid are not generally circulated through the core barrel so there is little if any dilution of the sample material. Similarly, less of the soil contaminant or contaminated soil material is brought to the ground surface, greatly reducing the level of exposure to the contaminants.

4. The Rotasonic drill casing provides a relatively tight seal against the borehole, reducing the loss of contaminants from the boring as described above, but also provides the opportunity to set temporary monitoring points (stainless steel screens for instance) at isolated stratigraphic intervals to detect potentially confined or interconnected hydrologic units, or collect preliminary water samples, prior to well installation.

5. Rotasonic drilling can be accomplished quickly in unconsolidated materials reducing disruption at active sites. At other sites the Rotasonic may be the only method capable of collecting continuous samples from coarse-grained deposits.

ASL Hydrologic & Environmental Services in cooperation with Northstar Drilling and Summit Envirosolutions completed over 30 exploratory borings and wells during 1994. The results of these efforts included successful sampling for laboratory analysis from cobble-containing sediments, identification of thin contaminant-retarding fine-grained units within thick coarse-grained sediment sequences, identification of previously undescribed, closely spaced perched aquifers that had been cross connected during earlier work at a site, and efficient installation of vapor extraction and groundwater wells. While the Rotasonic Drilling Method is probably not required at every site, we feel the method presents considerable interpretive advantages at complex sites when combined with HIRES.

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ARIZONA HYDROLOGICAL SOCIETY

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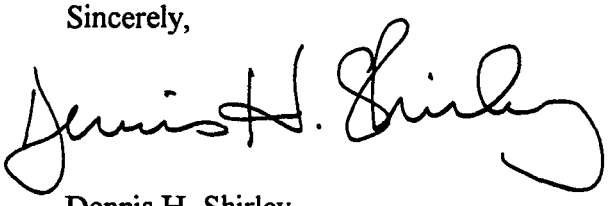
PREFACE

As we approach the coming of the next Millennium, there is a natural tendency to look to the passage of time and reflect on where we are and what lies ahead. Such soul searching can provide a valuable opportunity to learn from the past and plan for the future. In addition, the self assessment allows us to gain important perspectives on our personal identity and how it relates to a broader view of life, or the "big picture".

In much the same way, the Arizona Hydrological Society planned the 1994 Symposium with the intent of appraising the science and technology involved in water resource management. The general session entitled: "Living in an Uncertain World: Science, Technology, and Social Responsibility" offers presentations by five internationally renowned experts on the role of science and technology in the broad view of societal development and global impacts. We have linked the discussion of science and technology to social responsibility to underscore the significance that our actions have in both advancing and impeding the development of society. Additional presentations in the session entitled, "Environmental Policy in the Public Eye" will further explore ways in which science can be melded with political, social, institutional and economic considerations to develop better public policy.

The Arizona Hydrological Society maintains a strong belief that the policies and programs that govern water resources should be based on a clear understanding of science. This, we believe, is particularly important today in the face of competing pressures for environmental protection and economic development. In keeping with the goal of AHS, we hope the 1994 Symposium provides water resource professionals with the interest and inspiration to help advance the science of water resources research, planning, development, management, and education.

Sincerely,



Dennis H. Shirley
Salt River Project
Chairman, Symposium Organizing Committee

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LIVING IN AN UNCERTAIN WORLD: SCIENCE, TECHNOLOGY, AND SOCIAL RESPONSIBILITY

Moderator: Dennis Shirley
Salt River Project

PAST, PRESENT, AND FUTURE OF WATER AND WASTEWATER

Herman Bouwer[1]

Old civilizations are better known for their water supply works than for their sewage works. In Europe, sanitary conditions in the Middle Ages and early Renaissance were atrocious. Documented objections to polluted water primarily came from the beer breweries. The flush toilet as we now know it was invented in England by Thomas Crapper in the late 19th century. While a marvel of home and urban sanitation, it is also a big water user and polluter, and not the answer for large cities in water short areas in poor countries. Use of chlorination to disinfect drinking water started early in the 20th century and gave cities a license to phase out sewage farms and dump their sewage into streams and lakes. Sewage treatment was then aimed at avoiding undue oxygen sags in receiving water and not exceeding the assimilative capacity of such water. This was achieved by reducing suspended solids and biodegradable organic matter (biochemical oxygen demand or BOD.) Now there is increasing concern about what is not removed from the sewage and its effect on aquatic life, recreational benefits, and downstream use of the water. Discharge requirements are becoming increasingly stringent and more removal of nitrogen, phosphorous, metals, organic compounds, and microorganisms will be required. This makes sewage treatment more expensive and treatment plants will be built for local use of reclaimed water, such as urban and agricultural irrigation, recreational lakes, industrial use, toilet flushing, etc. Potable use, while technically possible, normally will be a practice of last resort because of treatment costs and public acceptance aspects. Groundwater recharge for seasonal storage and soil-aquifer treatment of the effluent will be increasingly used for economic and aesthetic reasons. Planned reuse will be increasingly practiced as populations increase and renewable water resources are finite. This requires treatment of wastewater so that it meets the quality requirements for the intended use.

The world population is projected to double to about 11 billion by the middle of the next century. Most of the increase will be in the Third World. Also, people will live and migrate more and more to the cities, creating mega cities with mega water needs, mega sewage flows and mega problems. There will be a large underclass of urban poor, which will join the rural poor in poverty, starvation, disease, mortality, and plain misery. There will be local, national, and international conflicts over water. Diplomacy and conflict resolution must be used to prevent war. Integrated water management will be a must, including efficient use of water for food production, conjunctive use of surface water and groundwater <u>and</u> of surface storage and underground storage (artificial recharge), water transfers, water marketing, water reuse, water treatment, water pollution control, supply and demand management, and water conservation, all in keeping with accepted principles for sustainability and environmental protection. Greenhouse effects and climactic changes may be possibilities, but they are difficult to predict with any degree of reliability. While different scenarios can be selected for academic exercises, planning for greenhouse effects

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1 Herman Bouwer, Chief Engineer, U.S. Water Conservation Laboratory, Phoenix, Arizona.

and climatic change currently is still premature. Even positive effects of increased atmospheric $C0_2$ levels on crop production are difficult to predict because ozone and other air pollutants can decrease yields.

Better quality standards are needed for potable water. The current practice of rodent bioessays for carcinogenicity evaluation has several inherent weaknesses, including use of high chemical doses which can cause cancer by killing body cells of the test animals and the formation of malignant tumors by spontaneous mutation in the new cells formed by the body to repair damaged tissue. Subsequent reduction to low doses by assuming a linear dose-response relation then can grossly overestimate the carcinogenicity of the chemical. Also, metabolic pathways may be different for high doses, causing toxic byproducts that would not be formed when normal low doses are used. Thirdly, extrapolation of results from mice or rats to humans is difficult because of genetic differences. Overly conservative standards to be on the safe side lead to unnecessary treatment and remediation costs. There is also the question of why basing standards on an additional cancer death of 1 in 100,000 or 1,000,000 people when about 25 percent of the people die of cancer anyway?

IRRIGATION – A BLESSING OR A CURSE?

Jan van Schilfgaarde[1]

Irrigation is vital to the well being of the people in this world and plays a significant role in local, national, and international economics. However, irrigation also has created problems, such as salinization of land and water resources, adverse socio-economic and cultural effects, and environmental damage. Civilizations have risen and fallen with the growth and decline of their irrigation systems, while others have maintained sustainable irrigation for thousands of years. In the last century or so, many large and impressive irrigation projects have been installed as monuments to engineering technology. Often, these systems have centralized (top-down) management, which is not in the best interest of farmers and local people. Gradual development of existing local irrigation practices and farmer (bottom-up) management, while less spectacular, may ultimately be more successful. Many of the problems in irrigated agriculture can be mitigated or avoided by improved technology and management, and by adequately addressing cultural, social, and environmental aspects.

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1 Jan van Schilfgaarde, Associate Deputy Administrator, Natural Resources and Systems, Agricultural Research Service, U.S. Department of Agriculture.

CLEAN WATER AND REGULATORY SCIENCE: WHAT IS ENDANGERED?

Margaret N. Maxey, Ph.D.[1]

Now that we have entered the final decade of the second millennium, it is to be expected that prophets of doom at our own hands should follow a pattern clearly visible in the final decade of past centuries. Ours is an era dominated by "Deep Ecology." Its advocates exhort us to adopt a new "Environmental Ethic" displacing an old and discredited "Ethic of Utility." We appear to be persuaded that our health and safety have never been so imperiled, despite the fact that ordinary citizens enjoy a standard of living and social amenities that were once the prerogative of royalty as recently as 200 years ago.

After two decades of experiencing the aftermath of an explosion in environmental laws and regulations, a taxpaying consumer has more than enough reason to ask: Have we been paying for certifiable health improvements, or instead, for a costly legal system of regulations which rely on aggressive enforcement activities? Have costs of enforcement been matched by funds for methods to supplant them -- namely aggressive scientific and engineering advances which could produce improved detoxification technologies more economically?

There is every indication that an underemployed legal profession has been eminently resourceful in devising ways to redeem us all from alleged evils of an industrialized capitalistic society, already tried and convicted of heedlessly contaminating a pristine environment. Ernest Rosenberg has articulated the pivotal issue:

> *"The move toward controlling less and less pollution at greater and greater expense -- until you are spending everything to control nothing -- is one of the big water quality problems that we are facing in the future."*

Two ethical questions must be answered:

- First, what popular assumptions about "Nature" lead deep ecologists to conclude that man-made toxics are the dominant threats to present and long-term levels of public health?
- Second, does the status of scientific evidence and instrumentation lend support to the belief that "zero pollution" is a desirable, much less attainable goal?

Evidence indicates that we have been drawn into a bottomless vortex, driven by the belief that "safety" depends on achieving "zero pollution." But in fact, zero is receding into infinity. Safety is becoming a mirage a bloated bureaucracy is siphoning away our only bulwark against genuine dangers to health and safety -- the ravages of poverty. It is the wealth-creating innovators in society who are endangered. We so easily forget these time-tested truths: Richer is safer! Wealthier is healthier! Poorer is riskier!

---

[1] Margaret N. Maxey, Ph.D. is Professor, Biomedical Engineering, College of Engineering, University of Texas at Austin

THE DECLINING CREDIBILITY OF SCIENCE AMIDST A GROWING SCIENTIFIC ILLITERACY

Jay Lehr Ph.D.[1]

A combination of overzealous environmentalists, opportunistic politicians, sensation seeking journalists and poorly trained scientists have contributed to the establishment of some very inappropriate political policy aimed at protecting the planet and its citizens from controllable environmental damage. Money has been spent and public fears exacerbated with no basis for either. Such unfortunate and unwarranted results would be less likely to occur if the public was exposed to a basic set of rules for critical environmental thinking, as well as some simple lessons to be learned from science.

It is reasonable to believe that the average citizen could learn to recognize that:

1) correlation is not causation,
2) trends cannot predict the future,
3) facts count for more than opinions,
4) the past is prologue to the future,
5) we can never avoid risk completely, and
6) we must make choices because the same dollar cannot be spent in two places.

Concurrently from science we can teach people a few basic principles to help them evaluate information being presented from diverse sources. These might include:

1) it is impossible to prove that something does not exist,
2) the dose makes the poison,
3) dose relationships are commonly not linear,
4) mice are not little men,
5) epidemiological studies can be unreliable,
6) risks can be measured and ranked, and
7) science is not immune to politics.

A concerted effort by all those desiring a sane environmental policy to better prepare the public to make the necessary decisions of a democratic government could achieve a great deal in balancing risks with reactions.

---

[1]Dr. Jay Lehr, Senior Scientist with Environmental Education Enterprises.

SESSION 1A:

REAUTHORIZING THE FEDERAL CLEAN WATER ACT AND SAFE DRINKING WATER ACT: CAN WESTERN WATER NEEDS BE RECOGNIZED? (PART 1)

Moderator: Chuck Graf
Arizona Department of Environmental Quality

POLITICAL AND LEGISLATIVE HISTORY OF CLEAN WATER ACT REAUTHORIZATION

James D. Ogsbury[1]

Efforts to reauthorize and reform the Federal Water Pollution Control Act (a.k.a. the Clean Water Act) during the 103d Congress illustrate many of the conflicts inherent in the intersection of science with public policy development. These efforts are examined in the broader context of national environmental politics and by reference to a recent backlash against legislative environmentalism. This backlash has manifested itself in the growing popularity of the "unholy trinity" of influences gaining favor in congress: protection of private property rights; risk assessment and comparative analysis; and restriction of unfunded federal mandates.

As originally enacted in 1972, the Clean Water Act was largely designed to abate the direct discharge of contaminants by industry and other "point" sources of pollution into navigable streams and rivers of the United States. Because of the Act's success in reducing water pollution from point sources, reauthorization efforts focus principally on the expansion of non-point source pollution control programs. Other substantive issues involved in the reauthorization debate include: watershed management, wetlands regulation, water quality standards for the arid West, estuary management, antidegradation, and enforcement. A recent Supreme Court decision *(PUD No. 1 of Jefferson County et al. v. Washington Department of Ecology et al.)* upholding the authority of the states to impose instream flow requirements as a condition for the issuance of section 401 water quality certifications is certain to influence future debate on reauthorization of the Act.

---

[1]James D. Ogsbury is the manager of federal relations for the Salt River Project in Washington, D.C.

ARIZONA'S PARTICIPATION IN CLEAN WATER ACT AND SAFE DRINKING WATER ACT REAUTHORIZATION[1]

Brian E. Munson[2]

Arizona is an important stakeholder in the reauthorization of the federal Safe Drinking Water Act (SDWA) and Clean Water Act (CWA). For this reason, the Arizona Department of Environmental Quality (ADEQ) has participated frequently in national and regional dialogue with respect to issues related to the implementation and administration of these acts. This presentation explains Arizona's involvement in this dialogue and discusses major issues that are of importance to State water quality programs.

Arizona's perspectives on the SDWA compared to the CWA differ in one important respect. The concerns with the SDWA are not markedly different from those of other states, and focus primarily on the prescriptive nature of requirements and the impact on state and local resources. On the other hand, the concerns with the provisions of the CWA are more ecological in nature, and reflect a discomfort with the imposition of national standards on phenomena that have different regional expression. A review of the issues and efforts to address them are provided below.

Safe Drinking Water Act

ADEQ sponsored a "Decision Maker's Seminar" in the winter of 1991 to discuss the issues surrounding the State's drinking water program. The seminar was attended by many major state stakeholders, including state lawmakers, various state and local officials and representatives from regulatory agencies and the regulated community. The attendees at the seminar confirmed that the State should retain primacy (authority to administer) for the federal Drinking Water Act, and identified some major issues that needed to be addressed in the near future. These issues included the need for:

1) adequate funding for state programs,
2) administrative penalty authority,
3) the ability to determine whether a new water system is able to sustain itself (viability), and
4) capital funding mechanisms for small systems.

Although a process was suggested for pursuing these issues at the State level, it soon became clear that many of them would be addressed nationally with the SDWA reauthorization effort.

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[1]Extended abstract of a presentation at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22, 1994.

[2]Brian E. Munson is the Director of the Water Quality Division, Arizona Department of Environmental Quality.

In the spring of 1992, Governor Symington was invited by then EPA Administrator William Reilly to be a member of a Governor's Forum on Environmental Management. The purpose of the Forum was to identify issues, from a state's perspective, related to environmental legislation and to propose solutions to Congress, if necessary, to address the issues. Because of the pending reauthorization of the SDWA, it was the first (and last) topic to be addressed by the group. Several recommendations were suggested by the group for consideration by lawmakers as they proceeded with reauthorization. The recommendations included:

1) increase appropriations to the state and avoid future requirements unless at least 75% of implementation costs are provided,
2) require states to explore alternative funds,
3) adopt a risk based approach for program implementation,
4) encourage pollution prevention by providing incentives for wellhead and watershed protection initiatives,
5) give states flexibility to determine scope of monitoring requirements and streamline variance, exemption and waiver procedures,
6) avoid new statutory requirements unless they address significant risks and resources are available to deal with them,
7) eliminate provisions requiring specified numbers of contaminants unless shown to be of significant risk, and
8) incorporate 4 and 5 into statute if there is not sufficient flexibility now.

In September of 1993, EPA Administrator Carol Browner (who participated in Administrator Reilly's Forum) issued ten recommendations for the reauthorization of the SDWA. These recommendations were:

1) establish a drinking water state revolving fund to offer low interest loans for capital improvements,
2) maintain state primacy through establishing user fees with federal backstop (minimum fees),
3) establish baseline Source Water Protection Programs (i.e. wellhead protection),
4) establish enhanced Source Water Protection Programs with incentives for alternative monitoring and prevention-based treatment exemptions,
5) ensure viability of small systems (contract out O&M, service or utility districts, consolidation),
6) establish small system "Best Available Technology" - less expensive than conventional BAT,
7) train and certify systems operators,
8) improve process for selecting contaminants to be regulated (adopt risk-based study approach),
9) provide EPA flexibility to set compliance timeframes (60 months vs. 18 months to adopt regulations), and
10) streamline and strengthen enforcement provisions (including administrative authorities).

The Administration proposal addressed all of the issues raised by the stakeholders in the Arizona Decision Makers Seminar as well as

the recommendations by the Governor's Forum on Environmental Management.

The Senate passed a bill earlier this year that substantively addressed all of the issues with the exception of user fees. Although the practice of specifically requiring a set number of contaminants for regulation was not replaced, the number of contaminants to be adopted was significantly reduced. A bill is also under consideration in the House, but it's status is considered "volatile." Most people following the activity feel (at the time of this writing) that a reauthorized Safe Drinking Water Act is still likely in 1994.

Clean Water Act

The CWA has also come forward for reauthorization in 1994 (after previous unsuccessful attempts). Arizona has been actively involved in issues surrounding CWA legislation. There are a number of broad provisions in the reauthorization bills that have been proposed which affect many states, and which have been subject to a great deal of controversy. Arizona's chief concern, however, is the applicability of CWA provisions to the arid southwest and the degree to which the CWA takes the arid situation into account.

During Arizona's most recent triennial rule-making effort for surface water quality standards, several distinct issues were raised by ADEQ and individuals participating in the process. The issues concerned special problems with respect to protection goals for 1) ephemeral and intermittent streams, 2) water conveyances and 3) drainages with flows which are dominated by discharges from wastewater treatment facilities. There was also concern about protection of wetlands in the nation and the potential to protect valuable riparian resources in Arizona.

In the spring of 1992, ADEQ, with the help of the Arizona Water Quality Advisory Council, sponsored a series of public meetings to collect input from the public on the CWA and related programs. Meetings were held in Phoenix, Tucson, Flagstaff, Yuma, Holbrook, Wilcox and Kingman. Following these meetings, the Council compiled the comments into ten recommendations for the reauthorization of the CWA. In general, it was stated that the CWA programs were working well, but could use some fine tuning in the areas of:

1) developing specific water quality criteria for ephemeral waterways and effluent-supported waterways that reflect their unique characteristics,
2) giving states sufficient flexibility to make determinations on protection appropriate for canals, flood control systems and municipal park lakes based on the intrinsic use patterns of these water bodies,
3) maintaining a neutral position relative to water quantity issues so as not to interfere with state appropriations of water rights,
4) maintaining an appropriate balance between the protection

of outstanding national waters and the public's ability to use them,

5) controlling discharges from storm water run-off through use of best management practices rather than permits,
6) giving EPA appropriate authority, responsibility and resources to deal with trans-border issues,
7) streamlining existing provisions for EPA approval of tribal clean water programs and adequately fund them,
8) providing sufficient flexibility for appropriate identification, classification and protection of wetlands in arid environments,
9) ensuring that there is adequate funding for existing and proposed regulatory, research, loan and non-point source programs, and
10) providing for a process of establishing and implementing water quality standards that considers both the costs and the benefits associated with them.

These recommendations were then sent from Governor Symington to members of the Arizona congressional delegation to consider during reauthorization proceedings.

In 1992 the Arizona legislature passed a law, sponsored by Governor Symington, to address the protection of riparian-related resources in Arizona. The law required the establishment of a Riparian Area Advisory Committee (RAAC) comprised of representatives from various agencies, municipalities, counties and special and public interest groups from around the state. The RAAC is tasked with the responsibility of identifying an approach for the protection of riparian resources that makes the most sense for Arizona. The results of this effort will likely fill the gaps between the wetland protection anticipated for the CWA and the protection needed for riparian resources in Arizona. A final report and recommendation are required of the RAAC by December of 1994.

In January, 1994, after hearing a group of western states reviewing issues related to the CWA, Robert Perciasepe (Assistant Administrator of the EPA Office of Water) directed Harry Seraydarian (Director of the EPA Region IX Water Management Division) to form an Arid West Work Group. The purpose of the group was to identify recommendations concerning the CWA reauthorization which would address the western state's issues. ADEQ, one of the states originally presenting the issues, was invited to participate.

Later in the spring, after an Arid West Work Group was identified consisting of representatives from EPA regions and headquarters and several western states, development of the recommendations began. At about the same time, an amendment to the CWA was presented to the U.S. Senate by Senator Reid of Nevada. The "Reid Amendment," which was obviously the result of efforts of individuals in the western states, quickly became the focus of the Work Group. The important provisions of the Amendment included:

1) research to develop water quality criteria documents for species and environments for ephemeral and effluent-

dependent streams in the arid west,

2) schedule for developing water quality criteria for ephemeral and effluent dominated streams based on results of the research,
3) consideration for existing and planned uses of canals in adopting standards for the quality of canal water, and
4) statement of policy regarding the importance for promoting the beneficial reuse of water.

The members of the Group representing EPA were obviously uncomfortable with certain provisions of the Amendment, and began by suggesting language which they found more palatable. The states responded with a counter-proposal which they felt they could better tolerate. After several iterations, all of which were conducted by conference call and facsimile machines, a document was produced. An April 25, 1994 memo from Harry Seraydarian and Tudor Davies (Director, EPA Office of Science and Technology) summarized the points of consensus and non-consensus for the Group. Areas of consensus included:

1) clear goals supporting beneficial reuse of wastewater,
2) arid west water quality research agenda to address a broad range of arid west issues (less burdensome than Reid), and
3) a more workable approach for developing standards for constructed conveyances.

Areas of disagreement were:

1) the "breadth" of applicability for provisions for protection of water limited streams (definition of non-perennial),
2) the development of water quality criteria by EPA versus states (using results from arid research projects),
3) the protection of "reasonably foreseeable" uses of effluent dependent streams, and
4) language concerning consideration of hydrologic modifications and water rights in developing water quality standards.

The states involved in the Group followed with a letter to Mr. Perciasepe summarizing their sentiments relative to the process. While greatly appreciative of the efforts of the EPA representatives toward consensus on the issues, there was a shared feeling that the process, due to limitations in time and the nature of the communications, did not result in substantial improvements in addressing arid west water quality concerns.

The most recent proposal in the Senate essentially includes the Reid language. A proposal in the House gives minimal attention to arid west issues. At the time of this writing, there is little hope of a CWA reauthorization Bill passing this session.

SESSION 1B:

DOING BUSINESS IN THE ENVIRONMENTAL FIELD: THE RULES HAVE CHANGED

Moderator: Tracey S. Moore
Transwest Geochem

INNOVATION, TRANSFORMATION, AND THE POWER OF PARADIGMS[1]

Judyth S. Peterson, M. A.[2]

ABSTRACT: The Hazardous Materials industry has traditionally followed a status quo model, which parallels most U. S. business paradigms. With rapidly changing technologies and an increasingly more sophisticated client base, continued growth and effectiveness within the industry will depend upon the development of fundamentally different thought processes, approaches, and applications.

Structurally and philosophically the industry has relied upon paramilitary form and function. Based on autocratic management, regulation by control and command, adversarial relationships, and minimal client involvement, highly skilled specialists have narrowly defined their roles, unilaterally imposed solutions on their clients, and exploited "safe" technologies to assure minimal risk. These paradigms limit innovation and creativity, and block the ability to recognize opportunities.

To survive in a dynamic and sophisticated environment, this global industry must develop new paradigms as a response to societal and business changes, as well as increasingly complex technical requirements. These new models will be most noticeable as they relate to holistic, systems-oriented, collaborative and customer-driven strategies. There will be interdependent, multi-skilled employees, linked with knowledgeable clients in flexible teams; new definitions of success and quality; and a demand for effective, visionary leadership.

This paper reviews past paradigms and values, and proposes opportunities for innovative thinking in the hazardous materials industry. It also suggests resources and methodologies to assist in creative and effective change management.

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1 Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994

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INTRODUCTION

From the civil rights marches of the Sixties to the fall of the Berlin Wall in 1989, and now into the '90's, massive cultural, political and societal changes continue to shatter this country's traditional views and values and threaten its ability to successfully adapt. The United States, historically the world's leader in innovation, technology, and industry, has been competitively challenged and has significantly lost its previous singular position. Changes in personal values, family structure, community demographics, financial opportunities and technology have impacted every societal institution in the country.

Business trends of the '80's and '90's have followed these shifting values and priorities. Change, chaos, transition, transformation, reengineering, restructuring, downsizing, rightsizing all shout the message--things just aren't going to be the same any more. American companies are frantically trying to catch up and secure a position in the international race for customers and dollars, in a market that is continually shrinking as it becomes more demanding.

American managers, who from the Fifties to the mid-Eighties could function more or less effectively in a strong economy, are now hard-pressed to become lean, mean and smart in a very short amount of time. They're chasing an economic moving target, following rules which have all changed in a volatile and unforgiving environment.

Today, customer satisfaction is everything. With the customer driving quality, initiatives for continuously measuring and implementing improvements are imperative. Customers want fast turn-around times, flexibility, personalized service, and the best value for the price.

Strategic planning, partnering, total quality management, policy deployment, employee involvement, teaming, agile manufacturing. Pick up the latest management magazines and count the suggestions for regaining superiority in this global fight for survival. Virtually all of these initiatives challenge our cultural bias for quick fixes and band-aid solutions. They're urging us to work in fundamentally different ways, to change not only the outward, short-term behaviors, but the core attitudes and values which made the U. S. an industrial giant in the first place.

PARADIGMS

Paradigm--a set of rules and regulations that establishes boundaries and tells how to be successful while solving problems within these boundaries. A term borrowed from science, which so aptly describes a powerful human psychological phenomenon. Paradigms form, if you will, windows on the world, describing what is "right" and "wrong," what will work and what won't. But in this time of exponential change, the

future is not just an extension of the past, and what worked yesterday will probably not work tomorrow. When paradigms shift, everything goes back to zero, and all related rules have to be reinvented or reestablished.

Paradigms which support a society or culture have developed over centuries, and are not easily changed. Economic survival, however, depends at this point on our ability to make major paradigm shifts in the way we approach business theory, philosophy and practices. To do so we must first recognize existing paradigms, let go, and move to the next one. Joel Barker describes those hardy souls who are willing to do this as "paradigm pioneers." This is a difficult role to play, because frequently evidence continues to validate the old paradigms, and there's a lag time before the new paradigms begin to demonstrate results.

Business paradigms of the recent past began as early as the 1770s with Adam Smith, continuing into the Industrial Revolution, and Taylor's Scientific Management, and other theories, promoting specialization of tasks, hierarchical structure, division of labor, and so on. These beliefs created paradigms which were necessary to manage complexity, and which provided safely, order and systematic production.

These philosophies have continued, for the most part, supplemented by humanistic concerns generated in the Twenties and Thirties, and continuing to the present time in various industrial psychologytheories, leadership studies and organizational behavior disciplines. Add to that the cultural bias toward decisive action, quick fixes and "heroics." and one begins to see how the foundation for today's economic crisis was established early in our industrial history.

The hazardous materials industry, as an outgrowth of American industry at large, has generally followed the same organizational principles. Basic paradigms include control-based rules and rule-based behaviors; a para-military model of hierarchy and autocracy; crisis management; regulation by command/control; band-aid solutions/one generation view. "Out of sight, our of mind; ignorance is a solution. Philosophies, practices and technologies that are based in the past, anchored in the status quo, "proven" versus innovative. Technical specialists who tell the uninformed client what he really needs, accomplishes short term gains, and disappears.

OPPORTUNITIES

The environmental and hazardous materials industries are at a critical juncture. There has been phenomenal growth as society in general and industries in particular become more aware of, and concerned about, the earth and the need to make dramatic changes if we are to provide a clean world for our future.

Today, customer expectations have soared in all markets. Competition is intense, and

good performers drive out the inferior performers. A "best performance" from one organization soon becomes the standard for all. Change has become a constant, the norm, and the pace is accelerating.

The key words today are fundamental, as in looking at our fundamental processes, ignoring what is and concentrating on what should be; radical, by reinvention and not improvement, disregarding existing structures and procedures; dramatic, a willingness to abandon what has long been successful in order to achieve quantum leaps in performance; and processes, focusing on overall organizational processes and systems rather than narrow tasks, recognizing that tasks don't matter if the overall process doesn't work.

TQM, reengineering, innovation, thriving on chaos, reinvention--what do they have in common? Chief among them is their advocacy of rule-breaking, of throwing away old paradigms, old assumptions about specialization, sequentiality, and timing. They all suggest radical breaks with old traditions, of "going back to zero" to creatively redesign, not just "fix," fundamental business processes and practices.

The most innovative companies, the Xeroxes, Motorolas, 3Ms of the world have taken the lead in developing, implementing, and proving new leadership and organizational technologies. Customer satisfaction has become the leading corporate value, providing a new superordinate framework for organizational operations. Exceeding customer expectations. One hundred per cent customer satisfaction. How can companies expect to meet such lofty goals?

Today there are opportunities to truly develop and use the unlimited talent of the American work force. A small, rapidly expanding environmental sampling firm has taken some significant first steps. The leaders of the company have stepped outside the industry paradigms to imagine "what-ifs". What if our vision were based on the competitive edge of innovative technology? What if our employees were fully involved, committed to our vision, energized around common goals? What if our clients were full participants in the planning and execution of our services? What if we were truly a group of interdependent, multi-talented persons linked in a team organization? What if we could create an innovative business model that would turn the industry upside down with excitement and possibilities?

They began by having leadership retreats, to develop the vision, cohesiveness and commitment at the top. They stretched themselves to examine their current organizational and industry paradigms, and identified what was still working for them, what was not. They began developing a strategic plan, with corporate values, goals and metrics to flow down throughout the organization. They looked at their organizational structure, the opportunities that exist in the market, their potential for both long- and short-term growth. They are determining how to position themselves for maximum structural flexibility and technical ability in order to meet and exceed customer expectations now and in the future.

New paradigms will also include the fusion of historical factions, the partnering of previously adversarial parties, whether consultants/engineers and remediation, bargaining unit and management, attorneys and clients.

A solution based approach, lasting solutions for multiple generations, requires the participation, commitment, and support of all the key players, with regulation by cooperation and mutual consent. Actual risk and prioritization of sites will displace perceived risk, and the legal role will become supportive and diplomatic. Any valid analytical technique may be worth considering, including fixed lab, field lab, and field screening. Perhaps most significantly, there will be a paradigm in which the client is educated and experienced with environmental regulations, and will have had experience in dealing with consultants, engineers, remediation, and attorneys.

Business philosophies will be based on the recognition of change, with heightened awareness of the need to anticipate, observe, act, and respond to industry changes. Teams, as described above, will be the basis of company structures and operations, with new ideas encouraged from all employees, a high level of open and relevant communication, and a strategic view driven by vision, integrated goals, and personal commitment. Products and services will be based on the competitive edge of innovative technology, with an acceptable and calculated level of risk.

Work units will change--from functional departments to process teams. Jobs will change--from simple or specialized tasks to multi-dimensional work. People's roles will change from controlled to empowered. Job preparation will change--from training to education, and the focus of performance measures and compensation will shift from activity to results, from individual contribution to team performance and personal development.

There will be new definitions. *Success*, in the new paradigm, will be defined by satisfying the needs of internal/external customers, by building core competencies and team depth, and by being responsive to market changes and opportunities. *Quality* will be defined by exceeding the expectations of the customer, by innovation, reliability, consistency. *Management* will be a leadership function, fostering development of minds, skills, and values, gaining participation, commitment and synergy, developing collaboration and sharing vision.

The new paradigms take a holistic, systems perspective, in which all stakeholders must be included and all processes and sub-processes must be optimized to meet the competitive requirements. Teams and leaders will spend time in "think tank" settings, future search conferences, skunkworks, and creativity workshops to design the industry of the future. Innovation and critical thinking skills will be as important to employment as the latest technology.

There are implications for all organizational systems and processes, from the

organizational structure, to the selection process, training, compensation, job definitions, work flow, leadership practices. Impacts too massive to be done in incremental steps. Changes that will require breakthrough thinking and a willingness to continually go back to zero.

CHALLENGES

Paradigm pioneers take great personal, professional, and corporate risks. Blazing new trails requires suspending judgment long enough for results to finally appear. It means breaking away from the "tried and true" long before it looks like the "right" thing to do. It means trusting in gut feelings before the facts and data add up to proper evidence. It's setting aside proven assumptions and making a "leap of faith."

It also means supporting personal and organizational change, as the industry transforms itself from what was and is to what could be. It's "hanging in there" while human beings struggle with new ways of relating to one another and to their world of work. It means acknowledging the fluid and dynamic nature of business in the Nineties, of the precarious position of a young, rapidly expanding, and globally essential hazardous materials industry positioning itself for the twenty-first century. It's establishing and maintaining an integral partnership with clients, regulatory agencies, and technical disciplines in order to define and meet mutual goals. Exclusive self-interest and territoriality will have no place in enlightened working relationships.

RESOURCES AND METHODOLOGIES

One of the first steps is to establish alignment, empowerment, and innovation as core values within organizations. This may be done by strategic planning, creating a corporate vision, supported by strategic goals, corporate values, best practices, and a review of the integrity and consistency of internal procedures and practices. A total commitment to customer satisfaction, and use of continuous measurable improvement philosophy and tools is critical, with careful attention to customer involvement and feedback. Companies must be well-informed on the latest improvement principles and technologies, in order to better identify what makes sense to implement, rather than continuing to jump on the latest bandwagon.

There are innovative thinking training courses, techniques and processes which may become a regular part of organizational problem solving and decision making. A critical question should be asked continually, in order to identify breakthrough improvement opportunities: **What is it that today is impossible for us to do in our business, but if we could do it, would fundamentally change the way we operate?** The answer to this question will enable an enterprise to set new industry standards of excellence, and establish dramatically new and powerful paradigms.

The concepts of teaming and partnering hold perhaps the most promise for major innovations. Not only is there great value in combining talents, perspectives, and disciplines, but often those "on the fringes," those who are outside the technology or on the edge of the business, can be most helpful in exposing outdated assumptions and in creating new possibilities. Dynamic organizational structures, such as flexible project teams, will allow quick response to changing customer and situational requirements as well as technology and process innovations.

CONCLUSIONS

The Hazardous Materials industry has developed rapidly, following traditional structural and management models from manufacturing and military organizations. In order to position itself competitively for the future, and assure continued delivery of high quality environmental services in a global market, it must avail itself of a variety of innovative strategies currently understood and embraced by leaders in other industries and disciplines. This requires a recognition that many traditional paradigms, if continued, will maintain the status quo and lead to stagnation and ultimate organizational failure. It also demands a willingness to move on to new models of thought, belief, and operation. Although this involves considerable risk, it significantly increases the probability of continued effectiveness and organizational success through quantum improvements in ability to meet and exceed customer demands.

RECOMMENDED RESOURCES

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EVOLVING CONCEPTS FOR OPTIMAL UTILIZATION OF ENVIRONMENTAL LABORATORY SERVICES[1]

by Tracey S. and Ted R. Moore[2]

ABSTRACT

A means of improving utilization of mobile and fixed-base environmental laboratory services and decreasing costs by enacting an 'Intelligent' Planning program is presented. The program is presented following a historical perspective of how mobile lab services have evolved over the past ten years.

The environmental laboratory business has evolved significantly over the last ten years. As a result of changing technologies and the ever-increasing need for faster results, mobile laboratories are becoming the standard in environmental field projects as opposed to the exception just a few years ago. In order to fully utilize mobile analytical services, and remain competitive, the environmental professional will find that increased interaction, management, and an understanding of the services being provided is necessary to optimize the rigorous constraints of available time and funds.

In order to provide insight to the optimal usage of mobile and fixed-base lab services in the late-1990's, the authors, both geologists (who operate an environmental laboratory), have implemented loose analogy to the geologic eras. These eras are exemplary of distinct periods in the evolution of environmental laboratory services over the past twenty, or so, years. The Paleozoic Lab Era (before 1985) describes the period prior to existance of mobile laboratory services. The Mesozoic Lab Era refers to the earliest inception of mobile laboratories in the mid- to late-1980's. The Cenozoic Lab Era refers to the period of rapid proliferation of smaller fixed-base and mobile environmental laboratories during the early 1990's. As we progress in the mid 90's, a more evolved and utilitarian approach to the usage of laboratory services is developing as a result of 'Intelligent' Planning and the 'Team' Planning approach. The "GOAL" of this optimized lab usage system is to provide:

- real-time data gathering as well as an increase in the amount of data;
- legally defensible and certified analytical data;
- a reduction of on-site personnel and equipment costs by providing quick results;
- reasonably priced lab services in conjunction with a long-term reduction of lab costs related to rational planning and usage.

It is important to backtrack and look at where the industry has been in order to assess what is currently being offered and how best to utilize those services. Like most industries, the environmental lab business has evolved through trial and error, supply and demand, market competition, and the resulting education and sophistication of their client-base.

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[1] Paper presented at the New Mexico HAZWaste Management Society Annual Symposium, Albuquerque, New Mexico, March 8-10, 1994

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THE PALEOZOIC LAB ERA (before 1986)

The Paleozoic Era of environmental laboratory operations is characterized by a relatively small number of large, fixed-base laboratories. During the Paleozoic Lab Era, the environmental client would submit a sample set to an environmental laboratory and wait patiently for two, three, or four weeks until analytical results were received. In general, a 2 to 4-week turn-around-time (TAT) was the norm. The use of 'RUSH' analyses for substantially increased fees was the exception as these services were either unheard-of or prohibitive. During this era the most cost effective way to facilitate rush analyses was to Fed Ex samples to a distant laboratory, shortening the turn-around-time by one or two days. Thus, the poster "You want it when??!!" Pricing among the individual laboratories was comparable, though expensive. High, per-analysis rates were common, and negotiable only for massive projects and contracts.

Usually, there was little discussion about project objectives, analyses run times, dilutions, and number of samples that could be run in one day. Unless a large set of samples was to be submitted, or rush analyses were planned, it was generally not critical that the laboratory even be contacted ahead of time. Few samples were analyzed per project, usually the minimum required by regulatory agencies, due to price. The actual extent of contamination was determined by lab fees instead of the scientific method. It was common to leave high liability excavations, trenches, and boreholes open during the two to four-week period. Occasionally, it was possible to leave heavy equipment onsite; however, a second mobilization (with ensuing costs) was usually required. The client generally did not interface with the laboratory to any degree, other than to submit samples. Upon receipt of results, "hits" would possibly be discussed with the lab director if the results were questionable.

Similarly, the client was generally not "cognizant" of the Quality Assurance (QA) process during the analytical process. QA was a black-box concept; an extra page in the report which told us the data must be OK. The client had no knowledge of common laboratory problems regarding high concentrations, dilutions, equipment failures, re-runs, and the time (cost) of re-doing entire sets if the QA didn't work. For smaller sample sets, QA or calibration could be run for several data sets at once resulting in cost reduction for the laboratory. Large sets could be run on auto samplers for additional cost reduction.

THE MESOZOIC LAB ERA (1986-1989)

The Mesozoic laboratory era is characterized by an increased demand for Rush services and the inception of mobile laboratories. These increased demands were a result of environmental site assessments with difficult time constraints and the realization that faster turnaround would result in decreased personnel, equipment, down-time, and liability costs for tank removals and other routine projects.

Larger laboratories realized there was a market for "Rush" analyses. Analyses were offered at one-week (100%), 48-Hour (200%), and 24-hour (300%) surcharge increments. The demand for even faster turnaround resulted in the introduction of the first mobile labs with astronomic setup and mobilization fees, minimal on-site reporting, and RUSH per-analysis fees. Mobile laboratories were too costly for most projects. With the ever-increasing costs associated with environmental projects, the mobile analytical laboratory assisted the environmental professional's "need to know", NOW! The use of mobile labs was limited to expedience for the purpose of excavation closure and meeting critical deadlines. The mobile units were used only as a last resort with a minimal number of samples analyzed due to the high rates. Federal Express combined with fixed-base lab RUSH TAT was usually less expensive. The operative phrase was "Sure, we could do that, how big is your client's budget?"

The introduction of mobile laboratories could be considered analogous to that of the facsimile. The advent of the mobile analytical laboratory made it possible to plan analytical results in "real time," thereby making it possible to; 1) provide immediate information regarding distribution of contaminant "plumes"; 2) backfill high-liability excavations and trenches rapidly; 3) knowingly drill exploratory boreholes to points of non-detection of contaminants; and 4) assist in decisions regarding additional locations for sampling and exploration points. The limited availability of mobile laboratories had to be considered early in the planning process when scheduling field work as the lab was the most critical part of the on-site puzzle.

The quality assurance programs for the early mobile laboratories ranged from non-existent and screening mode (EPA Level I) to standard state certified EPA Level II. In the early days of mobile labs, many states refused to recognize the legitimacy of mobile labs due to low quality operations and the unsuitability of many bench instruments to field operations. Chemists had to struggle with the evolving technology, as well as the added time and cost of providing dedicated QA data sets. Another problem related to misconceptions about immediate turnaround capabilities also evolved. Once again 'black-box" technology took over and clients began to say, "Here's my sample, where are the analytical results?"

THE CENOZOIC LAB ERA (1990-1993)

The Cenozoic era was characterized by a rapid proliferation of smaller mobile and fixed-base laboratories in a rapidly growing and competitive market. This lab proliferation was spurred by the demand for RUSH analyses related to real estate assessments and the growing realization by project managers that field expenses are reduced by rapidly obtaining results. Thanks to use of mobile laboratories, 'immediate' TAT became the norm. The transition from 24-hour lab service to 'instant' service is analogous to the facsimile and modem replacing express mail and has had a similar impact on the expectations of lab clients. The proliferation of mobile laboratories was not without its problems, as the following paragraphs will indicate.

In order to gain entry to the market and survive, smaller start-up labs gained an advantage over the lethargic larger labs by introducing the concepts of daily rates and high volume analytical production. This high-volume, low priced infusion has revolutionized environmental field projects. Clients were no longer crippled by Paleozoic lab budget constraints and finally had the flexibility to request the analysis of a large portion of their sample sets. The consultant is able to gain a much better understanding of a given contamination problem by reducing the 'insufficient data' problem.

The laboratories offering field services have become highly competitive in services and pricing. These conditions have both positive and negative ramifications for the client. On the up-side, the client can conceivably get more for their money, as laboratories, in their efforts to obtain more of the market share, promise high volume. In fact, mobile lab analytical services have become less expensive than fixed-base standard turnaround rates. The down-side develops when a laboratory representative over-promises volume or fails to be specific about the limitations and add-on charges for the field services being purchased.

The net effect of over-committing services is one in which the best interest of the field chemist has been compromised. As a result, it is inevitable that these laboratories will experience chemist burnout and high employee turnover. The field chemist is a highly evolved species. They are educated individuals who knowingly subject themselves to intensely long days (14 to 18 hours are not uncommon) on a regular basis.

Rapid turnover within a laboratory is not in anyone's best interest. Overly competitive offers by laboratories and price-volume competitive shopping by overly-aggressive members of the consulting community have taken their toll in chemist attrition in the Cenozoic Lab Era. The client has experienced less efficiency during the ensuing training periods resulting in overall higher costs.

Planning, and the interface between the lab and the client, began to develop during the Cenozoic Lab Era. With the inception of daily rates and volume pricing, clients began to change their approach to analytical planning and management of the sample submittal to

the on-site laboratory. However, the misconception that a daily rate meant unlimited analyses per day led to extensive and abusive use of mobile laboratories and chemists. Toward the end of the Cenozoic, the daily rate became subject to extensive restrictions and add-on fees when projects did not go as planned (which is most of the time).

Due to the proliferation of mobile laboratories, with some companies having several labs available, the laboratory was often scheduled last after the other pieces of the field puzzle were set. When another sub-contractor had a schedule problem the lab was cancelled or re-scheduled on short notice. This short-notice cancellation resulted in tremendous loss of revenue for the laboratories due to idle days that could have been scheduled elsewhere with sufficient notice. Most clients still did not make efficient usage of the labs with respect to analytical run times, screening, or combinations of analyses to provide the best information for the dollar.

The greatest difficulty in laboratory interface with the client during the Cenozoic Lab Era was conveying the necessity to dedicate time for Quality Assurance. When a mobile laboratory is scheduled, the client is buying a dedicated QA set, consisting of 8 to 10 analyses whether one or ten samples are to be run. There are QA analyses which must be run every ten samples in order to validate that set. The common response is "What do you mean you can't run this right away, the drillers are on standby?" Or at the end of a fourteen-hour day, the chemist is looking at two more hours of post-set QA and the client says "All we need are two more analyses." What the client does not realize is that not only is the QA for the just-completed set not done, but the additional two analyses he has requested will necessitate another two-hour QA data set. This means a total of five more hours of work for the chemist.

THE NEXT GENERATION LAB ERA (1994-??)

The Next Generation Lab Era has already begun and is characterized by 'Intelligent' Planning to obtain the optimal combination of TAT, information, and price. By carefully planning a project in conjunction with the laboratory a manager can optimize his laboratory investment and avoid many of the problems of the Cenozoic Lab Era. The process of Intelligent Planning consists of the following key points:

Strategic Analytical Planning

By discussing project needs with the laboratory, the following topics can be considered with regard to optimizing analytical efforts:

- Immediate analysis of all samples, by all required methods, is not necessarily the most efficient use of the mobile laboratory because some analyses, e.g.,. Method

8010, have much longer run times on the gas chromatograph and will drastically slow down other analyses with shorter run times (e.g., BTEX).

- Rather than using the mobile lab with slow analyses, it may be preferable to run slow analyses in a second mobile lab or shuttle them back to the fixed-base lab. This way the mobile lab can be using on-site time more efficiently.

- Some analyses can be performed in a mobile lab, but are not practical in terms of time and set up costs, eg. metals and TCLPs. Other methods such as Method 8010, are marginal due to problematic conditions related to power conversion and temperature fluctuation.

- In situations where compliance testing is not an issue, i.e., where a contaminant plume has been characterized and defined, customized methods may be applied to save the client both time and money.

Team Scheduling

By incorporating the laboratory into the team for planning scope and scheduling time allocations, the client may reduce his cost, improve performance, and reduce cancellation and re-scheduling fees. Communication between the project manager, the lab operations manager, and the field personnel for each team member is the most critical factor to establishing an efficient rapport. The field personnel must be aware of possible contingencies when the project does not go as planned, and also be aware of the costs associated with various options for changing the scope.

Quality Assurance and Quality Control

By taking the Intelligent Planning approach, it is necessary to understand the amount of time the mobile lab MUST commit to QA/QC. For a typical "10-hour" on-site analytical day, the chemist (or lab) is actually conducting 13 to 14 hours of analytical work. Of this 14 hours, 5 to 6 hours (if all goes well) may be dedicated to calibration and other QA analyses as follows:

- Pre-Project Setup and Calibration - Approximately 2 hours.
  Includes: blanks, low, middle, and high standards, and QC check standards.

- Mid-Day QA (after each set of 10) - Approximately 1.5 hours.
  Includes: sample duplicate, blank, continuous calibration, and matrix spike.

- Follow-up QA (after last set) - Approximately 2 hours.
  Depending on number of samples this QA set is the same as a Mid-Day QA set plus additional analyses as required, re-runs, and confirmation runs.

Price

Many considerations in this paper have been directed toward cost savings, either directly or indirectly, through Intelligent Planning. It is important for the project manager to thoroughly understand the laboratory fee schedule and know how changes to the initial plan may affect the cost of the project with respect to laboratory services. The trend in mobile lab services may be back to per-sample rates because most projects fall short of daily quota; the number of samples is generally smaller reducing chemist overload and burnout; and the overall cost is generally lower. Intelligent Planning **will** reduce costs!!

CONCLUSION

The environmental laboratory service of the future will require heavy participation and communication between the client and laboratory prior to project commencement and on-site activities. In the future, the client will need to understand not only the regulatory scenario for his assessment but also the nature of work practices and regulations regarding the analytical laboratory.

The client must set realistic analytical project goals, based on analytical equipment and personnel capabilities, time and budget constraints, and subsequently manage the submittal of samples to the laboratory to achieve the desired outcome. Clients must consider the impact of sample submittal timing, prioritization, and potential concentrations. The client should be aware of the QA/QC schedule with respect to allocation of time for analyses, especially at the end of the day.

As a result of the above discussion, it is anticipated that the mobile laboratory of the future may commonly provide on-site services on a per-analysis basis. This type of fee structure is self-regulating and ultimately in the best interest of clients. The daily rate may still be available for certain applications and for the convenience of clients. Both methods of setting fees should be comparable if the work product is fairly priced by the laboratory.

The "GOAL" of this Intelligent Planning method is to optimize lab usage by providing:

- real-time, increased data gathering;
- meaningful and defensible analytical data;
- reduced on-site project costs through efficiency;
- reasonably priced lab services now and later.

By working together, intelligently, the GOAL is attainable.

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SESSION 1C:

GROUNDWATER MONITORING: TIPS, TOOLS, AND TECHNIQUES

Moderator: Rich Petrus
Roy F. Weston, Inc.

GROUNDWATER MONITORING REQUIREMENTS AT MUNICIPAL SOLID WASTE LANDFILL FACILITIES[1]

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ABSTRACT: Due to the recent state implementation of federal solid waste rules presented in 40 Code of Federal Regulations (CFR) Part 258, commonly referred to as Subtitle D, owners and operators of municipal solid waste landfills are required to satisfy specific requirements related to the location, operation, design, groundwater monitoring, and closure of their facilities. Unless a demonstration of no potential for migration of contaminants from the landfill is made, landfill owners and operators must design and construct a long-term groundwater monitoring system to monitor groundwater quality in the uppermost aquifer, both upgradient and downgradient of the facility. Samples must be collected from each facility monitoring well at a minimum of semi-annually and analyzed for a discrete set of chemical constituents. The results are statistically evaluated for specified constituents to determine if there is statistically significant evidence of groundwater contamination from the landfill.

This paper describes the groundwater monitoring program; the schedule in which landfills are required to have groundwater monitoring systems in place; what is required of landfill owners and operators regarding the design of a groundwater monitoring system; sampling and analytical requirements; and requirements for detection monitoring, assessment monitoring, and corrective action. Statistical methods which are mandated by regulation for the evaluation of monitoring data are also discussed.

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BACKGROUND

Potential Impact of Landfills on Groundwater Resources

Contamination of groundwater resources represents the most significant environmental threat posed by landfilling of municipal solid wastes. The United States Environmental Protection Agency (EPA) has estimated there are approximately 75,000 landfills in the U.S., of which approximately 75 percent may be impacting groundwater quality (Lee, 1991). Within the State of Arizona, there are 91 operating landfills and 217 closed landfills on record with the Arizona Department of Environmental Quality (ADEQ), with an unknown number of illegal and unidentified dumps throughout the state. Several federal and state superfund sites are the result of past practices related to the landfilling of solid wastes.

Landfills pose a threat to groundwater resources by providing an environment which, if not managed properly, will allow stormwater to infiltrate and leach pollutants from waste materials, and discharge contaminants to the vadose zone and aquifer system underlying the landfill. The characteristics of leachate produced in the landfill is dependent on the characteristics and age of the waste materials, with common contaminants such as total dissolved solids (TDS), hardness (total alkalinity), chloride, ammonia, hydrogen sulfide, chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total organic carbon (TOC) produced from mature landfills. In younger landfills, where wastes are undergoing aerobic decomposition, the leachate generated will be more oxidized with higher concentrations of constituents, such as nitrate and sulfate.

Historical Regulation of Landfills for Groundwater Protection

The first regulatory protection of groundwater resources from landfills in Arizona was through the Groundwater Quality Protection Permit (GQPP) program promulgated by the Arizona Department of Health Services in 1984. From its inception the GQPP program was problematic in implementing, and litigation resulting from questions over the scope and validity of the GQPP program prompted the development of the Aquifer Protection Permit (APP) program included in the Environmental Quality Act of 1986 (Fennemore Craig, 1993).

The APP program was the first comprehensive program in Arizona requiring all landfill facilities to obtain an environmental permit in which the protection of groundwater resources beneath the site was required as a condition for facility operation. The APP program required facilities to characterize pollutants in a potential facility discharge and to prepare demonstrations to the satisfaction of ADEQ that the facility was utilizing the best available demonstrated control technologies (BADCT), that the facility would not cause or contribute to a violation of an Aquifer Water Quality Standard (AWQS), and that the facility had available sufficient technical and financial capabilities to comply with the conditions of the APP (ADEQ, 1991).

Implementation of Subtitle D Regulations

In response to growing national concern over the impact on the environment due to the disposal of municipal solid wastes, Congress amended the Resource Conservation and Recovery Act (RCRA) with Subtitle D. This amendment defined minimum national standards for municipal solid waste landfills (MSWLFs) with the option of using alternate standards that satisfy specified performance criteria (EPA, 1991). Subtitle D mandated minimum standards for location requirements, operating requirements, design criteria, groundwater monitoring and corrective action, closure/post-closure requirements, and financial assurance requirements for MSWLFs.

The intent of Subtitle D is to allow states to develop solid waste programs suited to their own needs which satisfy the national standards. EPA-approved states have the authorization to approve demonstrations for landfill designs and operating practices that satisfy the Subtitle D performance-based criteria. For landfills in unapproved states, all prescriptive standards of Subtitle D must be satisfied.

To obtain an EPA-approved state program for Arizona, ADEQ developed a draft rule package for solid waste landfill facilities incorporating the requirements with the APP program and existing state solid waste rules. After several unsuccessful attempts to obtain EPA approval, Senate Bill 1417 was passed on April 25, 1994, which adopted Subtitle D by reference as part of the state requirements for municipal solid waste landfills. The bill also removed municipal solid waste landfills from the APP program. ADEQ anticipates EPA approval to implement the Subtitle D program by December, 1994. ADEQ intends to continue to develop their solid waste landfill rule package for future approval.

Those facilities that accept municipal solid waste are regulated under Senate Bill 1417; all other solid waste facilities remain regulated by the APP program. This paper presents groundwater monitoring requirements for municipal solid waste facilities under the new Senate Bill 1417, including applicability, system design requirements, monitoring well design requirements, sampling and analysis requirements, monitoring plan and corrective action requirements, and statistical evaluation of groundwater data.

GROUNDWATER MONITORING SYSTEM REQUIREMENTS

Applicability

Subtitle D groundwater monitoring requirements are not applicable to solid waste facilities that have not received waste subsequent to October 9, 1993 for facilities that receive more than 100 tons per day, or April 9, 1994 for facilities that receive less than 100 tons per day. Any facility that has received or will receive

municipal solid waste subsequent to the applicable date is regulated under the new rule.

A provision is allowed for an exemption from these groundwater monitoring requirements if ADEQ, upon obtaining EPA approval, is provided with an adequate demonstration by the facility that there is no potential for migration of hazardous constituents from the landfill to the uppermost aquifer system during the active life of the facility, including the post-closure period. To obtain an exemption under this provision, the owner or operator of the facility must provide ADEQ with a satisfactory demonstration of no potential for migration certified by a qualified groundwater scientist based on modelling of contaminant fate and transport for the facility. The model must incorporate site-specific field measurements to determine the physical, chemical, and biological properties affecting the fate of migrating contaminants. Where assumptions are made for variables affecting fate and transport modeling, they must be made so as to maximize the potential for migration (EPA, 1991).

Implementation Schedule

Most MSWLFs will not be exempted from groundwater monitoring, and are required to have operational monitoring systems installed according to a compliance schedule which is based on the distance between the landfill and the nearest drinking water intake. The nearest drinking water intake may include water supplied from either a surface or groundwater source. MSWLFs that receive over 20 tons per day must have a monitoring system in place by October 9 of this year if they are located within one mile of a drinking water intake, by October 9, 1995 if they are located over one mile but less than two miles from the nearest drinking water intake, and by October 9, 1996 if located further than two miles from the nearest drinking water intake. Smaller landfills that receive less than 20 tons per day must have groundwater monitoring systems in place by October 9, 1995 if located less than 2 miles from a drinking water intake, or October 9, 1995 if located further from the nearest drinking water intake.

System Design

The objective of the groundwater monitoring system is to detect groundwater that has been impacted by a discharge of contaminants from the landfill. The system must consist of a set of both upgradient and downgradient wells monitoring the uppermost aquifer system. The downgradient wells must be located at an approved relevant point of compliance, which is required to be on the landfill property no more than 150 meters from the waste management area. The system should provide as early a detection as possible to allow time for implementing corrective actions before contamination reaches supply wells downgradient of the facility. Figure 1 illustrates the necessary elements of a groundwater monitoring system for landfill facilities.

Due to the extensive duration for which the monitoring system must provide representative groundwater samples, which typically includes the active life of the facility and a 30-year post closure period, Subtitle D specifies minimum monitoring well design requirements for use in the groundwater monitoring program. Monitoring wells must be cased to protect the integrity of the borehole, with a screened or perforated interval to allow groundwater to enter the well casing. The annular space between the screen and the borehole wall must be filled with a filtering media to prevent the migration of formation material into the well. The openings in the well screen must be sized according to the filtering media used. The annular space above the filter pack must be sealed to provide a discrete sampling interval. The design, installation, and decommissioning of monitoring wells at landfills must be certified by a qualified groundwater scientist.

Subtitle D does not specify a method for determining the location of sampling points in the monitoring system, but does require that hydrogeologic conditions be accounted for in determining the number, location, and spacing of monitoring wells. Hydrogeologic characteristics that must be accounted for include:

- Aquifer thickness;
- Groundwater flow rate;
- Groundwater flow direction;
- Vadose zone stratigraphy; and
- Aquifer characteristics.

The hydrogeological characterization should determine unit thicknesses, hydraulic conductivities, and porosities for the vadose zone and aquifer unit. The design of the groundwater monitoring system must be certified by a qualified groundwater scientist stating that the system will provide representative samples of groundwater both upgradient of the facility and at the facility point of compliance.

SAMPLING AND ANALYSIS REQUIREMENTS

In order to provide consistent and accurate representation of groundwater quality, Subtitle D specifies minimum groundwater sampling and analysis requirements. The sampling and analysis program must be documented with procedures for sample collection, sample preservation and transport, sample analysis, chain-of-custody control, and quality assurance and quality control measures for both field and laboratory activities.

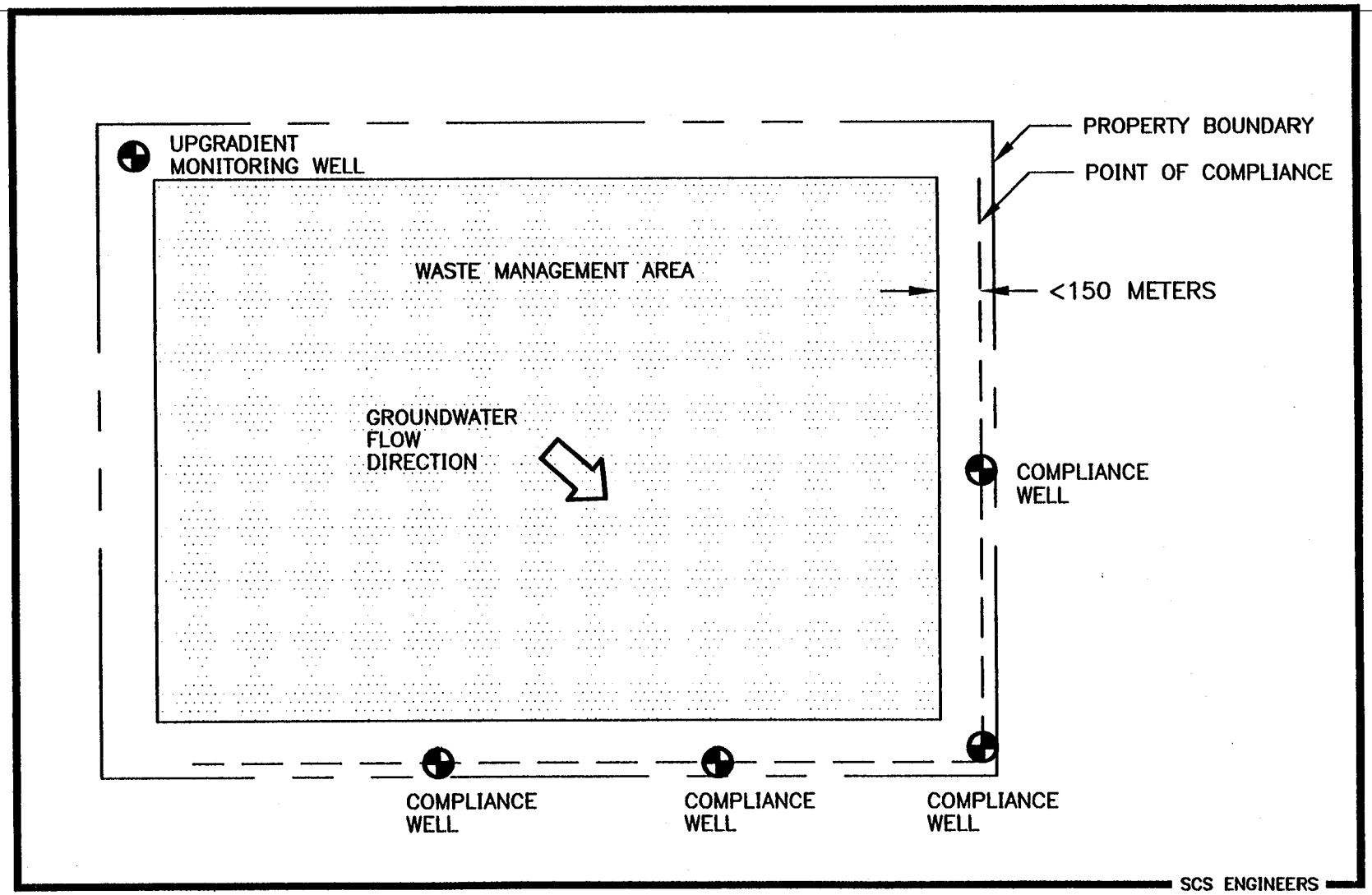

FIGURE 1. MONITORING SYSTEM LAYOUT SCHEMATIC

The frequency of sampling must be at least semi-annual, unless ADEQ authorizes a less frequent interval upon obtaining EPA approval. Groundwater elevation measurements should be made prior to sampling to determine groundwater flow direction and gradient at the time of sampling. During the first sampling period, four independent samples should be collected and analyzed at each sampling location to provide a background characterization of groundwater quality. The number and frequency of sample collection must be determined in consideration of the anticipated statistical evaluation methods that will be used for each analytically tested constituent.

The sampling and analytical procedures should provide adequate accuracy, precision, and detection limit levels for each of the constituents monitored. Analytical methods are not specified, but standard methods that provide suitably low detection limits should be used. Field quality control samples, such as trip blanks, equipment blanks, and duplicates should be collected to verify sample collection quality. The quality assurance and quality control program used in the laboratory should be reviewed for acceptable analytical quality. Analytical reports provided by the laboratory should be validated to ensure data is of acceptable quality.

STATISTICAL ANALYSIS REQUIREMENTS

Approved Statistical Methods

An important aspect of the Subtitle D program is the use of statistical methods to determine if the landfill has impacted groundwater quality. The rule requires the groundwater data be statistically evaluated following receipt of validated analytical data for each sampling event. Several methods for statistical evaluation are allowed in Subtitle D, as well as other methods should they satisfy specific performance standards. Methods specifically mentioned in Subtitle D criteria include:

- Parametric analysis of variance (ANOVA);
- Non-parametric ANOVA (Kruskal-Wallis Test);
- Tolerance intervals;
- Prediction intervals;
- Control charts; and
- Alternative statistical methods.

ANOVA methods, both parametric and non-parametric, determine whether the compliance wells collectively have significantly different mean concentrations of particular constituents from the mean concentrations in the upgradient wells. If ANOVA detects a difference, the test is followed by a multiple comparisons procedure to determine which specific compliance well or wells have mean concentrations significantly different from the upgradient wells.

Tolerance intervals are intervals constructed to contain a designated proportion of the analytical results; results outside of the interval can be interpreted as significant evidence of contamination. Prediction intervals are constructed to contain future analytical data based on past data with a specified probability.

Control charts monitor the constituent levels over time and indicate significant evidence of contamination when a given threshold is exceeded. Control charts are only suitable for wells that have not been impacted by a contaminant release; impacted wells will already be above the given threshold. Control charts are useful in identifying trends in monitoring data.

A common alternative statistical method used for evaluating groundwater monitoring data is the student's t-test, which is suitable for individual well comparisons with normally distributed data. A non-parametric variation of the student's t-test, the Wilcoxin Rank-Sum test, is often used as a non-parametric method in place of non-parametric ANOVA (EPA, 1992).

Statistical Evaluation Methodology

Each constituent in the monitoring program should be evaluated according to a suitable statistical method for that constituent. It is required that the method selected be suited for the distribution of data for a given constituent. Prior to selecting a statistical method, the normality of the sample distribution should be evaluated using a statistically suitable determination of the distribution, such as the Shipiro-Wilkes test (EPA, 1992). Parametric ANOVA, tolerance intervals, prediction intervals, and several of the alternative statistical methods available require that the data be normally or log-normally distributed. Non-parametric ANOVA does not require normality in the sample distribution. Parametric ANOVA also requires that the data be checked for homogeneity of variance.

The number of non-detects in the data greatly effects the effectiveness of statistical evaluation. For data sets with 15 percent or fewer non-detects, a parametric statistical method should be used with the non-detect results set equal to one-half the laboratory's practical quantitation limit. Should the number of non-detects range between 15 and 50 percent of the data, either a non-parametric should be used or the mean and standard deviation should be modified according to the Cohen or Aitchison method prior to statistical analysis. For data sets with more than 50 percent non-detect, as is commonly the case for volatile organics and metals, non-parametric tests are required, or the detected values can be modeled as rare events using the Poisson model for describing independent rare events.

ADEQ presently encourages the use of the tolerance interval approach based on the alert level procedure previously used in the APP program. Using the ADEQ method, at least eight sets of data must be collected from each upgradient well and alert levels and aquifer quality limits established based on a tolerance interval (ADEQ, 1993).

Subtitle D specifies confidence criteria that are considered protective of human health and the environment when using statistical methods for evaluating groundwater data. For individual well comparisons between one background and one compliance well, it is required that the method selected must be utilized at a 99 percent level of confidence that a false positive, or an indication of contamination when none is present, will not occur. For multiple well comparisons, the method selected must be utilized at the 95 percent level of confidence that a false positive indication will not occur. Parametric ANOVA should not be used for individual well comparisons.

GROUNDWATER MONITORING PLAN REQUIREMENTS

Detection Monitoring Program

A detection monitoring program must be established whereby analytical results from the compliance wells are statistically evaluated relative to analytical results from the upgradient wells. In the detection monitoring program, each well is sampled semi-annually for all constituents listed in Appendix I of Subtitle D, plus all applicable Aquifer Water Quality Standards. (EPA, 1991; ADEQ, 1990). This list includes 47 volatile organic compounds, 15 metals, plus several inorganic and general chemistry constituents. A provision is made for modifying the list of monitored constituents after establishing the detection monitoring program with ADEQ approval.

To determine background groundwater quality and establish a database for statistical analysis, four independent samples must be collected and analyzed from each well during the first semi-annual sampling event. Based on the background data, a statistical method suitable for the type of distribution must be selected for each individual constituent. Different statistical methods should be used for different constituents, as determined from the type of distribution on a constituent by constituent basis. The detection monitoring program must continue through the 30-year post-closure period, unless an alternate schedule is negotiated with ADEQ.

Should there be a statistically significant increase in the concentration of a constituent in the compliance wells above the constituent concentration in the upgradient wells during the detection monitoring program, the facility is required to place a notice in the operating record indicating which constituents have shown significant concentrations above background levels. The facility must also notify ADEQ, and establish an assessment monitoring program within 90 days. Should there be evidence which suggests that the landfill is not the source of the increased levels, a 90-day provision will be made in which the facility may submit this evidence in a demonstration certified by a qualified groundwater scientist. If a successful demonstration is made, assessment monitoring is not required and the facility may return to detection monitoring.

Assessment Monitoring Program

Under an assessment monitoring program, the facility would need to collect and analyze samples for all constituents in Appendix II of Subtitle D in all compliance wells. Should any Appendix II constituents that were not part of the original detection monitoring program be detected, a set of four independent samples must be collected from all wells (upgradient and compliance) for those constituents to determine baseline levels and establish aquifer quality limits or groundwater protection standards (GWPSs). The new Appendix II constituents will be appended to the list of detection monitoring program constituents to form the new constituent list for the assessment monitoring program. The complete list of Appendix II constituents must be monitored at least annually during the assessment monitoring program. The facility may return to detection monitoring should the concentration of all Appendix II constituents drop below background levels.

Corrective Action

Should a GWPS be exceeded during the assessment monitoring program, the lateral and vertical extent of the probable contaminant plume must be characterized by installing and sampling an appropriate number of additional monitoring wells (including the installation of at least one additional compliance well at the property boundary in the direction of migration of the contaminant plume) and initiating an assessment of corrective measures. If groundwater monitoring indicates that contamination has migrated off-site, the facility must notify property owners or residents whose property overlies any part of the contaminant release.

An assessment of corrective measures is required to evaluate the performance, time, and cost aspects of each remedial option considered. The selected remedy must ultimately attain the GWPSs for all constituents, and reduce or eliminate, to the maximum extent possible, further releases of Appendix II constituents into the environment. The results of the assessment must be discussed in a public meeting with interested and affected parties. The cost and duration of the available treatment options must be evaluated, and will be dependent upon the size of the contaminant plume, the hydrogeological characteristics of the aquifer formation, and the chemical transport phenomena of the contaminants. Should an assessment of corrective action options be required, the following items will be included in an Assessment of Corrective Actions report:

- Hydrogeological Investigation;
- Risk Assessment;
- Literature/Technical Review of Treatment Technologies;
- Evaluation of Costs;
- Time Estimate for Each Remedial Option;
- Bench Scale Studies to Assess Potential Effectiveness;
- Selection of Remedial Technology;
- Regulatory and Public Comment Hearing;

- Full-scale Pilot Study of Selected Technology;
- Implementation of Remedial Technology; and
- Continuation of Remedial Action until Treatment Goals are Achieved.

Figure 2 illustrates the decision-making process under the groundwater monitoring program for detection monitoring, assessment monitoring, and corrective action.

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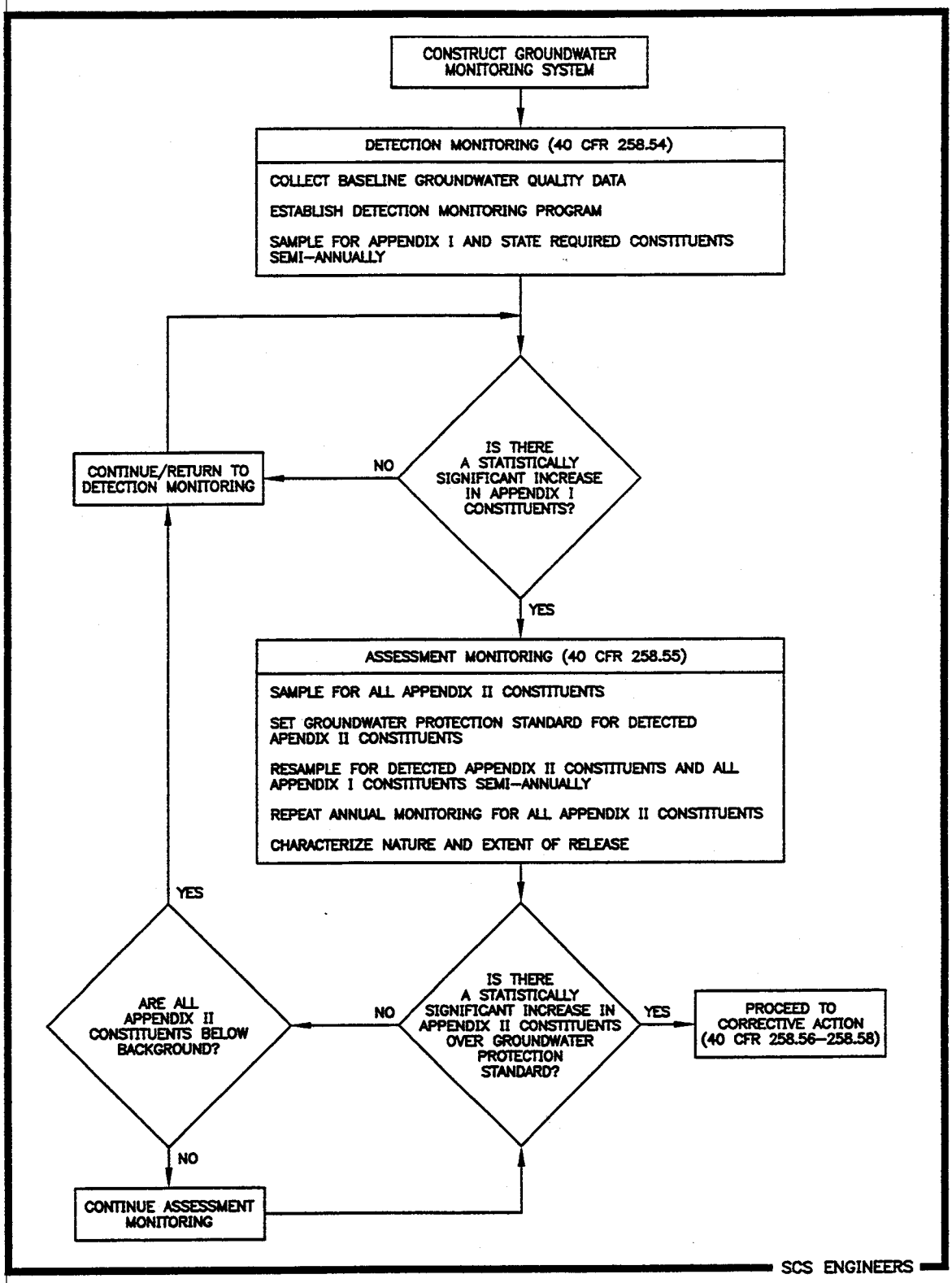

FIGURE 2. GROUNDWATER MONITORING PROGRAM DECISION FLOWCHART

ISOTOPIC ANALYSES OF CENTRAL ARIZONA PROJECT AND TUCSON BASIN WATERS[1]

Howard L. Grahn, C.J. Eastoe[2]

ABSTRACT: In order to monitor the influx of meteoric Colorado River water into the Tucson Basin aquifer via the Central Arizona Project (CAP), a base-line sample grid was established, and isotopic criteria were developed to identify CAP water in ground water samples. Isotopic analyses suggest that Deuterium is a good indicator of ground water source. CAP water shows a close δD grouping from -89 to -79 per mil while native basin waters run -64 to -50 per mil. Tritium values display wide variability within basin waters (n.d. to 14.4 TU) and were ambiguous as a source indicator. $\delta^{18}O$ exhibits near overlap in CAP and basin water values (-10.5 to -9.7, and -9.3 to -7.6 per mil respectively) but may be a useful parameter in controlled situations. Four $\delta^{34}S$ analyses show clear separation between CAP water (-2.2 to -2.4 per mil) and basin water (3.1 to 9.3 per mil) and should be investigated further. The project was suspended due to the sudden termination of the Tucson Water C-zone Pilot Injection Program.

INTRODUCTION

In 1992, after 23 years of planning and construction, Colorado River water was first delivered to Tucson, Arizona, via the Central Arizona Project (CAP) canal. This essentially meteoric water is conveyed over 300 miles and an elevation gain of 2000 feet, to the remote inland Tucson Basin, where it mixes with basin groundwater through injection and wastewater recharge. This event is hydrologically significant because the physical and chemical effects of mixing these two disparate waters are not well known. In addition, the inflow of CAP water into the aquifer was viewed as a possible long-term tracer study of unprecedented potential. With the aim of documenting this event over the

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long-term, a sampling network and monitoring program were established. In addition, an isotopic survey of CAP and Tucson Basin water was initiated to identify parameters that would distinguish the two waters most effectively in ground water samples.

HISTORY OF CAP WATER IN THE TUCSON BASIN

On November 2, 1992, CAP water was introduced into the Tucson Water delivery system. Approximately 53 million gallons/day were delivered for home use, of which roughly half (~81 ac.ft./day) was returned through the waste water system and discharged into the Santa Cruz River as effluent. Simultaneously, in ten C-zone wells of east-central Tucson, a pilot injection program initiated by Tucson Water, introduced a total of 2395 ac.ft. of CAP water into the aquifer until the program was suddenly terminated by the City Council in October 1993. In total, approximately 31,000 ac.ft. of CAP water entered the Tucson Basin between November 1992 and October 1993.

SAMPLE NETWORK

With the cooperation of local water agencies, a basin-wide monitoring program of 71 sample stations was established to determine pre-CAP baseline conditions and monitor aquifer changes over the long-term. Eleven public and private agencies participated in the collection of ground water samples. One hundred fifty three samples were collected and are preserved for future analyses. Fifty one isotopic analyses were performed on those samples, as discussed below. Sample collection was suspended with the termination of the Tucson Water C-zone injection program in October 1993.

ISOTOPIC STUDY

In order to develop a method for identifing the presence of CAP water in ground water samples, an isotopic survey was initiated. δD and ^3H were measured in a representative set of CAP and Basin waters, and $\delta^{18}x$ and $\delta^{34}S$ were measured in smaller sample sets. Locations of analyzed samples are shown in Figure 1.

Methods

All CAP and ground water samples were collected in Nalgene bottles and refrigerated unpreserved. For δD analyses, hydrogen was generated by reacting the water with zinc at 500°C. $\delta^{18}O$ water was equilibrated with CO_2 at 25°C, and the CO_2 was purified. To measure $\delta^{34}S$, sulfate was precipitated as $BaSO_4$ and converted to SO_2 by reaction with Cu_2O and SiO_2 at 1100°C. All isotopes were measured using a modified VG602 mass spectrometer. For tritium

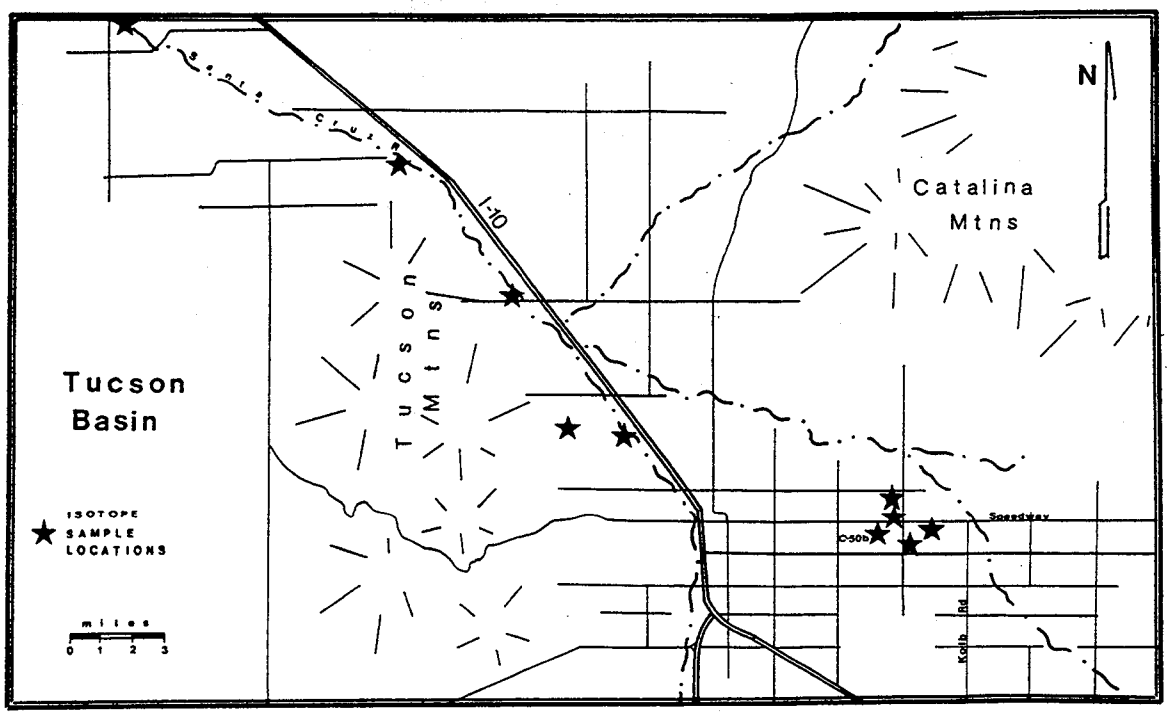

Figure 1: Pre-CAP isotopic sample locations.

samples, 180 ml water samples were distilled, then enriched electrolytically by a factor of 8. ^{3}H was measured in the enriched water by liquid scintillation in a Quantulus 1220 counter in an underground lab. Analytical precisions are: $\delta D = \pm 1.6‰$; $\delta^{18}O = \pm 0.2‰$; $\delta^{34}S = \pm 0.3‰$. The detection limit for ^{3}H is 0.7 TU.

Results

Results of the 46 isotopic analyses are shown in Table 1, and are compared with results from other recent studies of basin water in Table 2.

Deuterium

Eighteen deuterium analyses show non-overlapping ranges of δD (Table 1, Fig 2). The C-zone and Santa Cruz basin waters have a δD range from -64 to -50‰, while 6 CAP waters have a range from -89 to -79‰. The separation between the two groups is about six times analytical precision. Kalin (1994) using a larger sample set of basin waters (n=88) found a δD range of -50 to -71‰, with one outlier at -80. With the exception of the outlier, the distinction between the CAP water and the basin water is still clear. Values of δD vary more-or-less regularly across the Tucson Basin and have been contoured by Kalin; the differences in δD reflecting different sources of recharge. The lower δD values of CAP water are consistent with derivation of the bulk of Colorado

Tucson Basin Ground Water Samples

Date Coll	Samp #	Deuterium	O 18	TRITIUM	S 34
2/8/93	C26b	-64	-9.3	1.3	
6/9/93	C26b			14.2	
2/10/93	C48b	-63		n.d.	
2/10/93	C49b	-55		14.4	3.1
2/10/93	C50b	-61			
2/10/93	C58b	-63		n.d.	
7/21/93	LZC	-50	-7.6	n.d.	9.3
11/24/92	SC-3	-60	-8.4	2.7	
6/23/93	SC3	-61		6.7	
6/23/93	SC3E	-61		7.4	
11/24/92	SC6	-63		5.1	
12/1/92	WR 65B	-57		2.7	
10/21/93	Martin St			1.6	
12/2/92	SC-12	-56	-8.4	8.2	

CAP Water Samples

Date coll	Samp #	Deuterium	O 18	TRITIUM	S 34
12/15/92	929485	-82	-10.5	n.d.	
12/15/92	929486	-88		17.2	-2.4
12/15/92	929487	-84	-9.7		
5/12/93	9304320	-89	-10.5	16.9	-2.2
5/12/93	9304335	-87			
9/28/93	CAP-HG	-79			

Table 1: Isotopic Analyses for Tucson Basin and CAP waters.

River water from higher altitudes and latitudes in Colorado, Wyoming, and Utah (Drever, 1988). There is no evidence for seasonal variation of δD in CAP water. The large storage lakes upstream of the CAP intake should have a smoothing effect on seasonal isotopic variations in precipitation.

	O 18	Tritium	Deuterium	S 34
Kalin(1994)	-10.7 to -7.2		-79.8 to -49.9	+3.5 to +14.2
Esposito (1993)	-8.9 to -7.8	nd to 18.25	-62 to -48	
Lindquist(1992)		nd to 16.5		
Bostick(1979)	-11.9 to -7.8		-70.9 to -56.7	
Grahn&Eastoe(1994)	-9.3 to -7.3	nd to 14.4	-64 to -50	+3.1 to + 9.3

Table 2: Previous Isotopic Studies of Tucson Basin waters.

$\delta^{18}O$

Eight $\delta^{18}O$ measurements indicate a range of -10.5‰ to -9.7‰ for CAP water. Similar $\delta^{18}O$ ranges were found in basin water by Kalin (1994), Esposito (1993), and Bostick (1978). Although CAP and basin waters appear to be less distinguishable in $\delta^{18}O$ values than in δD, the analytical precision of 0.2‰ reveals that many basin wells have $\delta^{18}O$ values that are measurably different from those of CAP water. For wells which have an established analytic history, however, $\delta^{18}O$ values could be useful in documenting conversion of the well from basin to CAP water.

Tritium

Two tritium analyses of CAP water, 17.2 and 16.9 tritium units (TU), are as would be expected for contemporary high altitude meteoric water. Basin waters, however, show a range of content, from below detection (waters recharged prior to atmospheric nuclear testing) to a maximum 14.4 TU. Basin waters with finite tritium content contain some fraction of post-bomb water. Lindquist (1992) found no elevated ^{3}H values away from major drainages where recharge is rapid. This study suggests that the distribution of tritium may be more complicated than Lindquist supposed. Further measurements are in progress at the University of Arizona to investigate that possibility. In wells pumping "old" water, the inflow of CAP water could easily be detected using tritium. There appear to be a number of wells where tritium analyses would be ambiguous.

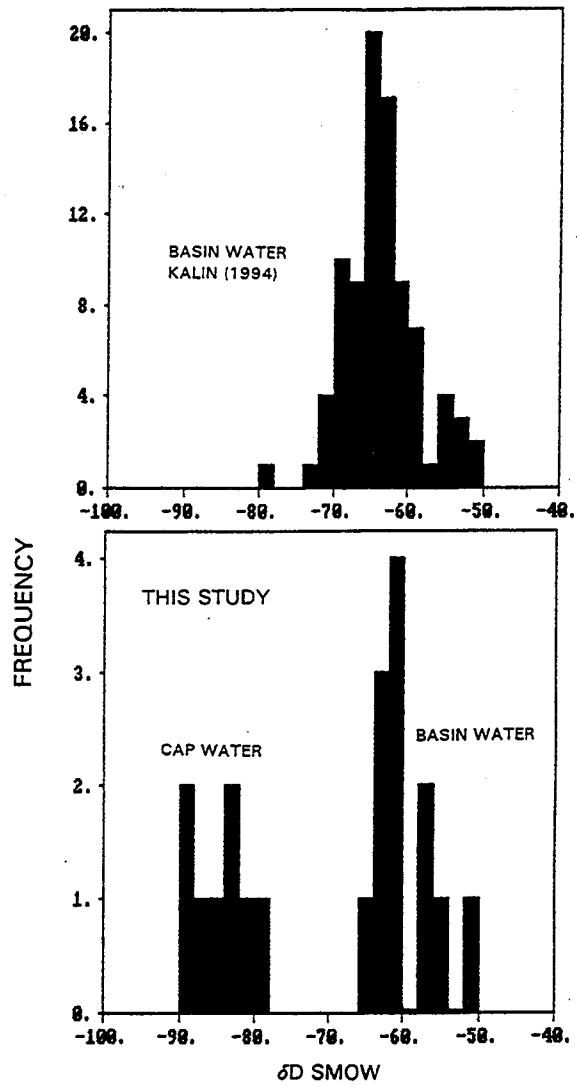

Figure 2: δD SMOW; CAP and Basin Waters.

Sulfur

Kalin (1994) found $\delta^{34}S$ for basin water ranging from +3.5 to +14.2‰ (n=50) as shown in Table 2. These data agree well with this study which found a clear $\delta^{34}S$ separation between two basin water samples (+3.1 and +9.3‰) and two CAP samples (-2.2 and -2.4‰), suggesting that $\delta^{34}S$ might be a useful distinguishing parameter.

Well C050-b

Table 3 shows isotopic and chemical analyses of Tucson Water monitor well C050-b. This well lies 64' from well C050-a, used as a CAP water injection well by Tucson Water. Up to October of 1993, a total of ~319 ac.ft. of CAP water were injected into well C050-a. Four deuterium analyses from monitor well C050-b clearly show the conversion of basin water to CAP water as

deuterium shifted from -61‰ to -80‰. A mixture of waters with an intermediate value of -72‰ was generated during the process of conversion.

Date Coll	Samp #	Deuterium	O 18	Tritium	EC-Field	Cl/Br
2/10/93	C50b	-61		n.d.	300	100
4/14/93	C50b	-72			350	748
6/21/93	C50b	-83	-10.1	13.7	995	1042
7/14/93	C50b	-80			594	995

Table 3: The Conversion of Well C050-b.

CONCLUSIONS

Although the data base is limited, these data indicate that δD is the most reliable and applicable isotopic parameter for recognizing the existance of CAP water in ground water samples. $\delta^{18}O$ would also work in many cases, but tritium is variable and would be useful only in limited situations. $\delta^{34}S$ is potentially useful as an indicator and should be further studied. Automation of $\delta^{18}O$ measurements may result in this parameter being the most cost-effective of those studied.

ACKNOWLEDGEMENTS

This study was funded by the University of Arizona Small Grants Program. It would not have been possible without the support and cooperation of Tucson Water and Pima County Wastewater Management. Thanks to Laurie Wirt and Dave Esposito who agitated to not let the CAP arrival go unnoticed.

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SESSION 2A:

REAUTHORIZING THE FEDERAL CWA AND SDWA: CAN WESTERN WATER NEEDS BE RECOGNIZED? (PART 2)

Moderator: Chuck Graf
Arizona Department of Environmental Quality

1994 CLEAN WATER ACT REAUTHORIZATION

by Catesby W. Moore

Areas of Concern

The Flood Control District of Maricopa County (District) receives stormwater runoff from over 9,000 square miles in central Arizona. The reauthorization of the Clean Water Act impacts our operations in two major areas. The first is the National Pollutant Discharge Elimination System Stormwater Regulations, the second is the 404 permitting program. These areas are addressed by three proposed pieces of legislation: HR 3948, S. 1114, and S. 1304.

HR 3948 "Water Quality Act of 1993"

The District has two main concerns with HR 3948:

1) When read in its entirety, this bill would probably require compliance with Water Quality Standards (WQS) before the end of the fifteen year window the bill supposedly provides. While the new language says that permits may not "directly" require meeting WQS, the stormwater management measures, effluent limitation requirements, watershed management requirements, and the antidegradation language all use WQS as the measure of compliance. Any permits issued that do not help these programs attain WQS will be modified until the goal is achieved, providing little or no relief in the fifteen year period from WQS.

2) Several new sections of HR 3948 integrate groundwater into the CWA. Defining and determining that a "direct hydrologic connection" exists will be time consuming and expensive, especially for arid regions, and will divert interest and efforts from existing CWA programs. With regard to stormwater programs, if BMPs such as stormwater detention basins take place in an area of hydrologic interface, the groundwater provisions could require new studies, new permits, and generally make it difficult to implement a BMP oriented or focused program.

S. 1114 "Water Pollution Prevention and Control Act of 1993"

The District supports provisions in this bill that delay the application of Water Quality Standards and numerical effluent limitations, and bases compliance on Best Management Practices. The District is concerned; however, that BMPs as described

in the Coastal Zone Management Act could be applied to our arid region. This is especially true in light of amendments that would allow the administrator or the permitting state to select which BMPs would be utilized. Arizona's arid climate calls out for flexibility and ingenuity in developing minimum Best Management Practices. Municipalities in Arizona need a voice in determining which BMPs should be utilized to improve water quality.

This bill specifically addresses the development of a national policy on mixing zones to prevent acute toxicity. We would like to stress the need for flexibility for arid regions. There are no mixing zones in ephemeral streams; there is no water in our receiving waters. Consequently, water quality standards become end-of-pipe requirements. Arid region discharges have to be cleaner, even though the impacts to "aquatic life" are nil. Municipalities in Arizona support the development of regionally appropriate stormwater discharge limits that are achieved though Best Management Practices.

The District would also suggest the inclusion of language granting small municipalities located inside larger municipalities a voice in determining the NPDES permit provisions that would be applied to their community.

As an arid region agency, we look to Congress to mandate that EPA provide sufficient flexibility in developing water quality criteria (Section 202) and guidance to states for non-point source programs (Section 303). This is critical in light of the anti-degradation section in this bill. Section 502 calls for EPA to develop standards for whole effluent toxicity. This is a section that the District cannot readily support. Based on our experience in stormwater quality analysis, this would more than double the analytical costs. Additionally, test results are highly variable, and extrapolating results to determine impacts to aquatic life in arid streams is of questionable value.

The most significant concern with S. 1114 is Section 703 which grants the U.S. Army Corps of Engineers the authority to expand the 404 permitting program to include all dredge or fill discharges to waters of the US, regardless of whether these are incidental or "de minimus." We strongly oppose this language and recommend that it either be removed or an exemption granted for maintenance of flood control channels and engineered flood control activities.

S. 1304 "Wetlands Conservation and Regulatory Improvements Act of 1993.

The District supports the proposed legislation and believes that the proposed changes go far to improve and streamline the 404 permitting process. We provide the following specific comments:

Section 4. Definition and Delineation of Wetlands

3) Delineation Guidelines:

The District supports the development of delineation guidelines that take into account regional variations in hydrology, soils, and vegetation. This provision is especially important given the unique ecology of arid regional riparian areas. In the past, the lack of recognition of arid rivers has led to a very subjective jurisdictional delineation process. In one instance, the local COE went so far as to propose that rather than the "ordinary, mean, high water mark," that the jurisdictional delineation be based instead on a 25 year flood event. The establishment of a training program and certification requirements for delineators is seen as a positive step towards eliminating much of the subjectiveness in the process. It is hoped that these improvements will eliminate the typical delays of obtaining a jurisdictional delineation, which often takes over three months.

Section 4. Permit Processing Improvements

a) Permit Decision Deadlines:

The District strongly supports the requirement that the Corps of Engineers issue a decision on Section 404 permit applications within 90 days of the publication of the pre-discharge notification. It has been the District's experience that the process is fraught with delays. The permit process for New River Channelization lasted over 2.5 years. It is not uncommon for permitting under Nationwide permit 26 to take six months to a year. The District feels that much of the delays can be attributed to inadequate staffing of local Corps' offices. Because of this, the District is pleased to see the inclusion of a directive to prepare a report to Congress on the personnel and resource requirements needed to improve the 404 permitting process.

c) Administrative Appeal of Permit Decisions:

The District is concerned that the administrative appeal process be thoughtfully considered and that the process for making decisions in appeal cases be formalized. Although this act addresses the time frame for permit decisions, it has been the District's unpleasant experience that once a decision is appealed, there are no set time frames. This can lead to interminable delays during which projects can be neither abandoned or built. The funds that were allotted for the project cannot be reassigned until the appeal process has been concluded. Therefore, the District suggests that a time frame and formalized procedure be established during the rule making process to avoid these issues.

Section 8. Coordination and Clarification of Program Concerning Agricultural Activities

d) Exempted Activities:

The District is strongly in favor of exempting routine maintenance and emergency construction of serviceable structures from 404 permitting requirements, and would like to see this exemption (granted to agricultural activities) extended to flood control facilities. During an emergency flood event, damage occurring to

structures often cannot be repaired until after the flood waters have receded. Repairs must be made quickly in order to prevent further deterioration or damage to public property. Additionally, recent evolutions in regulatory interpretation now require that routine maintenance activities, including removal of sediment and vegetation that obstruct flows, will require a 404 permit. The District expends over $750,000 annually on both routine maintenance and storm repair programs and we estimate that acquiring 404 permit coverage for these activities add an additional $625,000 to these programs.

Section 9. Mitigation Banking

The District strongly supports the concept of mitigation banks. Often, on-site mitigation as favored by the current 404 process is impractical and the costs of establishing a small mitigation area are prohibitive. Furthermore, small acreage wetland habitats lack sufficient productivity and diversity to adequately support self-sustaining populations of wildlife species. Frequently, despite best intentions, small mitigation areas fail to thrive. The establishment of mitigation banks to offset future habitat losses will maximize efforts to restore habitat values.

Section 322. Wetlands And Watershed Management Plans

The District supports the provisions for assistance and incentives for wetlands and watershed planning. Regional management of habitat restoration activities will result in more cohesive programs that will maximize the benefit to wildlife.

URBAN STORM WATER QUALITY IN THE PHOENIX METROPOLITAN AREA: REAL OR IMAGINED THREAT?

Lawrence A. Baker, Ph.D. Gary Lohse, and Roland Wass[2]

A recent comprehensive stormwater monitoring program conducted in the Phoenix, Arizona metropolitan area has resulted in the analysis of grab and composite samples from 60 storms in 16 drainage areas for over 200 constituents. An analysis of the data base indicates that lead concentrations are lower than those found in EPA's National Urban Runoff Program (NURP) study, probably a reflection of the declining use of leaded gasoline. A few samples contained detectable levels of DDT and DDE, a reflection of prior agricultural use. Despite the desert landscape, concentrations of suspended solids, BOD, nutrients, and most other constituents were comparable with concentrations observed in eastern cities. Runoff coefficients (RC = runoff/precipitation) were proportional to percent impervious area. Runoff coefficients were much lower than values reported for eastern cities, a phenomena most probably attributed to mandated on-site retention practices, the flat topography, and high evaporation rates. Low precipitation (18 cm/yr) and low runoff coefficients result in extremely low runoff volumes, therefore areal pollutant loadings from the Phoenix urban watershed are far less than those reported for eastern U.S. cities.

[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] Lawrence Baker is an assistant professor in the Department of Civil Engineering, Arizona State University, Tempe, Arizona 85287-5306. Gary Lohse is with HDR Engineering, and Roland Wass is with Flood Control District of Maricopa County; Mr. Lohse and Mr. Wass are also graduate students in the Civil Engineering Department at ASU.

SOURCES AND IMPLICATIONS OF ARSENIC IN THE SALT AND VERDE RIVER WATERSHEDS[1]

Taqueer Qureshi[2] and Lawrence A. Baker, Ph.D.[2]

Arsenic in surface waters can be derived from a variety of sources, including metal processing industries, mine tailings, and arsenic-rich geological formations. In a study of the 12,900 square mile watershed of the Verde and Salt rivers, we quantified watershed sources of arsenic and examined the fate of arsenic in a two-reservoir system. A low-flow arsenic mass balance was developed by sampling nearly all perennial streams during the summer of 1993. A multi-year mass balance was developed for nine USGS gauging stations in the watershed. An extensive geographic information system (GIS) data base was developed to facilitate interpretation of the water quality data. Arsenic in river water was primarily in the soluble form. Arsenic concentrations decreased with increasing flow (log-log relationship); highest concentrations (~ 25 μg/L) were found during low flow. The Verde River, which comprised 30% of the flow to the Salt River, contributed 58% of the total arsenic loading during the period 1986-1992. The major source of arsenic in the Verde River was the Verde Formation, a soft, sedimentary deposit in the middle Verde River valley. This is supported by four facts: (1) arsenic concentrations of all streams increased when they entered the Verde Formation, (2) arsenic concentrations were highest during low flows, implicating a groundwater source, (3) arsenic could be leached from soils collected from this formation in laboratory experiments, and (4) aquifers in this formation have elevated arsenic concentrations. Although there has been extensive mining (gold-copper-silver) in several districts within the watersheds of these rivers, there is little evidence of contamination form tailings. A two-reservoir system at the lower end of the Verde River traps about 16% of the total arsenic. Trapping of particulate arsenic (93% efficiency) is a major arsenic sink in the reservoir.

[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] Taqueer Qureshi is a graduate student and Lawrence Baker is an assistant professor in the Department of Civil Engineering, Arizona State University, Tempe, Arizona, 85287-5306

SESSION 2B:

WATER MANAGEMENT: REGULATORY APPROACHES AND RULES

Moderator: Linda Stitzer
Arizona Department of Water Resources

TRENDS IN ARIZONA'S WATER USE, 1984-1993[1]

Jeffrey M. Tannler[2]

ABSTRACT: The 1980 Arizona Groundwater Management Act created the Arizona Department of Water Resources. ADWR's primary roles include controlling overdraft, allocating groundwater resources, and promoting water augmentation in critical areas throughout the state. The Groundwater Code established grandfathered groundwater rights based on historic use, in regulated areas throughout the state. Since 1984, owners of groundwater rights have been required to measure and report annual groundwater withdrawals and total water use to the Department.

In the past ten reporting years, groundwater withdrawals have experienced an overall decrease. Total water use, which includes other sources such as CAP and effluent, has varied over those last ten years within municipal, agricultural, and industrial sectors. This paper examines these trends and some of the possible causes.

I. BACKGROUND

The Department of Water Resources manages the groundwater resources within critical areas, or active management areas, in Arizona. Four initial active management areas (AMAs) were created in 1980, which roughly follow the hydrologic groundwater basin boundaries in the areas surrounding Prescott, Phoenix, Casa Grande, and Tucson (see Figure 1). A fifth active management area, the Santa Cruz AMA, was established by the Arizona Legislature in 1994, and is also shown in Figure 1. Each AMA has a specific long-term management goal set by the Groundwater Code. The management goal of the Tucson, Prescott, and Phoenix AMAs is to reach safe-yield, or a balance of groundwater withdrawn and water recharged, no later than the year 2025. The

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]Jeffrey M. Tannler is a Water Resources Specialist, Arizona Department of Water Resources, Tucson Active Management Area Office.

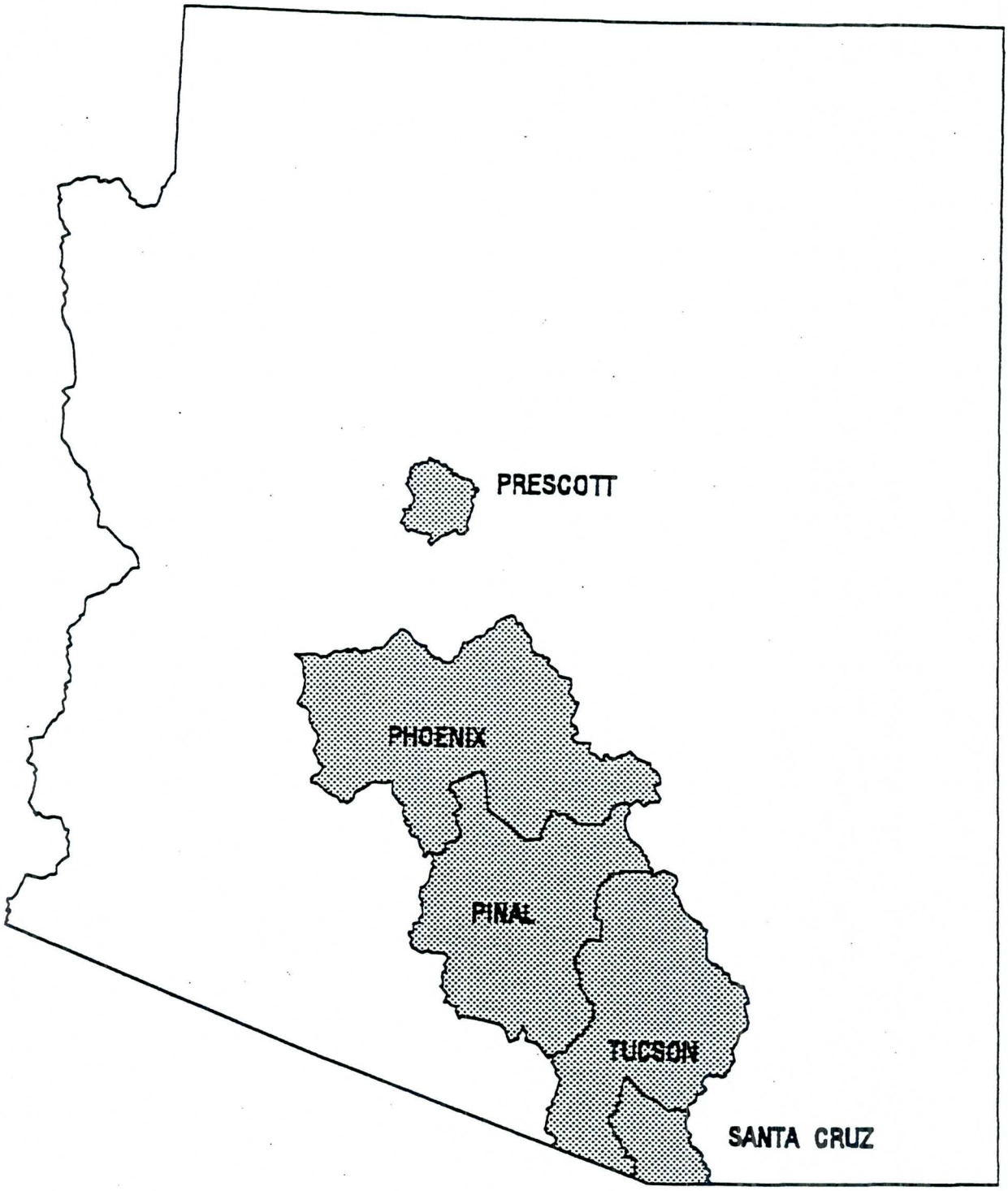


Figure 1. AMA Boundaries

management goal for the Pinal AMA is to sustain agriculture for as long as feasible, while preserving future water supplies to allow for the development of non-irrigation uses. The management goal of the Santa Cruz AMA is to maintain the safe yield condition which currently exists there, and to prevent long-term local water table declines.

II. WATER USE

Figure 2 shows a comparison of average yearly total water use for each of the five AMAs. *Note: In subsequent figures within this paper, Santa Cruz AMA's water withdrawal and use figures are included in Tucson AMA's.*

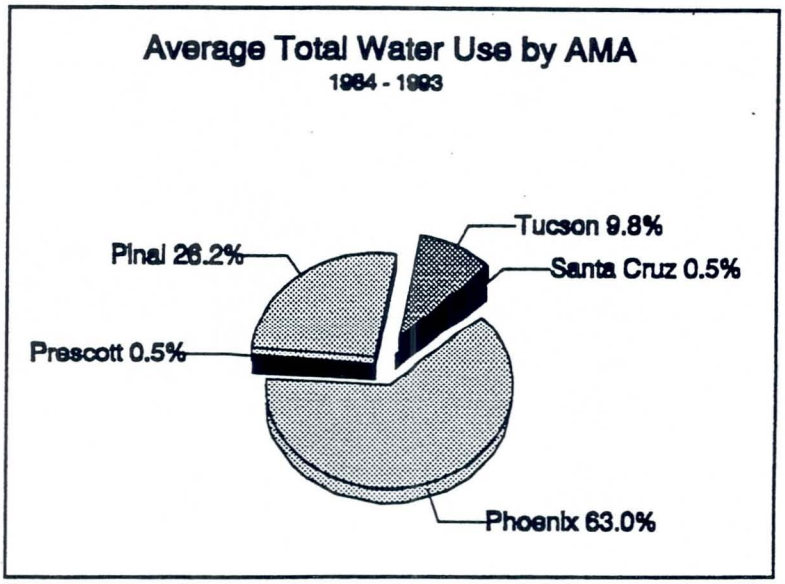


Figure 2

Figures 3 thru 6 show water use broken down by agricultural, municipal, and industrial sectors for each of the AMAs. Use by the mining sector is shown separately for the Tucson AMA because it represents a significant proportion of the industrial use. Some definite differences begin to emerge in the different AMA's water use trends, which are also representative of the different management goals for the AMAs. The graphs for the Prescott, Phoenix, and Tucson AMAs show how water used for agriculture has experienced a gradual, steady decline, while municipal water use has steadily increased. Municipal water use in the Tucson and Prescott AMAs has actually surpassed agricultural use.

Several reasons exist for the shift in water use from agricultural to municipal. The Groundwater Code put a permanent cap on the amount of land that may be irrigated within AMAs, so new lands cannot be brought into irrigation. Some of those lands that are legally irrigable have lain idle in recent years, as tough economic times have made farming more costly. Irrigable land is gradually being retired from farming and is being sold for development, especially in suburban areas.

In contrast to the other AMAs, the graph for Pinal AMA underscores the continued significance of the local agricultural economy. The amount of water

Water Use by Sector

FIGURE 3 Prescott AMA

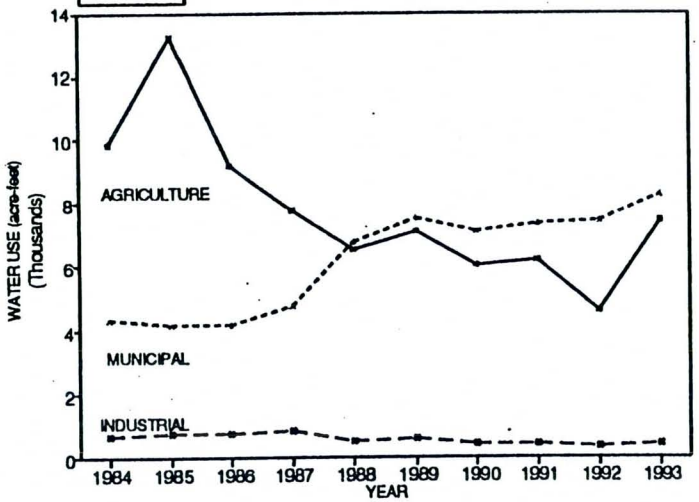


FIGURE 4 Phoenix AMA

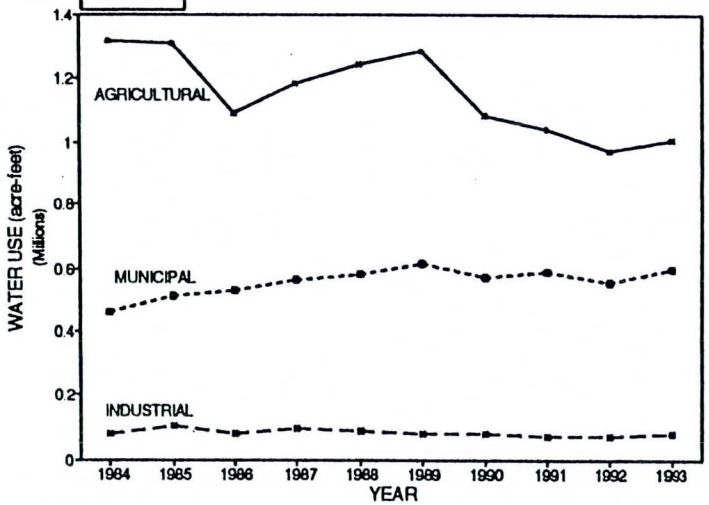


FIGURE 5 Pinal AMA

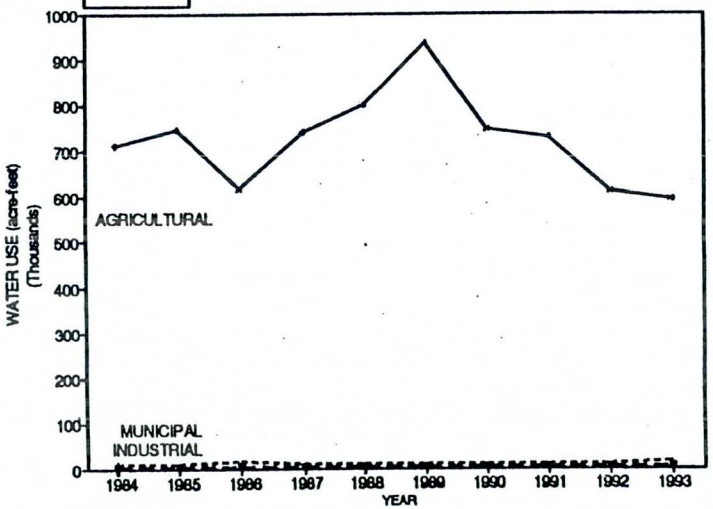
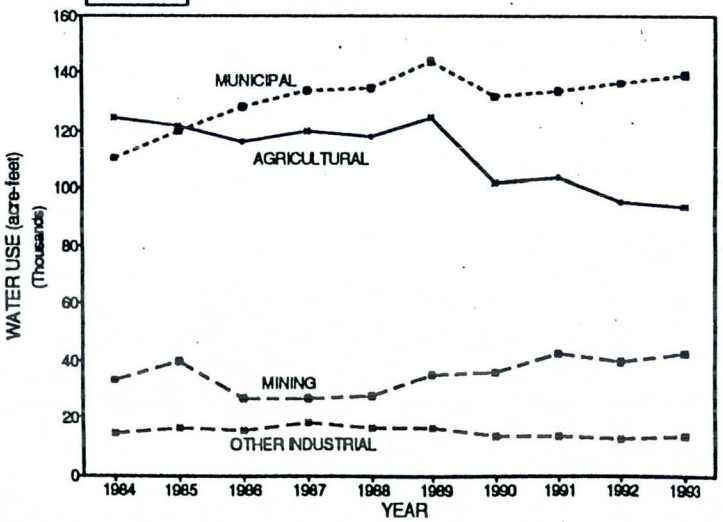


FIGURE 6 Tucson AMA



used for farming is on the order of 100 times that used for municipal or industrial purposes[3]. This agrarian emphasis is reflected as well in the management goal for the AMA, which is to sustain agriculture as long as possible.

Though the overall trend for water use is increasing for municipal and decreasing for agricultural, there are also notable fluctuations in water used from year to year. One of the possible causes for these fluctuations is annual precipitation. Figures 7 though 10 show agricultural and municipal water use plotted against precipitation, with precipitation plotted on a decreasing scale. The effect of precipitation on water use is seen most dramatically for the year 1989; in all AMAs, an extremely dry year is associated with a significant spike in water use.

Although a strong correlation is seen in some segments of each graph, in others the relationship is weaker. While precipitation is undoubtedly a factor influencing water use for both the municipal and agricultural sectors, there are a host of other environmental and economic factors that also affect use. These may include the timing and magnitude of precipitation events; the uneven nature of our summer thunderstorms; relative humidity; cloud cover; ambient temperature; and wind frequency and velocity, to name a few influencing climatic factors.

The most significant influence on water used by the municipal sector is population. Figures 11 thru 14 show municipal water use within each AMA vs. population, with both showing a general positive trend. The general slope for water use, though fluctuating, appears to follow a more decreasing slope in recent years for each AMA. This changing overall slope may reflect lower water use per capita, which in turn probably reflects success in the water conservation arena. (Note in Figure 13 that municipal use in the Pinal AMA has increased on the order of 30% over the past decade, though it still represents a very small fraction of the area's total use.)

The previous figures have dealt with total water use from all sources, including groundwater, surface water, spill water, and Central Arizona Project (CAP) water. One of the fundamental goals of the Groundwater Code is to conserve groundwater, through conservation and by promoting alternative water sources such as CAP. Figure 15 shows the relationship between total water used and actual groundwater pumped in all five AMAs. Total water use fluctuates prominently (note the highest water use in 1989, which was a dry year). However, groundwater usage has declined steadily with less fluctuation.

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[3] See appendix, water use figures by sector within AMA.

Precipitation Vs. Water Use

Precipitation Data Sources - NOAA (Prescott and Pinal AMA's); Nat'l Weather Service (Tucson and Phoenix AMA's)

FIGURE 7 Prescott AMA

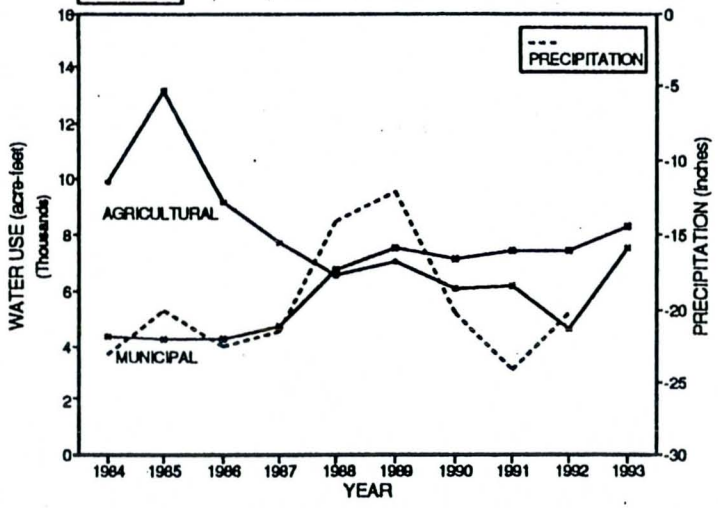


FIGURE 8 Phoenix AMA

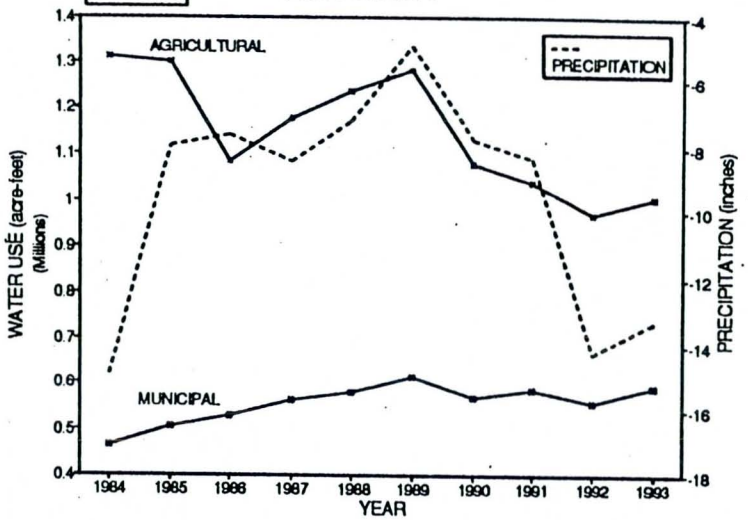


FIGURE 9 Pinal AMA

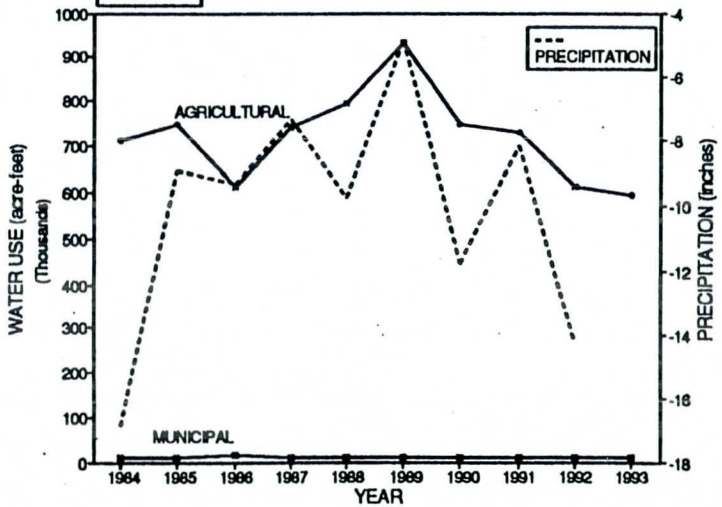
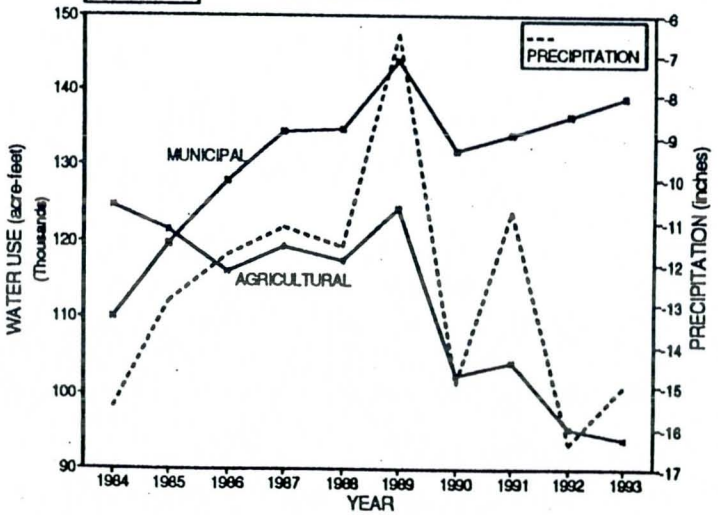
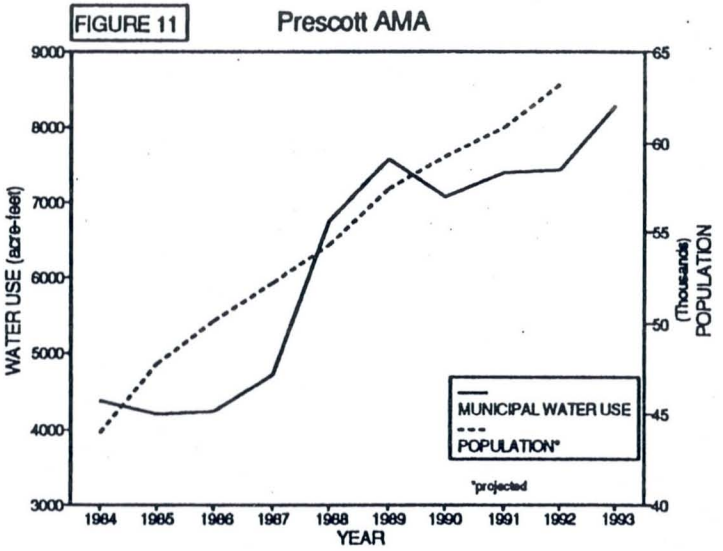
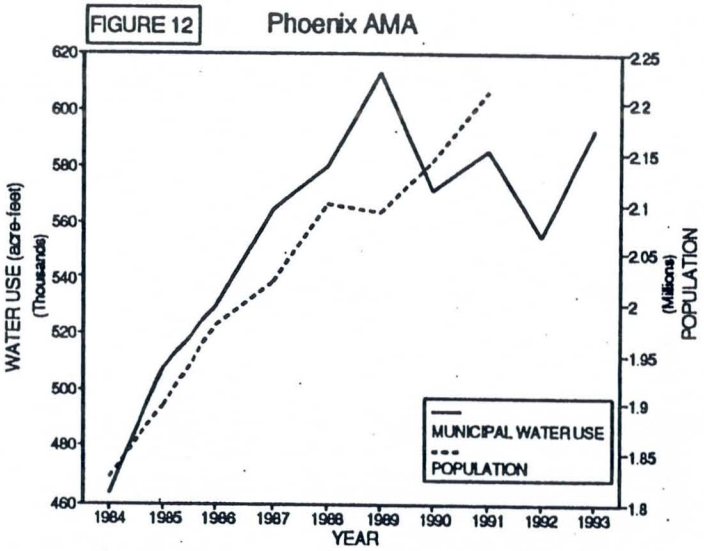


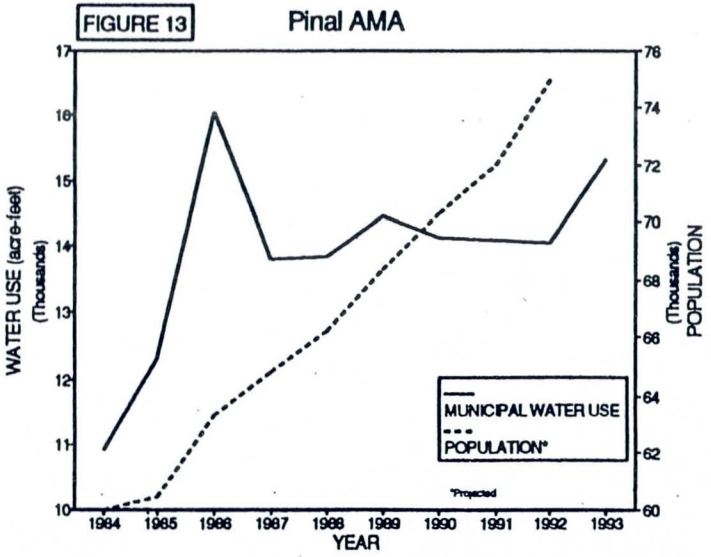
FIGURE 10 Tucson AMA

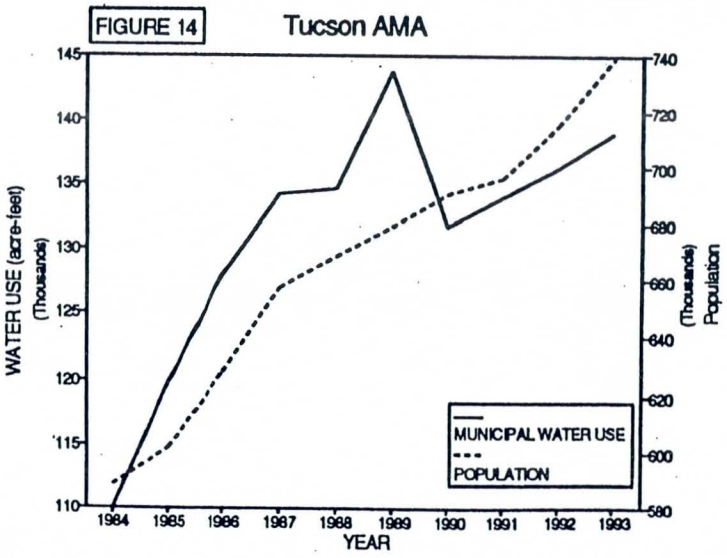


Municipal Use Vs. Population





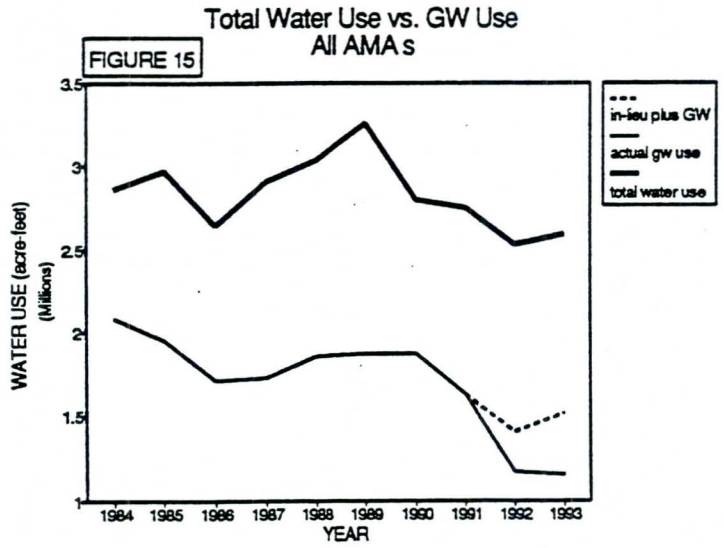




Recently, a number of large water users have taken advantage of the **Indirect Storage & Recovery (IS&R), or Groundwater Savings Program**, whereby CAP water may be used in lieu of groundwater[4]. The dotted line in Figure 15 represents the amount of groundwater that would normally have been pumped, while the solid line represents actual groundwater pumped. The difference between these two lines from 1991 to 1993 represents the amount of CAP water which was delivered in return for future pumpage credits. This relationship highlights the value of this innovative program, which was introduced in 1990. The program has been used most significantly in the Phoenix and Pinal AMAs because of the large amount of agricultural water use.

III. SUMMARY

Water use trends among the AMAs generally show that agricultural water use is declining, and municipal water use is increasing. The rate of increase of municipal water use appears to be less than the rate of increase of municipal population. Yearly fluctuations in water use may be due to population changes, precipitation, or other environmental and economic factors. Groundwater pumpage has declined since 1984, and has declined significantly since 1991 due to CAP use.



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[4]**Indirect Storage and Recovery Projects** were recently renamed *Groundwater Savings "Arrangements"*. In such arrangements, entities supplying renewable water such as CAP water, may accrue stored water credits by supplying that water to someone else that would otherwise normally pump groundwater.

APPENDIX 1

ARIZONA DEPARTMENT OF WATER RESOURCES
1984 - 1993 Annual Water Withdrawal and Use Summary
August 3, 1994

The following information is based on Annual Water Withdrawal and Use Reports on file with the Department for calendar years 1984 thru 1993. Surface water and effluent used pursuant to groundwater rights or permits are included in total use figures, and account for most of the difference between total water use and groundwater withdrawals. Withdrawals from exempt wells are not accounted for. All water use information is displayed in acre-feet.

I. ANNUAL REPORT STATUS (ALL AMAs and INAs)

Year	Reports Expected	Reports Received	Reports Outstanding	Percent Received
1984	10,656	9,720	936	91%
1985	11,365	11,158	207	98%
1986	11,695	11,603	92	99%
1987	11,316	11,149	167	99%
1988	11,418	11,080	338	97%
1989	11,593	11,235	358	97%
1990	11,881	11,293	588	95%
1991	12,058	11,609	449	96%
1992	12,150	11,714	436	96%
1993	12,249	11,463	786	94%

II. FEES RECEIVED (ALL AMAs and INAs)

Note: Figures represent fees collected by the Department pursuant to Annual Water Withdrawal and Use Reports.

Year	Withdrawal	Augmentation	Late Report	Late Payment	Conservation	WQARF	Total
1984	$1,011,616	$0					$1,011,616
1985	$1,361,147	$0	$27,367	$6,696			$1,395,210
1986	$1,653,940	$136,409	$57,646	$16,705			$1,864,700
1987	$1,658,895	$142,702	$52,755	$23,152			$1,877,504
1988	$1,672,785	$144,289	$48,662	$13,766			$1,879,502
1989	$1,772,865	$146,435	$30,453	$15,585			$1,965,338
1990	$1,767,949	$1,466,237	$20,302	$11,210			$3,265,698
1991	$1,716,355	$1,541,064	$15,475	$14,078	$66,491	$267,750	$3,621,213
1992	$1,492,741	$1,517,508	$13,903	$10,320	$86,724	$203,069	$3,324,265
1993	$1,623,783	$1,661,566	$10,022	$9,004	$111,695	$216,670	$3,632,740

III. GROUNDWATER WITHDRAWALS AND TOTAL USE, BY AMA

Year	Prescott AMA GW	Phoenix AMA GW	Pinal AMA GW	Tucson AMA GW	Total Groundwater	Prescott Total Use	Phoenix Total use	Pinal Total Use	Tucson Total Use	Total Use All AMA's
1984	14,140	1,196,561	560,897	256,363	2,083,189	14,938	1,854,886	726,300	282,675	2,878,799
1985	16,248	937,380	590,359	273,608	1,940,891	18,141	1,910,829	764,030	298,294	2,991,294
1986	12,869	904,010	480,134	264,486	1,716,522	14,208	1,698,132	636,829	286,960	2,636,129
1987	11,264	838,613	536,092	276,385	1,724,233	13,334	1,835,248	761,421	298,562	2,908,565
1988	12,429	990,676	500,746	279,322	1,851,833	13,854	1,907,007	817,421	296,644	3,034,926
1989	18,304	980,152	498,372	303,002	1,870,243	15,276	1,975,100	951,314	319,937	3,261,627
1990	15,950	1,145,297	393,383	261,322	1,875,522	13,580	1,729,961	765,684	284,223	2,793,448
1991	13,781	878,894	415,054	275,681	1,637,356	14,036	1,694,607	748,786	294,616	2,752,045
1992	12,018	581,528	250,392	261,152	1,161,221	12,408	1,597,857	627,524	284,775	2,522,564
1993	15,260	635,512	211,647	229,618	1,149,595	16,144	1,673,127	614,599	289,181	2,593,051

IV. TOTAL WATER USE BY SECTOR WITHIN AMA

Prescott AMA:

Year	Agricultural		Municipal		Industrial		Total
1984	9,892	66	4,366	29	680	5%	14,938
1985	13,182	73	4,214	23	745	4%	18,141
1986	9,192	65	4,234	30	782	6%	14,208
1987	7,754	58	4,726	35	854	6%	13,334
1988	6,559	47	6,767	49	528	4%	13,854
1989	7,077	46	7,556	49	643	4%	15,276
1990	6,051	45	7,086	52	443	3%	13,580
1991	6,195	44	7,399	53	442	3%	14,036
1992	4,613	37	7,436	60	359	3%	12,408
1993	7,479	46	8,259	51	406	3%	16,144

Phoenix AMA:

Year	Agricultural		Municipal		Industrial		Total
1984	1,310,576	71%	462,790	25%	81,520	4%	1,854,886
1985	1,300,913	68%	508,052	27%	101,864	5%	1,910,829
1986	1,085,375	64%	530,260	31%	82,497	5%	1,698,132
1987	1,175,113	64%	564,601	31%	95,534	5%	1,835,248
1988	1,237,308	65%	579,823	30%	89,876	5%	1,907,007
1989	1,279,326	65%	612,778	31%	82,996	4%	1,975,100
1990	1,081,187	62%	571,003	33%	77,771	4%	1,729,961
1991	1,036,653	61%	585,277	35%	72,677	4%	1,694,607
1992	968,949	61%	554,991	35%	73,917	5%	1,597,857
1993	1,001,931	60%	592,484	35%	78,712	5%	1,673,127

Pinal AMA:

Year	Agricultural		Municipal		Industrial		Total
1984	709,240	98%	10,925	2%	6,135	1%	726,300
1985	745,410	98%	12,303	2%	6,317	1%	764,030
1986	613,173	96%	16,032	3%	7,624	1%	636,829
1987	740,560	97%	13,816	2%	7,045	1%	761,421
1988	797,990	98%	13,859	2%	5,572	1%	817,421
1989	931,007	98%	14,473	2%	5,834	1%	951,314
1990	746,536	97%	14,121	2%	5,027	1%	765,684
1991	729,083	97%	14,090	2%	5,613	1%	748,786
1992	608,592	97%	14,047	2%	4,885	1%	627,524
1993	595,224	97%	15,330	2%	4,045	1%	614,599

Tucson AMA:

Year	Agricultural		Municipal		Non-Mining Industrial		Mining		Total
1984	124,549	44%	110,017	39%	14,714	5%	33,395	12%	282,675
1985	121,475	41%	119,674	40%	17,293	6%	39,852	13%	298,294
1986	116,158	40%	127,975	45%	16,148	6%	26,679	9%	286,960
1987	119,486	40%	134,088	45%	18,596	6%	26,392	9%	298,562
1988	117,526	40%	134,592	45%	16,867	6%	27,659	9%	296,644
1989	124,469	39%	143,654	45%	16,580	5%	35,234	11%	319,937
1990	102,454	36%	131,682	46%	14,185	5%	35,902	13%	284,223
1991	103,992	35%	133,870	45%	13,674	5%	43,080	15%	294,616
1992	95,288	33%	136,253	48%	13,182	5%	40,052	14%	284,775
1993	93,861	32%	138,928	48%	13,820	5%	42,572	15%	289,181

ADWR'S AGRICULTURAL CONSERVATION PROGRAM: IS IT WORKING?[1]

MICHAEL CAPORASO[2]

ABSTRACT: The Department of Water Resources, created by the 1980 Groundwater Management Act is required to set conservation requirements for agricultural water users within the Phoenix, Pinal, Prescott, Tucson, and Santa Cruz Active Management Area's (AMAs). Regulatory emphasis has been placed on agricultural water users by the 1980 Code and subsequent management plans as required by this landmark legislation. Implementation of the current regulatory requirements of the agricultural conservation program established in the Second Management Plan (1990-2000) has resulted in many issues. Among these issues is the agricultural water users ability to meet the conservation requirements set forth in the Second Management Plan.

An analysis of agricultural water allotments within the AMAs indicate that a small number of farmers are negatively impacted by the conservation requirements set in the SMP. The impacts on most farming operations to stay within their allowed annual water allotment has been mitigated by the flexibility account rules which allow the farmer to "bank" the unused portion of their annual allotment for future use. Even with these flexibility account provisions, many farmers are concerned and have taken a strong position in their ability to meet the progressively stringent requirements. As a result, the Department of Water Resources has contracted a study to evaluate agricultural water allotments and alternatives to the existing conservation program.

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

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I. BACKGROUND

The Groundwater Management Act of 1980 requires that for the Second Management Plan (SMP), the Director of the Arizona Department of Water Resources (ADWR) "establish a new irrigation water duty for each farm unit" and "the irrigation water duty and any intermediate water duties shall be calculated as the quantity of water reasonably required to irrigate the crops historically grown in the farm unit and shall assume the maximum conservation consistent with prudent long-term farm management practices within areas of similar farming conditions, considering the time required to amortize conservation investments and financing costs" ARS §45-565(A). The ADWR determined that for non-limiting soil conditions in the Phoenix, Pinal, and Tucson (including Santa Cruz) AMAs, a seasonal irrigation efficiency of 85 percent represented maximum conservation and that this level of efficiency could be attained by using level basin irrigation systems and proper irrigation water management techniques. The ADWR also concluded through analysis of on-farm conditions that existing irrigation systems could be economically converted to more efficient level basin systems largely due to the increased crop yields and reduced water usage associated with level basin irrigation systems.

Many Arizona farmers and farm groups have challenged ADWR's determination that 85 percent seasonal irrigation efficiency and associated crop yield increases are achievable. The argument has been made by the farming community that the data base used by ADWR in arriving at their conclusions regarding irrigation system efficiency and related crop yield increases was flawed. As a result of this challenge, legislation was introduced and passed in 1991 (House Bill 2499) which required the ADWR to review the irrigation water duties established under the SMP in the Phoenix, Pinal, and Tucson AMAs. This legislation required that a sum of $500,000 be collected to perform additional studies. The ADWR collected this money by adding a fifteen cent fee to each acre-foot of groundwater withdrawn in all AMAs.

The Director of ADWR appointed eighteen members to the Agricultural Technical Advisory Committee (AGTAC) in the late summer of 1991. The AGTAC membership included representatives from the Agri-Business Council, U.S. Soil Conservation Service, U.S. Agricultural Research Service, Cooperative Extension Service, University of Arizona Agricultural Economics Department, City of Phoenix, Irrigation Districts, Consulting Agricultural Engineers, and the farming community. The ADWR formed an internal Agricultural Special Studies Committee (ASSC) to conduct meetings and assist in the evaluation of the information developed during the AGTAC process. A series of AGTAC meetings were held during the ensuing months to evaluate the procedures and methodology used by ADWR in the establishment of the SMP Agricultural Conservation Program.

During this process, three AGTAC subcommittees were formed to evaluate the economic, technical, and total irrigation requirement components of the planning process. The results of the subcommittee findings were compiled into a final AGTAC Report to the Director entitled, "Analysis of Standards and Procedures Established for the Second Management Period", dated July 10, 1992. This report addressed issues related to the administrative review process, economics, limiting soil conditions, irrigation district delivery capabilities, tailwater reuse, crop history, crop consumptive use values, crop yields, frost protection, and farm management practices.

In order to evaluate the claims made in the AGTAC report, the Director requested that the ASSC respond to the AGTAC's conclusions. This was done in a report prepared by the ASSC entitled, "ADWR Response to the AGTAC Report to the Director", dated October 1, 1992. After the Director evaluated the conclusions and recommendations in both reports, a Director's order was issued which provided recommendations and responses to these issues.

The Director's order signed February 11, 1993 mandated that a study be conducted to provide the information necessary to allow the Director to determine whether the irrigation water duties established in the second management plans are reasonable and consistent with the Code requirements.

The agricultural sector strongly objected to the Director's order and believed that the contracted study would not provide an adequate resolution of the issues. The AGTAC recommended that any effort to analyze conservation requirements must include the evaluation of economic factors. As a result of this objection, new legislation was introduced.

Senate Bill 1260 passed during the 1993 legislative session included an amendment that revised the previous legislation (HB 2499) which directed ADWR to evaluate irrigation water duties. As a result, the irrigation water duty studies must now also include an evaluation of the economic variables impacting whether agriculture can achieve the maximum conservation standard set forth in the second management plans. The 1994 Omnibus Bill submitted by the ADWR and passed during the 1994 legislative session, included language that allows ADWR to use funds collected for an agricultural study that evaluates the reasonableness of the conservation requirements and alternative conservation programs for agriculture.

An understanding was reached between ADWR and the agricultural community that led to the vacating of the Director's February 11, 1993 order. The ADWR agreed not to implement the Director's order if AGTAC concurred that 85 percent seasonal irrigation efficiency was technically achievable. This agreement was reached.

II. GENERAL DESCRIPTION

The Agricultural Technical Advisory Sub-Committee (AGTASC) was formed in cooperation with ADWR staff to develop objectives and a Scope of Service to study and evaluate irrigation water duties established under the SMP for the Phoenix, Pinal and Tucson AMAs. The scope of service also includes the development and analysis of alternative program(s) to the existing water duty based agricultural conservation program. The purpose of the study is to develop technical data bases, evaluate farm water management practices, analyze the economic aspects of maximum conservation for agriculture, and develop alternatives to the existing agricultural conservation program. This will be accomplished through the objectives outlined below.

1. **Collect and evaluate data that exhibits baseline conditions of existing farm irrigation system efficiencies.**

2. **Assess different irrigation district abilities to make timely deliveries of sufficient volumes of water to meet selected levels of on-farm seasonal irrigation efficiencies for level basins and level furrow irrigation systems.**

3. **Evaluate the farmer's ability to economically invest in on-farm conservation improvements to achieve maximum conservation.**

4. **Develop alternative agricultural conservation program(s) to the existing water duty program.**

The consultant study was separated into two sections. The first part of the study involves objectives 1, 2, and 3 listed above. The study results obtained in part one will enable ADWR to develop policy criteria to address the farmers ability to meet the established SMP conservation requirements. This study report is expected to be completed by March, 1995.

Part two of the study specifically addresses the 4th objective above. These study results will facilitate ADWR with the evaluation and possible implementation of new agricultural programs for the agricultural sector. Any new alternative program is expected to be available as an optional program and will likely be offered to Irrigation Grandfathered Right (IGFR) holders in the Third Management Period (2000 - 2010). Part two of the study report is due for completion no later than July 1, 1995.

III. SMP AGRICULTURAL CONSERVATION PROGRAM

The agricultural conservation program requirements currently being implemented through the SMP for most farms have an assigned irrigation water duty based on an 85 percent seasonal irrigation efficiency. This efficiency which constitutes maximum conservation becomes effective in the year 2000. Farms that have proven problems with poor soils and/or water quality have been assigned an efficiency lower than the 85 percent benchmark efficiency to reflect on-farm conditions. For the Second Management Period, two intermediate water duties and one final water duty have been assigned to each IGFR holder. In general, the first intermediate water duty and allotment (effective 1992 to 1995) is based on the assigned target efficiency established in the First Management Plan (1980 -1990). The second intermediate water duty and allotment (effective 1995 to 2000) was based on an efficiency which was halfway between the first intermediate efficiency and 85 percent. The final water duty and allotment (effective in the year 2000) for most farms would be based on the 85 percent efficiency value.

Any IGFR holder that felt their assigned water duty and allotment was calculated in error for the SMP had the right to apply for an administrative review within 90 days from the receipt of their conservation requirements. If approved, an administrative review could offer a permanent adjustment to the SMP conservation requirements. The ADWR received a total of 2183 applications for administrative review for all AMAs. If a farmer could not economically invest in conservation improvements to achieve maximum conservation, they could apply for a variance. A variance could extend the "current" water duty and allotment up to a period of five years. The ADWR received 15 variance applications.

The ADWR does not require a farmer to invest in irrigation conservation improvements, however, the farmer must stay within the Groundwater Code requirements and policy guidelines established in the flexibility account rules. An operating flexibility (flex) account has been maintained by ADWR for each IGFR since 1987 (1988 in Pinal AMA).

In general, the operating flex account for each IGFR allows the farmer to accrue credits and "bank" the unused portion of their annual groundwater allotment. The accrual of credits, which may be used in future years, is not limited. If the annual groundwater allotment is exceeded, the farmer is given a debit in an amount that exceeds the annual groundwater allotment. Debits can accrue in an amount equal to 50 percent of the assigned annual groundwater allotment for each IGFR. If a debit exceeds the 50 percent level, compliance action is taken. If credits are accrued in a debit situation, the debit is reduced by the amount of accumulated credits.

As a result of House Bill 2340 (1991), IGFR holders are authorized to buy and sell flex account credits. According to this legislation, IGFR's must be located in the same irrigation district to transfer credits and only the credits accumulated in the previous reporting year may be transferred.

Most IGFR's in each of the AMAs are accumulating annual flex credits. Table 1 displays the cumulative credits and debits for each AMA for all IGFR's.

TABLE 1: AGRICULTURAL FLEXIBILITY ACCOUNT (1)

AMA	IRRIGATION ACRES	ALLOT-MENT	TOTAL USE (1993)	TOTAL CREDITS 1987-93	TOTAL DEBITS 87-93
Phoenix	331,500	1,848,700	947,800	5,375,700	17,700
Pinal	281,400	1,259,600	564,500	3,266,900	2,700
Tucson(2)	51,300	235,400	91,500	894,300	100
Prescott	6,500	29,400	7,500	144,800	700
Totals:	670,700	3,373,100	1,611,300	6,681,700	21,200

(1) All numbers are rounded to the nearest 100. Allotment, Total Use, Total Credits, and Total Debits values are in acre feet.
(2) These values include the Santa Cruz AMA.

The total amount of water currently allotted annually to all IGFR's is approximately 3,373,100 acre feet. The total amount of credits accumulated to date is about 6,681,700 acre feet. This compares to enough "stored" water to meet the full agricultural allocation for two years or approximately an extra 10 acre feet for each irrigation acre.

Generally, the distribution of accumulated flex credits occur in varying quantities for each IGFR. Some IGFRs have accumulated many credits while others have accumulated very few. Some IGFR flex accounts are in debit situations.

There are several reasons that contribute to flex credit accumulations. Due to economic factors including poor market conditions, many IGFR's are no longer irrigated. An IGFR holder with a groundwater only based allotment that does not irrigate during the year receives a credit for their entire annual allotment. Some IGFR's have been taken out of production, but have not been officially retired. Another contributing factor for flex credit accumulations is the Federal based set

aside program that requires cooperating farmers to leave a portion of their farm fallow. As a result of the set aside program, farmers will typically leave the least productive ground out of production which yields higher water use efficiency on the acreage cropped. Many farmers have implemented water conservation practices (i.e. laser land leveling, ditch lining, and irrigation scheduling) that have increased the overall efficiency of their on-farm water use. Also, water duties (annual allotments) were based on a historical crop mix (1975-1979) and the highest number of acres irrigated during that five year period, which may have reflected a higher water demand (consumptive use) than what is currently being produced.

It is probable that most of the accumulated agricultural flex credits will never be used since they can only be used pursuant to an IGFR. As conservation requirements get more stringent and if farms begin to irrigate full acreage, it is possible that stored credits may be used on some IGFR's. An ADWR study has indicated that even with the enforcement of maximum conservation (85% efficiency), many farms will continue to gain credits.

IV. CONCLUSIONS

There are still outstanding issues in the SMP Agricultural Conservation Program that need resolution. A consultant study currently under ADWR contract with CH2M HILL will assist the ADWR in developing policy for possible agricultural program changes in the SMP. The contract report will recommend alternative agricultural conservation programs to the existing water duty based program. The development of alternative agricultural programs are expected to be a major ADWR planning effort for the Third Management Plan.

The ADWR has begun the Third Management Period planning process. Much of this program will be developed from a resource based approach. The ADWR will evaluate available water supplies and the impact of conservation programs on the achievement of the overall ADWR goal of safe-yield conditions by the year 2025.

Through the evaluation of the agricultural consultant report and the development of new policy and conservation programs, the ADWR will move toward safe-yield goals in the agricultural sector.

UNDERGROUND WATER STORAGE IN ARIZONA

Charles L. Cahoy and Sheila K. Ehlers[1]

ABSTRACT: In response to an increased need to manage water supplies in Arizona, the Underground Storage and Recovery Act was enacted into law in 1986. Since then, Underground Storage and Recovery has evolved to contain many forms of underground storage programs. Although worthwhile in terms of water management goals, these programs were complex and lacked an integrated approach to underground water storage.

In 1994, the State of Arizona enacted the Underground Water Storage, Savings, and Replenishment Program. This program integrates many new elements, as well as the various underground storage programs adopted since 1986, into a single, unified program.

This paper identifies the goals of the Underground Water Storage, Savings, and Replenishment Program, characterizes the program elements, and describe how the stored water may be used.

INTRODUCTION

Competition for the use of water in Arizona is intense and becoming more so. Each year brings the state more people, new development and new industry, all dependent upon a finite water supply. The challenge of water management in Arizona is to satisfy current and future needs.

Satisfying those needs requires innovative solutions. Toward that end, in 1986 Arizona launched the Underground Water Storage and Recovery Program, that allowed persons with currently unneeded water supplies to store

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that water underground for future use. Although Arizona has used dams and reservoirs throughout its history to store water for future use, the Underground Water Storage and Recovery Program for the first time legally authorized the storage of water underground in aquifers.

Storing water underground in aquifers makes sense on a number of levels. Development of new dams and reservoirs above ground is extremely expensive and limited by environmental concerns. Even if the money is available to construct a new dam and environmental concerns can be mitigated, most good storage sites have already been utilized.

Storing water underground, however, is inexpensive in comparison. In some cases, underground storage sites can be located closer to the area of demand, thus decreasing both the cost of transporting the water and the amount of water lost during transportation. Storing water underground may help to reduce the rate of subsidence caused by excessive pumping of wells.

In recognition of the many potential benefits of underground water storage, the types of programs recognized by law in Arizona have greatly increased since the original 1986 legislation. An "indirect" storage program was introduced that recognized the storage of water by eliminating groundwater pumping by particular water users. A replenishment program allowed persons who pump certain excessive quantities of groundwater to replenish the water pumped. These and other new programs that were adopted were worthwhile, but did not constitute an integrated approach to underground water storage.

In 1994, the State of Arizona adopted the Underground Water Storage, Savings and Replenishment Program. This program includes the various programs adopted since 1986, but restructures them in to a single, unified program. The following is an overview of that program.

GOALS OF UNDERGROUND WATER STORAGE, SAVINGS AND REPLENISHMENT

Many of the concepts of underground water storage, savings and replenishment ("UWS") are more easily understood if the policies and goals behind the program are understood. The two primary goals of UWS in Arizona are:

1. To promote the use of renewable water supplies, such as effluent, surface water and Central Arizona Project water, over non-renewable groundwater, by allowing for effective and flexible storage and recovery of the renewable water supplies.
2. To provide for the efficient use of all water resources by allowing water to be "transported" by storing water in one location, but

recovering a like quantity elsewhere.

Using renewable supplies instead of groundwater is a goal of almost all water management in Arizona. For many years, millions of gallons of water have been pumped from Arizona's aquifers for agricultural, municipal, and industrial uses, while only a limited amount of water naturally infiltrates back into the aquifers. This imbalance has left the aquifers significantly depleted.

Because the aquifers are not being naturally replenished, Arizona has developed a policy to encourage the use of renewable water supplies and save groundwater supplies until shortages of renewable supplies occur. In very general terms, the UWS program works for the first goal by restricting the type of water that may be stored long-term to renewable sources that cannot be used directly. A person should not be allowed to store a renewable supply and meet immediate needs by pumping groundwater. The specifics of how it is determined whether a particular type of water can be used directly will be addressed later; the general goal of using renewable supplies before using groundwater should always be kept in mind when working with the UWS program.

The second goal recognizes the need to provide legal access to renewable water supplies where they are needed but not physically available. Thus, the UWS program allows a person to store water in one location, but recover it in a different location. Obviously, the water recovered will not be the same water that was stored. Thus, the UWS program may allow water to be recovered where it is needed, with some restrictions, without the expensive construction of canals and pipelines.

UWS PROGRAM

Permits and Terminology

Persons who wish to store, save or replenish water through the UWS program must apply to the Arizona Department of Water Resources for permits to do so. Depending on what the person is trying to accomplish, that person may need up to three types of permits: 1) a storage facility permit, 2) a water storage permit, and 3) a recovery well permit. (See Figure 1.)

Storage Facility Permits

A person who wishes to operate a storage facility within Arizona, at which water is stored, saved or replenished, must apply for a ***storage facility***

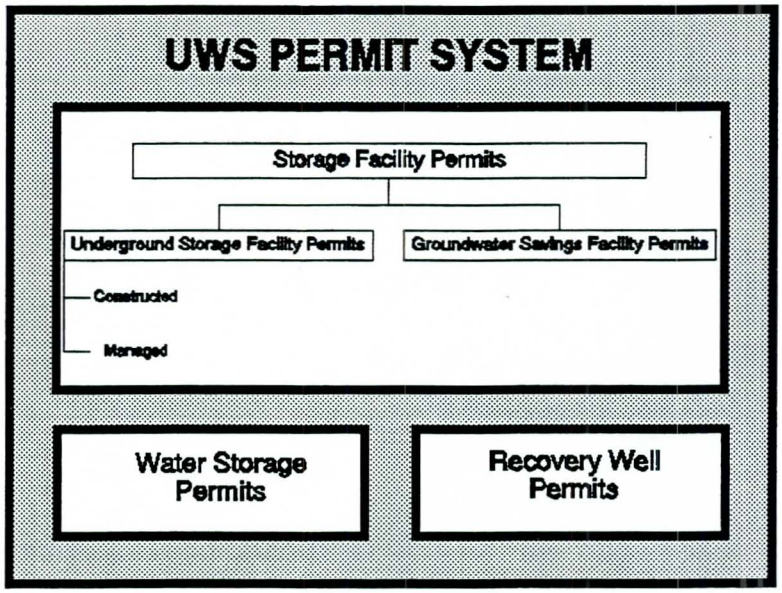

Figure 1.

permit from the Arizona Department of Water Resources. There are two basic types of storage facility permits: underground storage facility permits and groundwater savings facility permits.

An ***underground storage facility permit*** allows the permit holder to operate a facility where water is actually added to an aquifer. If the permit is for a ***constructed underground storage facility***, the permit holder adds water to an aquifer by using some type of constructed device, such as an injection well or a percolation pond. If the permit is for a ***managed underground storage facility***, the permit holder may utilize a naturally water-transmissive area such as a streambed and allow the water to percolate into the aquifer without the assistance of a constructed device.

In determining whether to issue an underground storage facility permit, the Department must determine that storage of the maximum amount of water that could be in storage at the facility at any given time is hydrologically feasible. The Department must also ensure that the applicant has the technical and financial capability to operate the project. The Department is further required to examine potential harms to land and other water users within the ***area of impact*** that might be caused by the facility. The applicant must have obtained any required flood plain use permit from the county flood control district. The final determination is that the Director of Environmental Quality has determined that the water storage will not cause a migration of poor quality water that might cause unreasonable harm.

A ***groundwater savings facility permit*** allows the permit holder to earn storage credits by delivering an alternate supply of renewable water, called ***in***

lieu water, to a ***recipient*** who agrees to replace groundwater use with in lieu water.

The Departments primary issue in determining whether to issue a groundwater savings facility permit is whether there will actually be a reduction in groundwater pumping as a result of the delivery of the in lieu water to the recipient. As a part of this determination, the recipient must agree in writing that for every gallon of in lieu water received, the recipient will reduce groundwater withdrawals from within an active management area or irrigation non-expansion area by a gallon. For example, a city may send its CAP water to an agricultural irrigation district (recipient) in lieu of the district pumping groundwater. The city may then use the earned storage credits to obtain an assured water supply for new development.

The Department must also determine that there is no other reasonable substitute for the groundwater used by the recipient except for the in lieu water and that the in lieu water could not have reasonably been used except through the operation of the groundwater savings facility. For example, if a farmer has historically received irrigation water from a surface water source, that farmer cannot become a recipient for the same surface water under a groundwater savings facility permit. The UWS statutes specifically state that if the water has been delivered to the proposed recipient prior to October 1, 1990, the arrangement cannot qualify for a groundwater savings facility, but the same principles discussed above can be applied to water that was not delivered before October 1, 1990.

Water Storage Permits

Water storage permits allow the permit holder to store water at a storage facility. There are three primary inquiries that the Department must make before a water storage permit is issued. First, the Department must determine that the applicant has the right to use the proposed source of water. Second, the Department must ensure that the water storage will occur at a permitted facility. Third, the Department must determine that the applicant has applied for all necessary water quality permits to undertake storage of the water.

Recovery Well Permits

The amount of water that is stored at a storage facility that will reach an aquifer, called the ***recoverable amount***, may be recovered at any time within the same calendar year in which storage occurred. A person seeking to recover the water must apply to the Department of Water Resources for a ***recovery well permit*** beforehand. When examining whether a recovery well permit should be issued, the Department examines whether recovery of water could damage

other land and water users due to over-pumping. However, a city, town, private water company or irrigation district that is applying to use one of its service area wells, drilled prior to the passage of the Groundwater Code, to recover water need only show that it has a right to use the well for recovery purposes.

Important Program Elements

Water That Cannot Reasonably Be Used Directly

Storage of ***water that cannot reasonably be used directly*** is one of the most significant elements of the UWS program. Since the program goal is to encourage use of renewable water supplies, the UWS program discourages long-term storage of renewable water supplies which could reasonably have been put to direct use.

Only water that cannot reasonably be used directly is eligible for ***long-term storage credits***. The UWS statutes provide a listing of water supplies that automatically qualify as water that cannot reasonably be used directly. The listing includes some Central Arizona Project (CAP) water, surface water that is made available by dams that are constructed or modified after August 13, 1986, and, until the year 2025, all effluent and any water brought into an active management area or groundwater basin that would not have reached that area without the efforts of the storer.

If the water storer has signed a water service subcontract for CAP water, the statutes assume that the storer will not immediately be able to put all of the water to direct use. The statute therefore imposes a thirty-year sliding scale on the amount of the subcontract. Use of the thirty-year scale will be discontinued beginning in 1998. Until then, however, the statutes assume that in the first year CAP water was available to the storer, the storer would be able to use directly only 30% of the amount of the subcontract and 70% would be eligible for long-term storage. Each year thereafter, less water is eligible for long-term storage. Figure 2 illustrates this provision.

Beginning in 1998 the test of whether CAP water will qualify as water that cannot reasonably be used directly will focus upon whether the storer is pumping groundwater in excess of what is allowed by assured water supply rules in any year. If in any year the storer is pumping groundwater in excess of that amount, the storer must subtract from that years storage an amount equal to the excess groundwater pumped. If the storer is storing CAP water and pumping groundwater, the storer may use the storage that does not qualify as long-term storage and report that pumping as recovery on an annual basis to eliminate the groundwater pumping. In other words, the withdrawals will be considered recovered CAP water, not groundwater. If there is sufficient annual

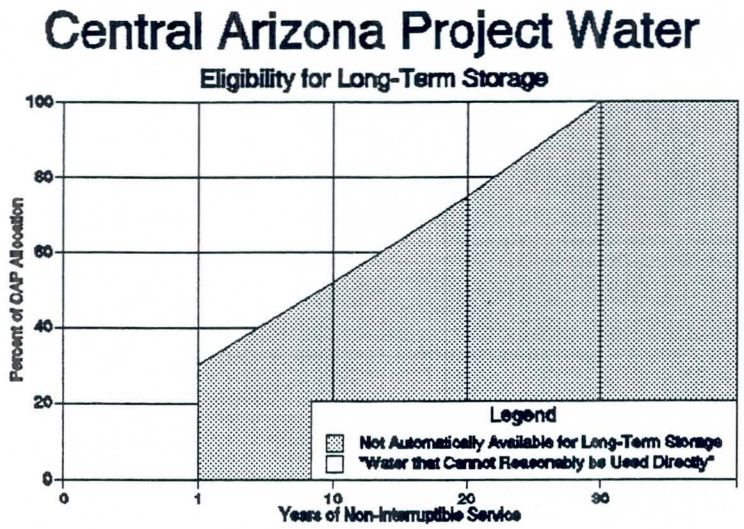

Figure 2.

storage and recovery to eliminate the groundwater pumping, then the storer may consider any water stored in excess of that annual storage and recovery as CAP water that cannot reasonably be used directly, thus qualifying for long-term storage credits. Figure 3 provides an example of how this rule will work.

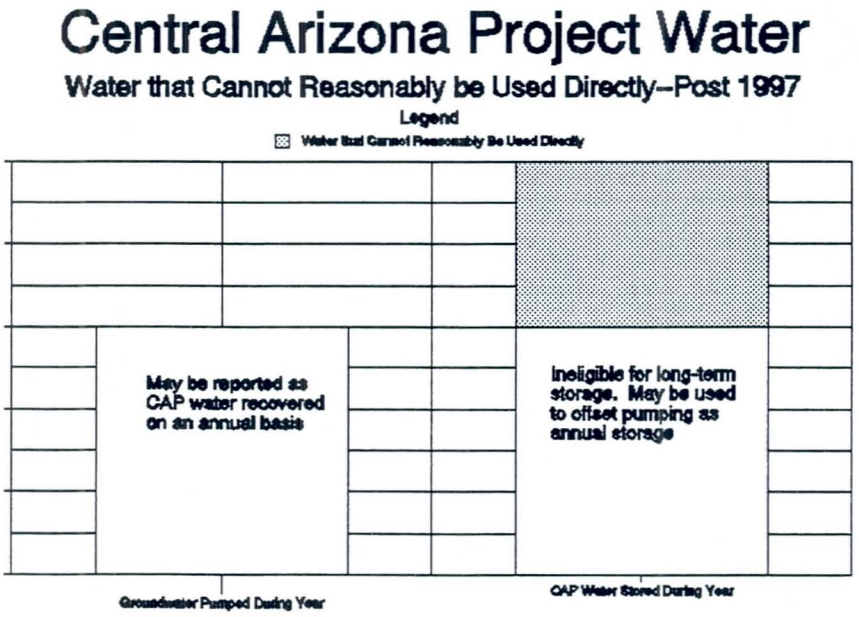

Figure 3.

Recovery Locations for Water Stored Within an Active Management Area

Within an Active Management Area (AMA) the water stored pursuant to the UWS program does not have to be recovered from the same area where it was stored.

An entity who holds both long-term storage credits and the water storage permit from which they were earned, may always recover the stored water from within the area of impact of the water storage.

Anyone holding long-term storage credits may recover stored water from anywhere within the same AMA in which it was stored, so long as a number of conditions are met. First, the recovery must be consistent with the management plan and achievement of the management goal of that active management area. In the Phoenix AMA, the management goal is to reach safe-yield by the year 2025. The management plan consistency requirements for recovery are that recovery may only occur in an area experiencing a long-term average annual rate of decline that is less than four feet per year, or is located so as to contribute to a sanctioned water quality corrective management program, or in an area which would remove and use poor quality water as part of a sanctioned water quality management program. Second, if the recovery will occur inside of or within three miles of the service area of a city, town, private water company or irrigation district, that city, town, private water company or irrigation district must be the person recovering the water or must have given consent to the recovery. These conditions are depicted in Figure 4.

Putting Stored Water To Use

Stored water always maintains the legal characteristics of the original source of water regardless of how it is used. Thus, if CAP water is stored, no matter where recovery occurs, the water is considered to be CAP water and may be used in any way that CAP water could be used.

There are three primary ways in which water that is stored pursuant to the UWS program may be recovered and put to use:

1. Water may be recovered and used within the same year that it is stored.

2. Water that is stored may be credited to a ***long-term storage account***, if it meets the eligibility requirements for long-term storage. Those credits may then be used to recover water beyond the year in which it was stored, be assigned to another person or, with some restrictions, be used for the assured/adequate water supply program that is administered by the Department of Water Resources.

3. Arizona law imposes ***replenishment*** obligations on certain entities. These specially authorized districts are required to replace water that has been

pumped by the district's members in excess of what is allowed by Arizona's assured/adequate water supply program. The districts fulfill their replenishment obligations, pursuant to Chapters 22, 27 or 28, Title 48, Arizona Revised Statutes, either by storing water at a permitted storage facility or acquiring long-term storage credits. Those credits are registered to the district's replenishment account and offset the district's replenishment obligations.

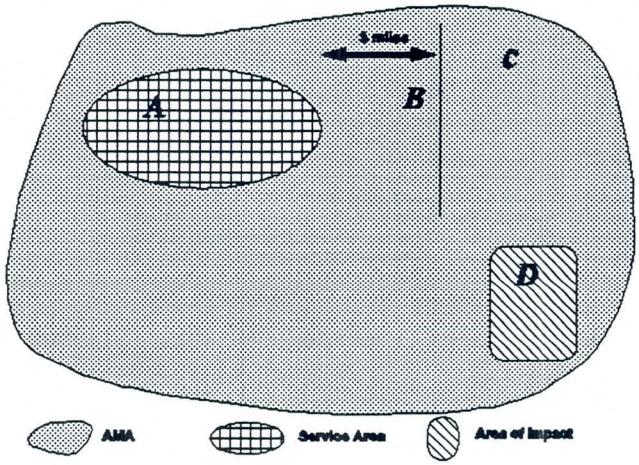

Figure 4 RECOVERY WELL LOCATION CONDITIONS

Location A	•	Recovery if consistent with the management plan and achievement of management goal
	•	Service area entity must be the recovering party or give consent for recovery at the location
Location B	•	Recovery if consistent with the management plan and achievement of management goal
	•	Service area entities within 3 miles must be the recovering party or give consent for recovery at the location
Location C	•	Recovery if consistent with the management plan and achievement of management goal
Location D	•	If the storer is recovering, no conditions
	•	If someone other than the storer is recovering, recovery if consistent with the management plan and achievement of management goal

Special Restrictions and Uses of Stored Water

The UWS program includes a number of special restrictions on uses of stored water.

Long-term storage credits designated by the holder for the Department's assured/adequate water supply program may be recovered and used only in accordance with that program. In addition, those credits may only be assigned to a person that is assuming the same responsibilities for the assured/adequate water supply program to which the original holder of the credits agreed.

Long-term storage credits earned by storing effluent at a managed

underground storage facility that has not been designated as enhancing a state park, national park or national monument may not be used for the assured/adequate water supply program.

When the Department is notified of an assignment of long-term storage credits, the Department may examine the transaction to determine whether the stored water would have qualified for long-term storage credits had the new assignee stored the water. This provision prevents the use of a "straw man" to defeat the restrictions on long-term storage.

Under certain circumstances, long-term storage credits earned by storing effluent or CAP water may be used to offset groundwater withdrawals in violation of a municipal provider's conservation requirement.

UWS Accounting

The long-term storage accounts will be maintained by the Department of Water Resources for any person holding long-term storage credits. This account is subdivided by each active management area, irrigation non-expansion area or groundwater basin or sub-basin where the person holds credits. The subaccounts are further subdivided by water type.

The statutes lay out numerous rules regarding what can and cannot be done with stored water. When read together, these statutes impose a rather complex accounting system for the UWS program. The Department of Water Resources has developed an equation for determining each year how much water is available for recovery through information reported to the Department in annual reports. Table 1 outlines the accounting equation:

Table 1. UWS Accounting System

Accounting Factor	Explanation
Total amount of water that enters the facility	This factor, like all of the others, is broken down by area of storage and by water type.
Less physical losses to the system	Any water that will not reach the aquifer is subtracted from the total amount of water entering the storage facility. This amount would include evaporation losses, evapotranspiration losses, and water that exits the storage facility. For a groundwater savings facility, this amount would include in lieu water that does not result in a groundwater savings. Only the "recoverable amount", not lost to the system will be eligible for recovery under the UWS program.

Less 50% of the "recoverable amount", but only if the water is effluent stored at a managed underground storage facility	The UWS statutes impose certain restrictions on effluent that is stored at a managed underground storage facility. The most significant is that only 50% of the recoverable amount of this water may be recovered, either on an annual basis or on a long-term basis. This restriction can be avoided if the managed underground storage facility is designated as enhancing a state park, national park or national monument. This designation may be obtained during the facility permitting process, if certain requirements are met. If the facility permit is given this designation, the 50% reduction does not apply.
Less water stored pursuant to a water storage permit that has been designated as storing non-recoverable water	Water that has been stored pursuant to a water storage permit that has been designated as storing non-recoverable water may not be recovered at any time. Therefore, the water is subtracted from the accounting system at this point.
Less water recovered on an annual basis	Except for the restrictions described above, any water that is stored in one year may be recovered in that same year. The annual storage and recovery is not subject to any of the eligibility requirements, explained below, of long-term storage and recovery. If more water was recovered than was stored, the excess recovery must be reported as long-term recovery or as groundwater pumping. If more water was stored than recovered, the water may be eligible for long-term credits.
Less water not recovered on an annual basis that does not qualify as long-term storage	Water that is stored and not recovered on an annual basis may be eligible for long-term storage. If it was not recovered on an annual basis and is not eligible for long-term storage credits, it may not be recovered at any time. Long-term storage is allowed for water for which the permit holder does not have a current need, that is, "water that cannot reasonably be used directly."
Less long-term storage credits assigned to another person	The UWS statutes allow all long-term storage credits to be assigned. Those assignments are not effective until the assignee and assignor notify the Department of the assignment.

Less long-term storage credits assigned to a replenishment account	This provision applies only to replenishment districts. Replenishment districts hold both long-term storage accounts and replenishment accounts. A replenishment district may at any time notify the Department that it wishes to transfer credits from its long-term storage account to its replenishment account. Once the credits are entered in the replenishment account, however, they may not be transferred back to the long-term storage account.
Less long-term recovery for the year	Any water that was stored during the year that is eligible for long-term storage and any long-term storage credits earned during previous years may be recovered.
Less "cuts to the aquifer"	The UWS program provides that generally a long-term storage account is debited 110% for each unit of water recovered. For example, if 100 acre feet of Central Arizona Project water is recovered outside the area of impact, the long-term storage account is debited a total of 110 acre feet. The extra 10 acre feet is commonly referred to as the "cut to the aquifer," indicating that the aquifer is receiving a lasting benefit from the storage and recovery. Although a 10% cut is the general rule, the rate of the cut to the aquifer varies with the circumstances. There is no cut to the aquifer when effluent is stored and recovered. Other types of water that are stored, but that are recovered within the area of impact of the water storage, are subject to a 5% cut. The statutes must be consulted to determine the cut required for the particular circumstances.
Plus any previous balance	If water has been stored for more than one year and long-term storage credits had previously been earned and not recovered, that balance is added to what has been earned for the year.
Plus any long-term storage credits that have been assigned to the holder of the long-term storage account	As has already been explained, all long-term storage credits may be assigned.
New Long-Term Storage Account Balance	

PERMIT APPLICATION PROCESS

The application process is similar for all permits in the UWS program. Although not required by statute, the Department of Water Resources encourages all potential applicants in the program to meet with Department staff before any application is filed. At this pre-application meeting, Department staff explains the permit requirements needed for the applicant to accomplish its goals. Potential problems may be identified and addressed, thus saving time during the formal permitting process.

When the application is filed on the application forms provided by the Department and the appropriate fee is submitted, Department staff will examine the application to determine if it is complete and correct. This review must be completed within one hundred days of the submission of the application; however, if an application is found to be incomplete or incorrect, the applicant is notified and the review period is suspended. When the applicant submits the requested information, the review period commences again and is extended by fifteen days.

Once the application is determined to be complete and correct, notice of the application is published for two consecutive weeks in a newspaper of general circulation in the counties that might be expected to be affected by the proposed facility, storage or recovery. Notice of the application is also provided by first class mail to all cities, towns, private water companies, irrigation districts and electrical districts in the area. The notices provide that interested parties may file an objection to the application within fifteen days of the last date of newspaper publication of the notice. Objections must be based on the assertion that the application does not meet the requirements specified in the statutes for the permit being requested.

The Director of Water Resources may choose to hold a hearing on the application to determine whether the application meets the statutory requirements. A hearing may be held whether or not an objection is filed. If the Director determines that the application meets the requirements of the statutes, a permit will be issued allowing the permittee to operate a storage facility, store water or recover water.

REFERENCES CITED

Title 45, Chapter 3.1, Arizona Revised Statutes

SESSION 2C:

INNOVATIVE TECHNOLOGY IN SOIL AND GROUNDWATER INVESTIGATIONS

Moderator: Marvin Glotfelty, R.G.
Southwest Ground-Water Consultants

VADOSE ZONE CHARACTERIZATION, MONITORING, AND REMEDIATION[1]

Dr. Lorne G. Everett [2]

The presentation will open with a discussion of regulatory changes to RCRA involving the vadose zone characterization and monitoring requirement which will appear as interim guidance this year and as a final EPA rule within twelve months. Discussions will then center on an overview of the three areas within the vadose zone, the interaction and relevance of the different phases within the vadose zone, and a description of soil, soil pore liquid, and soil gas monitoring methods. Recent breakthroughs in measuring water content in places using neutron probes, timedomainreflectometry,and capacitance probes will be presented. State of the art methods for measuring air permeability under controlled soil moisture levels will also be discussed. Issues related to VOCs and soil pore liquid sampling techniques will be evaluated. The presentation will identify new ASTM standards for soil sampling, hydraulic conductivity measurements, neutron moderation measurements, air permeability, soil moisture flux, dielectric constant sensors, etc. The vadose zone presentation will focus on evaluating methods which correlate soil vadose zone monitoring methods to soil cleanup levels and ultimately to the protection of the groundwater.

[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] Lorne G. Everett is Vice President and Chief Research Hydrologist, Geraghty & Miller, Inc. Santa Barbara, CA, and Director,Vadose Zone Research Laboratory, Univ. of Calif. at Santa Barbara.

Dr. Lorne G. Everett is the Chief Research Hydrologist and Vice President for Geraghty & Miller, Inc., Santa Barbara, and the Director of the Vadose Zone Research Laboratory at the University of California at Santa Barbara. He has a Ph.D. in Hydrology from the University of Arizona in Tucson.

Dr. Everett conducts research on subsurface characterization and remediation. He is Chairman of the American Society for Testing and Materials (ASTM) Task Committee on Groundwater and Vadose Zone Monitoring, and is responsible for writing nine new National ASTM Standards on Vadose Zone Investigations. He chaired the Remediation Session of the First USSR/USA Conference on Environmental Hydrogeology (Leningrad, 1990). Dr. Everett has authored several books including: *Groundwater Monitoring, Vadose Zone Monitoring for Hazardous Waste Sites, and Subsurface Migration of Hazardous Waste.* His book entitled *Groundwater Monitoring* was endorsed by EPA as establishing "the State-of-the-Art used by industry today" and is recommended by the World Health Organization for all developing countries.

HydroPhysical™ Logging: Overview of Case Studies

William H. Pedler
COLOG, Inc.
Golden, CO

HydroPhysical™ logging (HpL™) is a revolutionary advancement in subsurface characterization. HpL™ was originally introduced by the DOE's Lawrence Berkeley Laboratory in 1986 as a fluid logging method for characterizing inflow parameters of fractures in deep wellbores (5000+ feet) associated with nuclear waste isolation studies (Tsang, et al 1990). This technology has since demonstrated a much broader range of applications in a wide variety of case studies. HpL™ identifies the depth of the water bearing intervals to one borehole diameter resolution, quantifies the rate of inflow (0.01 to 100+ gallons per minute) for each water bearing interval during pumping, evaluates the vertical flow during ambient (non-pumping) conditions and evaluates vertical distribution of inorganic water quality (specific conductance and pH). When HpL™ is coupled with a discrete point fluid sampler, the actual (or "pore water") concentration for any aqueous phase contaminant can be calculated for each water bearing interval. In addition, when the interval specific inflow is integrated with the drawdown data, the vertical distribution of horizontal hydraulic conductivity can be calculated. A schematic of HpL™ equipment set up and log interpretation is presented in Figure 1.

Since its inception in 1986, HpL™ has demonstrated its efficacy in a wide variety of wellbore types and hydrogeologic environments (Pedler and Urish, 1988, Pedler et. al., 1990, Pedler, et. al., 1992, Paillet, et. al. 1993, Vernon, et. al. 1993, Pedler and Kennard, 1993, and Pedler, 1993) Borehole diameters have ranged from 4" to 16" and have included both open hole to fully and multi - screened completed wells. Hydrogeologic environments have included low transmissivity monitoring wells to highly transmissive fractured bedrock aquifers used for municipal water supply to a variety of porous mediums (monitoring wells in stratified sand and gravel to high yield water supply wells of the Central Valley, California) to the extremely high transmissivity environment found in the volcanic basalts beneath the island of Oahu, Hawaii. On going development of the HpL™ technology, suggests its applicability to identify intervals of horizontal flow in the ambient (non-pumping) condition and quantify the associated flow rates (Anderson et. al. 1993).

This presentation will discuss a variety of case studies which demonstrate the versatility of the HydroPhysical™ logging technology and is in conjunction with an exposition of the HpL™ field equipment at this conference.

Selected Bibliography

Tsang, C.F., F.V. Hale, and P. Hufschmied, "Determination of Fracture Inflow Parameters with a Borehole Fluid Conductivity Logging Method," Water Resources Research, vol. 26, no.4, pp. 561-578, April 1990 and LBL 24752, Lawrence Berkeley Laboratory, University of California, Berkeley, CA, and NDC-1, NAGRA, Baden, Switzerland, September 1989.

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Pedler, W.H., Barvenik, M.J., Tsang, C.F., Hale,F.V., "Determination of Bedrock Hydraulic Conductivity and Hydrochemistry Using a Wellbore Fluid Logging Method," Proceedings of the

Fourth National Water Well Association's Outdoor Action Conference, Las Vegas, NV, May 14-17, 1990; reprint LBL-30713, Lawrence Berkeley Laboratory, University of California, Berkeley, CA.

Pedler, W.H., "A Wellbore Fluid Logging Method for Aquifer Characterization," EOS, Transactions of the American Geophysical Union Fall Meeting, Vol. 72, No. 44, pg. 216, December 1991.

Paillet, F.L, Kay, R.Y., Yeskis, D, and Pedler, W.H, "Integrating Well Logs into a Multi-Scale Investigation of a Fractured Sedimentary Aquifer", *The Log Analyst*, pgs. 24-41, Jan.-Feb., 1993.

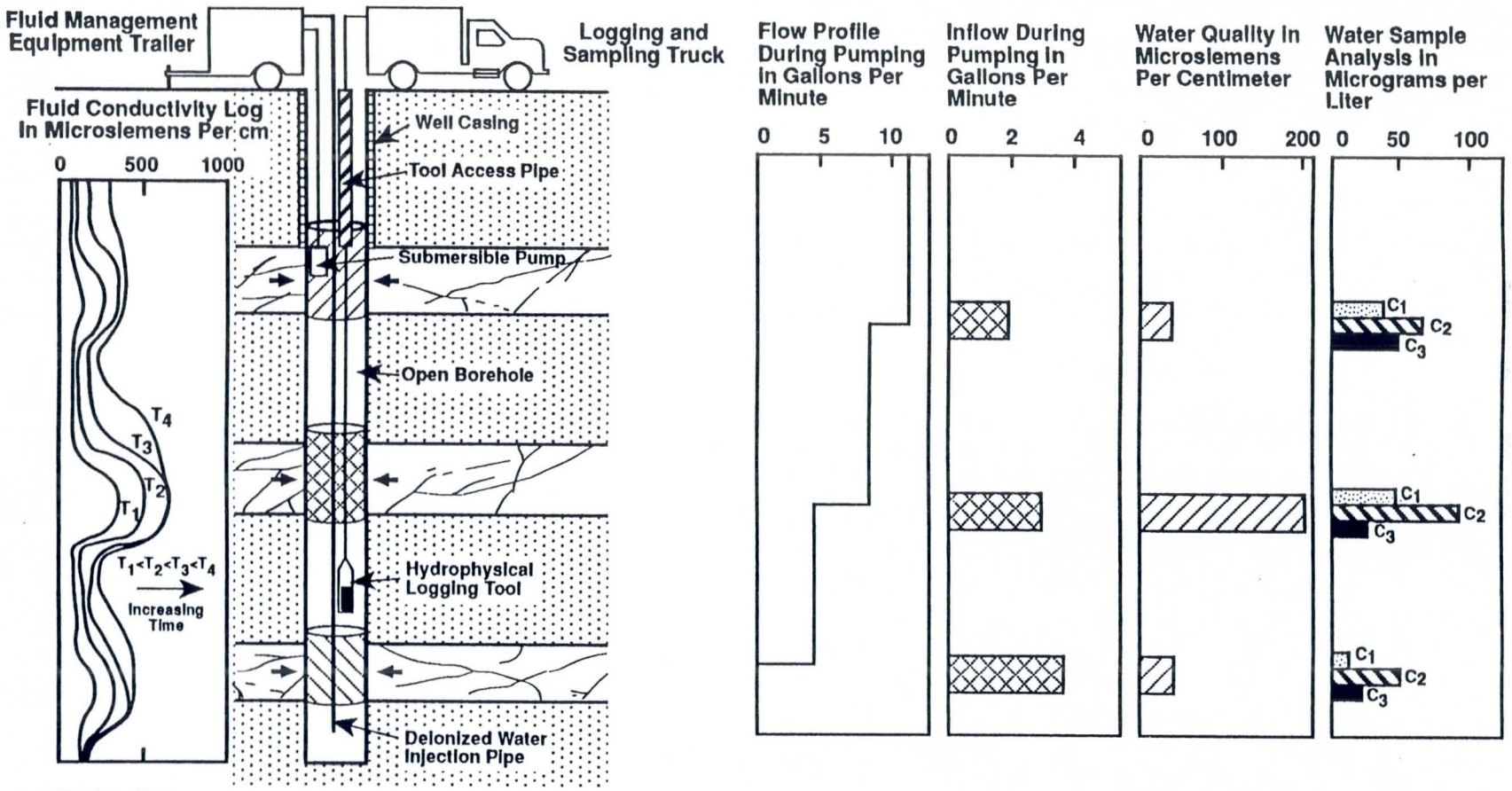
Vernon, J.H, Pedler, W.H., and Paillet, F.L., "Selected Borehole Geophysical Techniques for Well Protection in a Fractured Bedrock Aquifer", Special Environmental Edition, *The Log Analyst*, p. 41-58, Jan-Feb, 1993.

Pedler, W.H., Kennard, M., "HydroPhysical™ Logging at the WQARF Site; Payson, Arizona," Proceedings of the Arizona Hydrological Society Sixth Annual Symposium, 1993

Pedler, W.H., "Evaluation of Interval Specific Flow and Pore Water Hydrochemistry in a High Yield Alluvial Production Well by the HydroPhysical™ Fluid Logging Method" EOS, Transactions of the American Geophysical Union Fall Meeting Vol. 74, No. 43, pg. 304, Dec. 1993.

Anderson, W.P., Evans, D.G., and Pedler, W.H., "Inferring Horizontal Flow in Fractures Using Borehole Fluid Electrical Conductivity Logs," EOS, Transactions of the American Geophysical Union Fall Meeting Vol. 74, No. 43, pg. 305, Dec. 1993.

Figure 1.
Schematic of HydroPhysical™ Well Logging Equipment Set-up and Log Interpretation



Explanation

- Fracture zone
- Unfractured granite
- Deionized water in borehole before pumping
- T Time of fluid electrical conductivity log
- Groundwater flow
- Fresh water from upper fracture zone
- Brackish water from lower fracture zone
- Contaminated water from intermediate fracture zone
- Cm Centimeter
- C1 "Pore" water concentration of analyte 1
- C2 "Pore" water concentration of analyte 2
- C3 "Pore" water concentration of analyte 3
- Centimeter

THE USE OF INFLATABLE PACKERS FOR WATER WELL EVALUATION[1]

Mark Hay[2]

ABSTRACT: The Salt River Project (SRP) is the principal purveyor of water for the Phoenix metropolitan area. SRP owns and operates approximately 250 large capacity groundwater production wells which supplement surface water supplies and provide a hedge in case of drought. Most SRP wells were drilled in the 1940's and 1950's as irrigation supply wells. Typically they are cable tool drilled to depths of 800-1,000 feet, and cased with 18 to 24-inch stove pipe that has been mills knife perforated over most of their length. The wells utilize the extensive aquifers of the east and west Salt River Valley alluvial basins. The aquifers consist of an interbedded sequence of gravel, sand, silt and clay.

Because of the sunny weather and growing economy, Phoenix continues to attract new people. Land that once grew crops is now covered with houses. Water demand that was once agricultural is now municipal. This shift in water demand, plus increasingly restrictive water quality standards and spreading groundwater contamination, is combining to challenge SRP's ability to maintain a viable groundwater production capability.

Salt River Project is evaluating its groundwater production wells that have water quality problems. About 10% of SRP's wells are out of service for this reason. In response, SRP has recently undertaken a program of well testing and remediation. The objective of the program is to retain use of existing production wells as long as economically feasible.

[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]Mark Hay is Senior Geohydrologist, Salt River Project, Phoenix, Arizona.

This will be done by evaluating the specific geologic and hydraulic characteristics at each well site and, if possible, structurally modifying the well to pump from the clean water zones within the aquifer.

Inflatable test packers have proven to be a vital component to SRP's testing program. The packers' main advantage is their capability to limit extraction of water to selected depth intervals in the well. Field experience with SRP wells has shown a significant portion of the screened interval does not produce water during pumping. In fact, 50% or more of the screened area appears dormant under normal pumping conditions. Because these areas do not yield water, no information is available on their water quality or their production potential. By limiting the amount of screen available to produce water, packers can focus the hydraulic stress developed by the pump on these normally unproductive zones. Essentially 'forcing' them to yield water.

A significant obstacle to effective packer testing is selecting a depth where a competent natural seal exists outside the well. Without an outside seal, there is no restriction to flow and the test will be short-circuited. Such a seal may occur where low conductivity materials such as clays and silts are still in place against the casing wall. If no such areas can be found a manmade seal may have to be placed. The integrity of the seal should be apparent by carefully monitoring conditions during the test such as water pressures above and below the packer, discharge capacity of the pump and the characteristics of the discharge.

Figure 1 is a schematic diagram showing a typical SRP pump and packer installation. In this arrangement, the pump draws water from the bottom of the assembly through the open center of the packer.

Figure 2 illustrates DBCP (dibromochloropropane) concentrations in two sets of water samples collected from a SRP well. The first set of samples were collected from the discharge of the production pump with no special equipment or modifications in place. They illustrate that DBCP concentrations under normal conditions ranged from about 0.6 ug/L to 1 ug/L. These are 3 to 5 times higher than the MCL for DBCP (0.2 ug/L). The second set of samples were obtained using a packer to seal off a portion of the well. They show a reduction in DBCP concentration from 0.6 ug/L to 0.1 ug/L over about 6 weeks. The packer test data verify there is water available to the well that is within current water quality standards.

Packers can be extremely powerful tools for evaluating existing water production wells. By helping to determine

whether there is clean water available to a well and what the production capability of those zones might be, packers provide data that is critical to assessing the feasibility of remediating a well's water quality problems through downhole well modification.

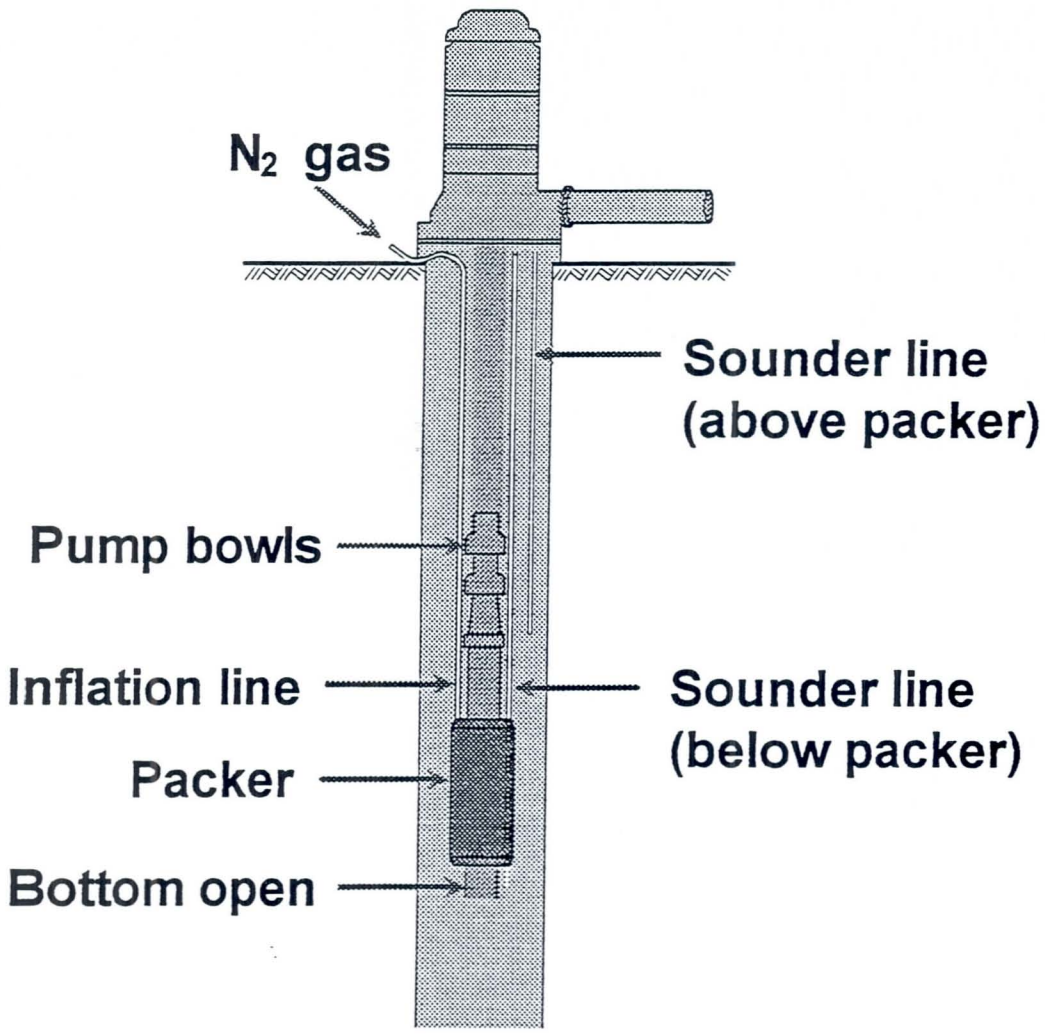


Figure 1. Schematic diagram of typical SRP pump and packer installation

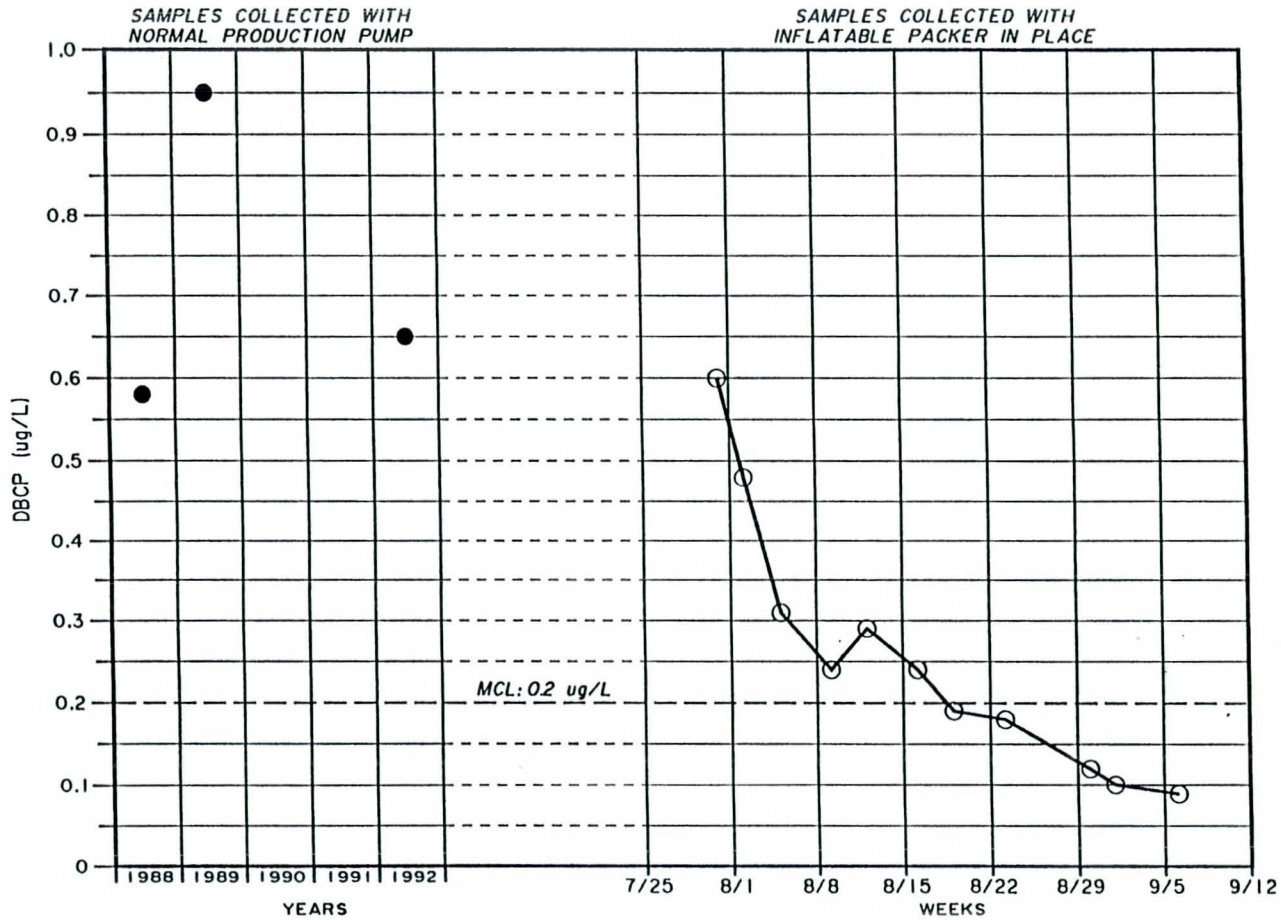


Figure 2. Packer test results for a SRP well contaminated with dibromochloropropane (DBCP). The data on the left represent samples collected from the discharge of the normal production pump. The data on the right represent samples collected from the discharge of a test pump using a packer to isolate a specific depth interval.

SPECIAL SESSION:

ENVIRONMENTAL POLICY IN THE PUBLIC EYE

Moderator: Donn Stoltzfus
City of Phoenix

MAKING GOOD ENVIRONMENTAL POLICY IN THE FACE OF HYPERBOLE

EDWARD Z. FOX
Director, Arizona Department of Environmental Quality

Biographical Information

Edward Z. Fox was appointed Director of the Arizona Department of Environmental Quality by Governor Fife Symington on July 1, 1991.

A native of Ohio, Mr. Fox holds a law degree from West Virginia University and a master's degree in Public Administration from American University in Washington, D.C.

Prior to coming to Arizona in 1985, Mr. Fox served as an assistant attorney general for the Environmental Task Force of the West Virginia Attorney General's Office. His area of expertise was enforcement of water, hazardous waste and surface mining laws.

From 1985 to 1991, Mr. Fox practiced environmental law with the Phoenix firms of Streich, Lang and Snell & Wilmer, representing corporate clients and municipalities on environmental issues.

ENVIRONMENTAL INJUSTICE – ITS CAUSES AND ITS CURES

T. J. HARRISON
Tucson City Attorney's Office

Summary

The speaker is not an expert on environmental equity, but will simply share information and experience relevant to the subject. First, we will attempt to defind environmental equity, justice, and racism. Then, examples from history and from current conditions will be explored. Finally, possible consequences of and solutions to these conditions and attitudes will be discussed. The principal focus will be on the role of public institutions and policies in creating, encouraging and preventing environmental inequities. It is hoped that the presentation will elicit active audience response and participation.

T. J. HARRISON
Tucson City Attorney's Office

Biographical Information

Since 1976, T. J. Harrison has been an attorney with the City of Tucson, specializing in water law, environmental law and natural resources law, building codes and other technical and safety codes, and low-income housing. Prior to joining the City, he had a private law practice. He has also worked for the United States Forest Service and as a graduate research assistant in Forestry and Hydrologic Studies at the University of Arizona.

Mr. Harrison worked to establish the Environmental and Natural Resources Law Section of the State Bar of Arizona, later serving on its governing board and as an officer. He has also served as Chairman of the Commission on the Arizona Environment.

In the late 1970s, Mr. Harrison participated in negotiations that resulted in the 1980 Groundwater Management Act. He later worked with the Arizona Clean Water Advocates (an association of environmental groups and the City of Tucson) to draft and press for enactment of a clean water initiative. That initiative effort eventually forced the state legislature to consider broad environmental legislation. He participated in the public drafting and negotiation process led by Governor Babbitt and made substantial contributions to the final closed-door negotiations that resulted in the 1986 Environmental Quality Act, which established the Arizona Department of Environmental Quality.

In 1978, Mr. Harrison worked to establish a lobbying presence for the United Way of Greater Tucson. He has served on that Governmental Relations Committee and has assisted in monitoring and attempting to influence state agencies and the state legislature on behalf of the homeless, mentally ill, abused children, affordable housing, etc.

Mr. Harrison holds a Bachelor of Science and a law degree from the University of Arizona.

RISK ASSESSMENT, SCIENCE AND THE COURTROOM[1]

Rolf R. von Oppenfeld[2]
Blake Ashley
Scott K. Ames

ABSTRACT: What is the legal significance of exposure to a dose of carcinogens sufficient to create, under EPA risk assessment methodology, an additional risk of one in one million chance of developing cancer over a lifetime? What impact, if any, do risk assessments have in a court action to recover claims for personal injuries or medical monitoring?

Recent legal developments in the area of toxic tort litigation have highlighted the importance of understanding the scientific and legal aspects of risk assessment. This importance is underscored by the recent filing of cases alleging injury and increased risk of injury from exposure to trace amounts of TCE in drinking water. Various aspects of plaintiffs' claims hinge on the validity of expert testimony as to whether or not exposed individuals are at a "significantly increased risk" of contracting cancer or various other maladies sometime in the future. Risk assessments also are used by plaintiffs' attorneys to support claims of immune system damage, cancerphobia or a need for cancer screening by medical personnel on a periodic basis. How do the courts respond to the use of risk calculations and how do they impact cleanup levels?

This paper examines the legal aspects of the use of risk assessment in the courtroom, especially in those cases where plaintiffs have no present physical manifestations of harm. This examination includes a review of the scientific theories of risk assessment and the issues involved in cases where the exposures are extremely small.

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[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] Rolf R. von Oppenfeld is a partner with the law firm of Kane Jorden & von Oppenfeld, a law firm concentrating its practice in environmental and land use law. Blake Ashley and Scott K. Ames are associates at Kane Jorden & von Oppenfeld. Mr. von Oppenfeld, Mr. Ashley and Mr. Ames, each possess undergraduate degrees in chemistry as well as law degrees and collectively have many years of experience in organic and environmental chemistry and toxicology. Mr. von Oppenfeld teaches Environmental Law as part of Arizona State University's graduate program in Hazardous Waste Management from which program Mr. Ames received an M.S. degree.

INTRODUCTION

Risk assessment is a science in ascendance. It has become an integral part of environmental, occupational, and consumer product regulatory activity. As these lines are being written, a greater role for risk assessment in environmental regulation is being debated in the U.S. Congress. However, government regulation is not the only venue where risk assessment plays a starring role. Civil litigation based on alleged exposure to toxic chemicals, often called "toxic tort", has become increasingly common in recent years. The parties to toxic tort litigation frequently invoke risk assessment as part of their case. This article will address the role of risk assessment in toxic tort litigation and to a lesser extent environmental regulation, but first an overview of the science of risk assessment is in order.

RISK ASSESSMENT

Risk assessment is the use of scientific evidence to define the probability that a population that has been exposed to a toxic substance will suffer adverse health effects as a result of that exposure. (Ris and Peters 1988). In general, it is impossible to predict whether any given individual will develop cancer or any other specific disease in response to a chemical exposure, even with detailed exposure data. The best that can be achieved in the usual case is a prediction on a population wide basis of the probability that a portion of that population will suffer a specific harm from a specific exposure. That prediction is a risk assessment. Risk assessment probabilities are usually expressed in terms of the number of persons who will contract the illness per 100,000 (10^{-5}) or per 1,000,000 (10^{-6}). (Gaylor 1988).

Risk assessment for exposure to a particular risk agent often involves a four step process (Cohrssen and Covello 1989):

1. **Source/Release Assessment.** This step attempts to estimate the amount of the risk agent that has been released to the occupational, residential, or outdoor

environment. This assessment can be based on actual measurement of a release, a known disposal volume from which a release volume can be calculated, documentation showing the loss of a risk agent not accounted for by known routes, and other direct and indirect measurements and/or estimates.

2. **Exposure Assessment.** This step attempts to estimate the concentration and duration of human exposure to the risk agent. The exposure assessment can be based on the release assessment, direct measurement of the actual exposure, direct measurement from a simulated exposure, or estimates from indirect indicators.

3. **Dose-Response Assessment.** This assessment estimates the amount of the risk agent that an individual member of the population absorbed into their bodies and an estimate of the percentage of the population or subgroups of the population that will be harmed from such exposure.

4. **Risk Characterization.** In this step, the previous steps are integrated into a risk statement attempting to quantify the risk of harm.

Scientific Foundations for Risk Assessment

The dose-response characterization for any given exposure must be based on scientific research. This research generally takes one of two forms: epidemiological studies and animal studies. Each has advantages and disadvantages.

Epidemiology is the study of the distribution and causes of diseases within a population. The study of diseases in the human population caused by exposure to toxic substances is one branch of epidemiology. Because it is unethical to dose humans with harmful quantities of toxic substances for experimental purposes, and in any event it is difficult to get volunteers, epidemiologists generally study human exposures to toxic substances that occur as a result of accident, self-administration, or unavoidable occupational contact. (Gaylor 1988).

An epidemiologist wishing to study the toxic effects of cigarette smoking, for example, might survey a population of smokers and compare the diseases reported by the smokers to those reported by a control group of non-smokers selected for their similarity in other respects to the smokers. The results of the study might show whether or not there is a statistically significant association between smoking and a particular disease. Smoking is an example of self-administration of a risk agent. Chemical plant explosions and the like, although rare, provide opportunities to study the effects of toxic substances to which few would deliberately expose themselves. The study of occupations like dry cleaning, where there is some level of daily exposure to a narrow range of risk agents, is also a popular epidemiological method.

The main problem with epidemiology is lack of variable control. Because epidemiologists are unable to control many variables, the best they can do is report associations between a substance and a disease. Associations are not definitive links. For example, it is possible to establish a statistically significant association between lung cancer and carrying matches in one's pocket. Common sense suggests that the association between carrying matches and contracting lung cancer is spurious. However, because it is difficult to separate the carrying of matches from cigarette smoking in the population being studied, the association between matches and lung cancer, as unlikely as it seems, is difficult to eliminate by the scientific method of variable control. Even greater problems arise when the spurious association is not obvious.

Often the substance being studied is found in matrix with other substances thereby confounding the study. For example, Scandinavian studies of agricultural workers exposed to 2,4,5-T, a phenoxy-herbicide, showed a weak association with soft-tissue angiosarcoma. Unfortunately, the 2,4,5-T, as is usually the case, was slightly contaminated with tetrachloro-dibenzo-dioxin so it is unclear which compound caused the disease and no follow-up study is possible with humans.

There are many other uncontrollable variables which inject uncertainty into epidemiological studies including synergistic effects or alternate causation from other chemical exposures and individualized factors such as genetic predisposition and diet. As a result, epidemiological studies are difficult to evaluate. Nonetheless, they often remain the best source for data on the effects of toxic substances on humans. In contrast, animal studies can be controlled with a high degree of exclusivity. But animal studies have their own problems.

The majority of dose-response data available for risk assessment comes from animal studies, also called bioassays. This is because animal studies lend themselves to laboratory procedures and complete variable control. Furthermore, unlike an epidemiological study, where the exposure occurrence may be unique, animal studies may be repeated several times with identical doses to verify the results. Theoretically, the results from animal studies should be capable of duplication by other disinterested scientists carefully following the original methodology.

Animal studies are usually conducted with very high doses of the substance being studied relative to typical human exposures. One justification for high-dose animal studies is the theory that in human beings subjected to toxic environmental exposures, diseases, particularly cancers, may not manifest themselves for many years. Animal studies are designed in part to produce measurable results in a much shorter period of time by subjecting the animals to much larger doses than would be expected in the human environment, followed by extrapolation of the results to predict the effects on humans from the much smaller typical environmental doses. However, many epidemiologists and toxicologists consider extrapolating the results of studies performed with high doses on rodents to humans exposed to low doses to be without scientific merit. These scientists believe such extrapolation is without merit because humans may not have the same general susceptibility to the disease being studied as rodents due to metabolic or other systemic differences. Humans also may differ from rodents in their susceptibility to the particular agent being tested. Even among rodent species, such as rats and guinea pigs, there are markedly different susceptibilities to some substances. Finally, there is the dose-response curve problem.

The dose-response curve problem arises because the shape of the curve is generally unknown. (Ames 1988). The dose-response curve is said to be linear where the risk of developing a disease is directly proportional to the amount of the dose throughout the range of doses. The dose-response curve is said to be non-linear where the risk of developing a disease is not directly proportional to the amount of the dose at all dose ranges. A linear dose-response exhibits no threshold - there is no dose without a corresponding toxic effect. However, higher organisms, such as humans, typically have the ability to detoxify small doses of toxic substances, but when the organism's detoxification system becomes overburdened at higher doses, the higher doses tend to produce disproportionately larger effects thus creating a non-linear, convex dose-response curve. (Gaylor 1988). Unlike a linear dose-response

curve, non-linear dose-response curves can predict a dose below which no adverse effects are observed. This is called the threshold dose. Thus, an observed response to a high dose of a substance with a non-linear dose-response curve may be a very poor indicator of the response to be expected from a low dose. In fact, if the low dose falls below the threshold, there will be no response at all. Animal studies seldom take into account non-linearity of dose-response.

The advancement of techniques for in vitro human tissue culture has opened up a new source of toxicological data to support risk analysis. Studies on human tissue culture usually involve exposing human tissue, which has been isolated and grown in the lab, to the substance being tested and then observing the tissue's response. While this method is in some ways an improvement on animal studies in that it involves human tissue, tissue cultures are still not identical to intact human tissue in the living organism with respect to response to toxic substances in part because they may not benefit from the detoxifying effects of other systems and tissues in the living organism. This field is relatively new and what its ultimate contribution to risk analysis will be is unclear.

The Importance of Risk Assessment in Toxic Tort Litigation

At the center of most toxic tort litigation is an allegation by a plaintiff that they have suffered an injury as a result of their exposure to a toxic substance. As part of their lawsuit the toxic tort plaintiff generally must prove by a preponderance of the evidence that the exposure caused their injury. It is in the battle over this link between exposure and injury that risk assessment is most frequently invoked in the typical toxic tort lawsuit. In Arizona, however, a new role for risk assessment in toxic tort litigation has recently emerged.

In 1987 the Arizona Court of Appeals issued an opinion that simultaneously weakened one of the most venerable pillars of tort law and potentially raised risk assessment to new heights of legal significance.

The case of Burns v. Jaquays Mining Corporation[1] had its genesis in a mobile home park in the Arizona town of Globe. Mountain View Mobile

[1]Burns v. Jaquays Mining Corp., 156 Ariz. 375, 752 P.2d 28 (1988)

Home Estates was located next to an asbestos mill operated by Jaquays Mining Company. Over a period of several years, the mobile home park was subjected to a wind-born influx of asbestos fibers from the adjacent mill and tailings pile. The park residents became concerned and filed suit against the mining company but their personal injury case was lacking in one important respect: they hadn't suffered any injury. They had inhaled asbestos fibers but no disease was present. The trial court granted summary judgment against the park residents and for the mining company.

The trial court granted summary judgment for the mining company because the park residents, lacking any signs of disease, had failed to show that the mining company had caused them any injury. To successfully bring a lawsuit to recover monetary damages for personal injury, a plaintiff must allege that they have suffered an actual injury. In the words of tort law authorities Prosser and Keeton, "The threat of future harm, not yet realized, is not enough."

The requirement of actual injury has a long history in American jurisprudence and had previously been upheld even in the asbestos exposure context. In a leading case on the issue, a Federal Circuit Court ruled that "subclinical injury resulting from exposure to asbestos is insufficient to constitute the actual loss or damage to a plaintiff's interest required to sustain a cause of action under generally applicable principles of tort law."[2]

This long-standing requirement of proof of actual injury for the recovery of monetary damages was based on sound reasoning. If a plaintiff merely expects damage in the future, there is no way of knowing in the present that the damage will actually occur or what its extent will be. If monetary damages are awarded in anticipation of future injury and the injury never materializes, or materializes in a form less serious than anticipated, then the plaintiff will have been unjustly enriched at the defendant's expense. Conversely, if the subsequent injury proves to be more significant than the plaintiff predicted, the plaintiff will find themselves undercompensated. Because awarding damages for prospective injury would often times result in injustice, Courts have uniformly required that actual injury precede an award of damages.

The Court of Appeals that reviewed the trial court's grant of

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[2]Schweitzer v. Consolidated Rail Corp., 758 F.2d 936, 942 (3rd Cir. 1985).

summary judgment against the Burns plaintiffs agreed that there was insufficient showing of actual injury to support monetary damages. However, it stated that "despite the absence of physical manifestation of any asbestos-related diseases ... the plaintiffs should be entitled to such regular medical testing and evaluation as is reasonably necessary and consistent with contemporary scientific principles applied by physicians experienced in the diagnosis and treatment of these types of injuries."

If an Arizona court allows plaintiffs to recover prophylactic medical expenses, the court is placing its faith in the predictive powers of science - in other words, it's expressing confidence in prediction through risk assessment. The court was faced with plaintiffs who could show strong evidence of the presence of asbestos fibers in their lungs, strong evidence that pulmonary infiltration of asbestos fibers can cause a unique and deadly disease, and strong evidence that their exposure was such that they were more likely than not to contract that disease. Rather than ruling, as the trial court did, and as precedent demanded, that the plaintiffs should come back if and when they actually developed the disease, the Burns court ruled that the cost of medical monitoring is available when it is reasonable and necessary in light of "'reliable expert testimony predicated on the significance and extent of exposure . . . the toxicity of [the contaminant], the seriousness of the diseases for which the individuals are at risk, the relative increase in the chance of onset of the disease in those exposed and the value of early diagnosis, . . . '"

The level of increased risk which a plaintiff must show in order to be awarded a lifetime of free medical care was not addressed by the court in Burns. Does any increase in risk justify a court ordered prophylactic remedy? Does the prospective injury need to be more likely than not to occur? Does future injury need to be certain? The question of what level of increased risk is required to support court-ordered medical monitoring in a risk-based lawsuit will most likely be answered in part in future cases where the increased risk will be demonstrated to be vanishingly small.

A group of cases recently filed in Phoenix based on allegations of trace exposure to trichloroethylene (TCE) contamination in the drinking water may answer the question of how minuscule the increased risk can be to justify the Burns remedy. The plaintiffs in the Phoenix TCE cases allege substantially increased risk of injury from exposure to 2 parts per billion (ppb) TCE - less than half of the EPA's maximum contamination level (MCL). These cases raise serious questions that must be answered by risk assessment but how will the litigants actually use risk assessment in court?

Risk Assessments as Evidence in Litigation

An attorney litigating a toxic exposure lawsuit often may try to obtain a favorable risk assessment, but that is only part of the battle. The attorney may have difficulty in having the risk assessment admitted as evidence. Courts will not allow litigants to present to the jury any information the litigant thinks is important in any form the litigant likes. In fact, one of the trial court judge's most important roles is that of screening the evidence which the parties to a lawsuit may present to the jury. The general purpose of the rules of evidence is to insure that only reliable, factual evidence is admitted. In accordance with that goal, opinions are generally forbidden and a risk assessment is, at bottom, an opinion. However, there is an exception to the rule prohibiting opinion evidence. The Arizona Rules of Evidence provide that "[i]f scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise." This rule reflects the impracticality of having all of the scientists who conducted the relevant toxicological research with respect to a particular substance come to court to describe first-hand what they did. Instead courts can, in appropriate situations, allow qualified experts to digest the relevant research, arrive at an opinion based on the research, and then present the opinion to the jury.

It is frequently through expert opinion testimony that risk assessments are presented to juries. Individuals whose expertise has been approved by the court typically will explain their opinion about the proper risk assessment. The plaintiffs present their experts and the defendants present their experts. And sometimes the court has its own expert. When the plaintiffs' and defendants' experts have differing opinions (always), the jury decides which expert it believes and decides the case accordingly.

The expert opinion method of educating juries on the complexities of risk assessment seems sensible at first blush. However, problems arise because all expert risk assessors do not hold to the same standard of scientific validity and, some would say, ethics. In other words, litigants are willing to pay large sums of money for experts with sufficiently impressive credentials to say favorable things about the litigant's position. Unfortunately, some experts can be induced by that pressure to say some remarkable things, including things not particularly well founded in science. The attorney faced with an opposing expert willing to give harmful opinions not well-founded in science has

two ways of responding: appealing to the judge to exclude the expert's testimony and undermining the expert's testimony in the minds of the jury with cross-examination and contrary expert testimony.

For many years, courts admitted expert opinion only if it was based on scientific methods generally accepted as reliable in the relevant scientific community. This standard, known as the Frye test because it was taken from a 1923 Federal Court case called Frye v. United States[3], prohibited the introduction of expert opinion evidence based on methodology that diverged significantly from the procedures accepted by recognized authorities in the field. Using the Frye rule, litigants could prevent "lone nut" scientists from presenting their unique theories to juries. Of course the Frye test could also prevent sound opinions from being heard in court simply because they were based on new theories.

In 1993 the U.S. Supreme Court struck down the Frye test in a case called Daubert v. Merrell Dow Pharmaceuticals[4]. In Daubert the Supreme Court held, broadly, that proposed experts may testify to any scientific knowledge that will assist the trier of fact to understand or determine a fact in issue. The Court went on to suggest that a trial court would need to make a "preliminary assessment of whether the reasoning or methodology underlying the testimony is scientifically valid and of whether that reasoning or methodology properly can be applied to the facts in issue." The Court then listed some factors a trial court might take into consideration when making its assessment of scientific validity.

The Daubert Court suggested that the methodology or technique underlying a scientific statement can be evaluated on the basis of its susceptibility to empirical testing, the peer review it has received, its publication, its rate of error, the existence of standards controlling its operation, and its general acceptance in the relevant scientific community.

Thus, under the old Frye rule, an attorney wishing to have expert scientific testimony excluded would present evidence to the judge that the opinion the expert was going to express was based on science not generally accepted by his peers. Under the new Daubert rule, an attorney must delve directly into the substantive merits of the expert's methodology in order to

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[3]Frye v. United States, 293 F. 1013 (1923)

[4]Daubert v. Merrell Dow Pharmaceuticals, 113 S.Ct. 2786 (1993)

undermine the scientific validity of the expert's proposed testimony sufficiently to have it excluded from trial. This new standard requires greater scientific sophistication on the part of attorneys than did the Frye rule.[5]

In response to concerns that the new rule would allow a "'free-for-all' in which befuddled juries are confounded by absurd and irrational pseudoscientific assertions. . . ." the Supreme Court remarked that "[v]igorous cross-examination, presentation of contrary evidence, and careful instruction on the burden of proof are the traditional and appropriate means of attacking shaky but admissible evidence."

Once an expert's opinion has been admitted, the opposing party must attack it through cross-examination. Cross-examination of expert scientific witnesses typically consists of confronting them with scientific literature contrary to their opinion, critical questioning directed at the research upon which they base their opinion, establishing their bias (by bringing up their fees, for example), establishing logical flaws in their scientific thinking, confronting them with prior inconsistent statements in their publications or other testimony, and otherwise undermining their credibility and the scientific foundation of their opinion. So in cross-examination, just as with admissibility, the trial attorney is required to challenge the scientific expert on the substance of his science.

More than ever, the new Daubert standard has left it to attorneys, with the assistance of their expert consultants, to bring the debate on cutting-edge scientific theories into the courtroom with large sums of money at stake and juries the final arbiters. The Burns case makes a forceful example of the importance of this development.

Toxic tort attorneys must not only have sufficient technical proficiency to master the risk assessments associated with the exposure directly at issue in a particular case; they must also be able to provide the judge or jury with perspective on risk through the use of risk assessments for commonly encountered risk agents. This approach is called comparative risk assessment.

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[5] Daubert construes the Federal Rules of Evidence and is not directly binding on Arizona State Courts. The Arizona rule on admission of expert testimony is identical to the Federal Rule and Arizona Courts generally look to Federal Courts for guidance.

COMPARATIVE RISK ASSESSMENT

Comparative risk assessment involves comparing the risk presented by an unfamiliar exposure, such as traces of TCE in the water supply, to a familiar exposure so that non-experts, like juries, can make decisions about the urgency of a particular risk. For example, the defendants in the Phoenix TCE cases previously mentioned might favorably compare the risk associated with such mundane exposures as peanut butter, coffee, alcohol, sunlight, and high-fat diets to the TCE exposure that the plaintiffs in those cases have allegedly suffered. In so doing, the defendants will be able to bring the very small risk from TCE exposure into the context of the daily lives of the jury. If a jury can be convinced that the risk from 2 ppb of TCE in the water supply is no greater than that presented by eating a peanut butter sandwich every day, they are unlikely to be particularly sympathetic to the plaintiffs' supposedly weakened condition.

As an example of how comparative risk assessment may by used, let us examine the toxicity of chlorination by-products contained in the drinking water virtually all of us consume and bathe in on a regular basis. Chlorine is added to almost all municipal water supplies around the country as an oxidizer to control pathogenic microorganisms. Chlorination can cause the formation of a wide variety of chlorinated and, by displacement and re-arrangement, brominated compounds. Four chemical species predominate as byproducts of the chlorination process: chloroform ("CFM"), bromodichloromethane, dibromochloromethane, and bromoform. Each of these compounds has been shown to be carcinogenic but CFM normally exists in the greatest abundance and displays similar toxic characteristics to TCE. Therefore, we will use the risks presented by CFM exposure from chlorination for comparison with the risks associated with consuming trace quantities of TCE in municipal drinking water.

The EPA regulatory limit for total trihalomethanes in drinking water is 100 ppb, based on technical as well as practical limitations. Suppose the CFM concentration in drinking water were 50 ppb, well within the established EPA regulatory limits. The calculated upper limit on excess lifetime cancer risk from the ingestion of 2 liters per day of water containing 50 ppb of CFM for 70 years equals approximately 8 excess cancers per one million people so exposed. (Rodricks 1992). In contrast, the exposure levels of TCE alleged by the plaintiffs in the Phoenix TCE cases fall short of a one in a million

increased cancer risk for 70 years of exposure, according to EPA's assessment. If one were to ignore the fact that the Phoenix TCE plaintiffs allege only a few years of exposure, and then attempt to compare the relative risks associated with TCE and CFM exposures over a lifetime, one would conclude that any incident of cancer in someone exposed to both substances would be eight times more likely to have been caused by the routine exposure to CFM than from TCE. Factoring in the 70 year exposure, the comparative risk assessment would likely be several orders of magnitude greater risk from CFM exposure. The purpose of making this comparison for the jury is not to alarm them about the safety of their drinking water. Rather, it is to put the abstract risk assessment for trace TCE exposure into a familiar context. It is hoped that jurors will realize that the risks they accept on a daily basis are far greater than any risk that might be posed by trace TCE exposure.

This is merely an example of the use of comparative risk assessment in the context of exposures to similar compounds from the same source. However, comparative risk assessment may go well beyond this. All of us face innumerable risks in our everyday lives that far exceed the risks associated with trace quantities of TCE or CFM in drinking water. These risks take the form of driving to and from work, workplace hazards, primary and/or secondary cigarette smoke, and dietary choices to name just a few. When viewed within the context of the inherent risks associated with living a normal life, the question of what constitutes an acceptable increased risk from trace chemical exposure becomes a serious public policy question - a public policy question that government regulation often addresses.

RISK ASSESSMENT IN ENVIRONMENTAL REGULATION

During the 1970s, government regulatory agencies began to make determinations of the risk presented to the public from exposure to carcinogens. The FDA was the first federal agency to adopt risk assessment as a means of establishing levels of insignificant risk for consumption of food products containing trace amounts of adulterants such as livestock drugs. Then EPA began to adopt risk assessment values for environmental exposures to carcinogens. OSHA followed by adopting risk assessment as a basis for establishing regulations for workplace exposures to carcinogens. (Rodricks 1992). As part of their legislative mandate, different regulatory agencies with different jurisdictions make their own decisions about appropriate risk goals for air pollutants, water pollutants, food additives, and occupational exposures.

The result is that people can be exposed to different levels of risk from the same chemical depending on what regulatory scheme controls the route of exposure.

For example, OSHA uses risk assessment values of one in 1,000 or one in 10,000 for workplace exposures rather than the one in one million typically used by the EPA for environmental exposures. It is not that OSHA views risk differently. Instead, OSHA compares the risk associated with workplace exposures to the lifetime risk of job-related fatalities from accidents or hazards other than exposure to chemicals. OSHA cites the Bureau of Labor Statistics data that the lifetime risk associated with relatively safe occupations (such as office work) is in the range of one per 1,000 over 40 years. (Rodricks 1992). Many occupations obviously are much riskier than office work.

The EPA, on the other hand, takes a position that exposure to carcinogens ideally should be zero. Even the EPA recognizes this as practically impossible and so factors in technical feasibility and a concept of acceptable risk when establishing MCLs. However, where an uncertainty exists as to the risk to humans presented by any particular threat agent, EPA policy generally favors the highest estimate of risk, which typically overstates true risk. (Rodricks 1992).

While the role of government risk assessments in the establishment of government regulations is fairly clear, the effect of government risk assessments on private lawsuits such as Baker is not.

The federal and state governments pervasively regulate the quality of water consumed through public water supplies. For example, A.R.S. § 49-223 provides that the EPA's MCLs are adopted as the State's drinking water quality standards. So Arizona and all of its political subdivisions have endorsed the safety of drinking water containing levels of contaminants less than the MCLs. This presents the following question: to the extent an MCL is promulgated for a particular chemical in drinking water and that concentration is not exceeded by the water provider, should consumers of that water be able to file a lawsuit against the provider and others for negligently exposing them to the chemical allegedly causing an increased risk of developing disease?

A related inquiry might be: to the extent future data suggests that certain compounds are not as toxic as once thought, should defendants have some recourse against Burns type plaintiffs who were unjustly enriched based on unsound risk assessment data? Again, TCE serves as an excellent example

of a compound that appears not to be as toxic as once thought. According to the ATSDR Toxicological Profile for Trichloroethylene (April 1993), numerous epidemiological studies have been performed on workers exposed to TCE and none have shown a higher incidence of cancer than from control groups. In fact, no definitive evidence linking TCE with cancer has been identified in case-control studies. In addition, recent studies challenge the propriety of predicting potential carcinogenic effects of TCE on humans from results on animal studies. (Larson, 1994).

In Arizona, in the absence of statute, the general standard of non-negligent conduct is reasonableness and due care under the particular circumstances. In other words, to be liable for negligence, a defendant must be shown to have acted with less than due care under a given set of circumstances. When someone violates a law which was enacted to protect the health or safety of a particular class of people, water drinkers, for example, and the violation of the law causes some member of that class to suffer an injury of the type the law sought to prevent, the violator of the law will be presumed to be negligent or what is called negligent per se. In other words, the statutory standard becomes the standard of minimum care for purposes of a civil lawsuit for negligence.[6] On the other hand, "[c]ompliance with such statutes . . . does not necessarily establish the defendant's freedom from negligence."[7] Thus, to fall short of the statutory standard is to risk civil liability, to meet the statutory standard may still be to risk civil liability. Of course, compliance with a statute can be sufficient in certain circumstances, for example where the laws and regulations have "occupied the field."

CONCLUSION

The science of risk assessment in general, and its use in risk-based litigation in particular, raise serious questions of public policy. Human life is fraught with risk. That we now profess to have the means to quantify that risk begs the question of what level of risk we are willing to accept and what level mandates redress. Clearly the only sensible approach is to strike a balance between a particular risk and the cost of reducing it. Is civil litigation the proper place for society to strike that balance?

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[6]Konow v. Southern Pacific Company, 105 Ariz. 386, 389 (1970).

[7]Cohen v. SRP, 153 Ariz. 326 (1987).

Government environmental regulation based on risk assessment imposes enormous costs which are passed on to everyone through higher prices for products and services. It is a regulatory agency's job to minimize future harm. Many state that regulatory agency rules presumably reflect something of a societal consensus about risk versus cost. The risks addressed by the agency are faced by the public at large, and the standards the agency promulgates should be relatively clear and consistent.

Risk-based civil litigation, on the other hand, uses the court system which is not primarily designed to prevent future harm but rather to redress harm which has already occurred, redresses the concerns of only a limited segment of the public whom it potentially unjustly enriches or under-compensates, is based on no clear or consistent standards, imposes its costs on a small circle of defendants, and balances risk versus cost on an ad hoc basis if at all. There is certainly reason to suspect that risk-based civil litigation is not the best forum for addressing public risks.

It has been suggested that when a regulatory agency has promulgated chemical exposure regulations on the basis of risk assessment, the regulations reflect a society-wide consensus on the balance of cost-versus-benefit of eliminating the risk and that under such circumstances compliance with the regulations should be reasonable conduct and due care under the circumstances, thus, non-negligence per se. Creating such a regulatory safe harbor from civil liability would certainly reduce risk-based litigation and return the debate on acceptable risk to the executive and legislative branches of government that are arguably the more appropriate fora.

In any event, risk-based litigation is here. The successful litigants in such cases will be those that are represented by attorneys sufficiently well versed in the technical and scientific aspects of risk assessment to enable them to both challenge and support risk assessment experts as the case demands and to weave the science of risk assessment into the overall strategy of litigation. Of particular importance is an attorney's ability to fully understand the complexities of risk assessment so as to allow him to teach the difficult concepts to the lay judge or jury. Thus, in selecting counsel to represent them in risk-based litigation a party should be sure that the attorney it selects has: 1) an understanding of risk assessment and background in science sufficient to allow the attorney to participate in close cooperation with the experts in the preparation of the risk assessment portion of the case; and 2) demonstrated ability to teach complex technical subjects to lay persons, such as judges and juries.

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MAKING THE SOLUTIONS TO SHORT-TERM DEMANDS MEET LONG-TERM NEEDS

RITA P. PEARSON
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Biographical Information

In March of 1993, Governor Symington appointed Rita Pearson as Director of the Arizona Department of Water Resources. Prior to this appointment, Ms. Pearson served as the Governor's Deputy Chief of Staff and Executive Assistant for Environment and Natural Resources. In this position she oversaw ten state agencies including the Department of Environmental Quality and the Department of Water Resources. She also acted as the Governor's liaison to a wide variety of boards, panels and national associations. During her two years on Governor Symington's staff, Ms. Pearson was involved in a number of high-profile environmental issues including the ENSCO buyout and the Navajo Generating Station negotiations.

Prior to joining the Symington administration, Ms. Pearson had both public and private sector work experiences. While at the Arizona State Senate, she gained an extensive legislative background. From 1981 through 1985, she was the Research Analyst for the Senate Commerce and Labor Committee. Her most recent work in the private sector was as an attorney with Snell & Wilmer, where she practiced natural resources and administrative law for three years.

Ms. Pearson holds three degrees from Arizona State University: a law degree, a Master's of Business Administration, and a Bachelor of Science.

SESSION 3A:

GROUNDWATER VERSUS SURFACE WATER: APPROACHING CONJUNCTIVE MANAGEMENT

Moderator: Greg Bushner
Arizona Department of Water Resources

A DEFINITION OF NAVIGABILITY FOR ARIZONA STREAMS[1]

Jonathan Fuller, P.E., P.H.[2]

ABSTRACT: Under the "Equal Footing Doctrine," states receive ownership of the beds of all navigable rivers on the date of statehood. Historically, Arizona did not act on its claim of ownership, and titles to streambeds have been held by a wide variety of public and private parties. However, recent legislation directs the Arizona Navigable Stream Adjudication Commission (ANSAC) to identify river reaches that may have been navigable at statehood. "Navigable" is defined as "used, or susceptible to being used, in its original or natural condition, as a highway for commerce, over which trade or travel could have been conducted in the customary modes...on water" at the time of statehood. Some courts have interpreted this definition rather broadly, citing such activities as floating logs or canoe travel as proof of navigability. However, 1994 Arizona streambed legislation sets up more stringent criteria for defining navigability, including a presumption of non-navigability unless demonstrated otherwise. Regardless, it is possible that title to the streambeds of some Arizona streams may be transferred to the state if ANSAC renders a decision of navigability, and that decision is then upheld by the State Legislature. This potential for transfer of title from private and public parties to the state could have significant impacts for management of rivers, in-stream mining, wetlands, and riparian areas.

INTRODUCTION

CH2M Hill, in cooperation with SWCA Environmental and the Arizona Geological Survey, was selected by the Arizona State Land Department (ASLD) to provide ANSAC with hydrologic, geomorphic, and historical data for the Salt, Verde, San Pedro, Hassayampa, and Gila Rivers. To date, data collection activities have been completed and a report for the Salt River has been accepted by ASLD and ANSAC, though no final decision of (non-)navigability has been reached by ANSAC for any river. This report summarizes information for the Salt River, between Granite Reef Dam and the Gila River confluence.

The objective of the CH2M Hill/SWCA was to develop a database of information to be used by ANSAC in making determinations of navigability. Because the State's definition of navigability includes both actual navigation and susceptibility to navigation, the data collection effort was directed at two areas: (1) *Recorded Historical Uses of the River* - data describing actual uses of the river as of the time of statehood were collected to help

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answer the question, "Was the river used for navigation?" (2) *Potential Uses of the River* - data describing river conditions as of the time of statehood were collected to help answer the question, "Could the river have been used for navigation?"

STUDY TASKS

Specific tasks for the study included agency contact and an extensive literature search. The objectives of the agency contact task were to inform community officials of the on-going studies, to obtain information on historical and potential river uses, and to obtain access to data on the river already collected by agency personnel. For the latter task, public officials from every community, town, city, and county located along the Salt River study area were contacted. The objective of the literature search was to obtain published and unpublished documentation of historical river uses and river conditions. Information collected from agency contacts was supplemented by published information from public and private collections.

The literature search focused on five subject areas: (1) Archaeology, (2) History, (3) Hydrology, (4) Hydraulics, and (5) Geomorphology. Archaeological data augmented the historical record of potential river uses at statehood by providing an extended record of river conditions, use of river water, climatic variability, and cultural history along the rivers. Historical data provided information on actual river uses as of the time of statehood, and also provided information on whether river conditions would have supported navigation. SWCA historians prepared a report summarizing use of the river and adjacent area in historic times, with special emphasis on the establishment, growth, and development of towns, irrigation systems, commercial activities, and transportation systems. Hydrologic/hydraulic information was the primary source of information regarding susceptibility to navigation. These data included estimates of flow depths, width, velocity, and average flow conditions at statehood, based on the available modern records for natural stream conditions at statehood, as well as for existing stream conditions. Geomorphic data provided information on river stability, river conditions at statehood, and the nature of river alignment changes since statehood.

Other elements of the study included collection of land use information and ethnographic data. Land use data were compiled for each of the four rivers and were entered in a GIS database. Land use data included existing title records from county assessors offices, state and federal land leasing records from ASLD, the Bureau of Land Management, and the US Forest Service. Ethnographic data, or the recollections of individuals with personal knowledge of historical conditions, supplemented formal historical and archaeological records. Interviews were conducted with long-time residents, professional historians, avocational historians, and professional land managers who were knowledgeable about the Salt River.

SALT RIVER DATA COLLECTION

The data collected was organized into six main subject areas: archaeology, history, ethnography, geology, hydrology, and land use. Archaeological records indicate that the prehistoric inhabitants of the Salt River Valley, the Hohokam culture, occupied the study area from approximately A.D. 250-1450. The Salt River Valley was one of the most densely populated areas in the prehistoric Southwest and contained the most extensive irrigation system in prehistoric North America. The Hohokam depended heavily upon the Salt River for their existence. Fish found in the river were used to supplement their food sources, the water was used for irrigation and for direct consumption, and the riparian habitat fostered by the river was heavily utilized for food, fuel, and construction purposes. The entire Salt River irrigation system constructed by the Hohokam extended over 315 miles. The system included at least ten separate canal systems, some as long as 16 miles. Most canals measured 10 to 20 feet wide and were 3 to 12 feet deep, with a total diversion capacity of about 240 cfs. Although most of this extensive canal system has been destroyed by modern development and farming practices, in 1877 Mormon settlers were able to clean and reuse some of the prehistoric canals.

Euroamerican colonization of the Salt really began with the establishment in 1865 of Camp McDowell on the Verde River just upstream from the junction of the Verde and the Salt. Establishment of Fort McDowell not only provided protection from Apache raids, but also created a market for crops. Within two years, permanent white settlement of the Phoenix area began, with the goal of providing crops to Fort McDowell. The main commercial uses of the Salt were for irrigation, fishing, milling of grain, and transportation. In 1867, Jack Swilling and Joseph Davis separately began developing canal systems in the Phoenix area. Commercial fishing on the Salt River, primarily by Native Americans, was reported in the newspapers between 1879 and 1909. The newspapers reported that the Indians were able to supply Phoenix with fresh fish. As early as 1867, the Army began to leave a boat at McDowell Crossing on a full-time basis. By the late nineteenth century, at least five commercial ferries were in existence on the Salt. Sixteen accounts of attempted or successful boating or transportation of goods have been identified between about 1873 to 1915.

Thirteen professional historians, four avocational historians, and one long-term resident were interviewed to provide ethnographic information on the Salt River. A number of interviewees could cite or recall instances of the Salt River being used for boating. One historian said that an article in the Mesa Free Press, circa 1890-91, described how wooden construction material from abandoned Fort McDowell was floated down the Verde and Salt rivers to be used in constructing canal headgates. One long-term resident said that his father used to tell how, around 1910, he and other high school students built rafts from debris in the Salt River and floated them down river for recreation. Two historians suggested that nineteenth-century trappers might have used canoes or boats, although

primary historical documents indicate that the mountain men traveled through Arizona on horseback.

The Salt River geomorphology was substantially changed from its condition at or before statehood. As of the time of statehood, the stream was formed in deep alluvial deposits which allowed the low flow channel to shift periodically within a more stable floodplain channel in response to floods. The stream bed was composed of sandy silty material, which together with perennial flow supported healthy riparian vegetative communities along the banks. Prior to the changes brought on by urbanization and 19th century flooding, the Salt River probably existed in its relatively stable pre-statehood conditions for several centuries.

Like its geomorphology, the hydrology of the Salt River has significantly changed during the last century in response to human impacts. The Salt River Valley has a long history of reliance on the reliable perennial flows its watershed. Prior to statehood, streamflow rates were sufficient to support rich riparian vegetation, fish and beaver populations, and extensive prehistoric irrigation systems. During this period the mean annual flow was about 1,300 to 1,700 cfs, according to tree-ring records. Stream gage records indicate the study reach had perennial runoff with average monthly flow rates ranging from about 300 cfs to about 3,400 cfs. By 1912, irrigation diversions significantly reduced flow rates in the study reach river bottom, creating dry reaches during periods of some years. After settlement of the Valley, reliance on the river for supplying irrigation water led to depletion of water flowing in the channel. Unusually low streamflow supplied from the upper watershed and normal irrigation and other diversions combined to produce reaches of dry or limited flow in the Salt River in February 1912. Likely perennial reaches in 1912 were located between Granite Reef Dam and the Tempe Canal head (irrigation supply), between Tempe Butte and Jointhead Dam (ground water forced to the surface), and downstream of Phoenix to the Gila River confluence (irrigation return flow and ground water discharge).

Boating occurred on the Salt River prior to statehood throughout the entire year, but was generally limited to low-draft boats floating downstream. By 1912, use by boats was restricted due to declining streamflow caused by upstream diversions and impoundments, though boating during high flows and floods still occurred. Recreational boating in the study area continues to the present time during periods of high flow.

CONCLUSIONS

The CH2M Hill/SWCA report for the Salt River accepted by ANSAC and ASLD concluded that the Salt River could have and did support some types of boating during the period surrounding statehood. By 1912, use of some types of boats on the river had declined, but was still possible during portions of some years, a condition which persists today, though to a lesser degree. Therefore, whether the Salt River was navigable at

statehood is really a question of how the ordinary and natural condition of the river is defined, how that definition is interpreted by the courts, what types of boats are considered to demonstrate proof of navigation, for what period of time during a year or era, the stream must be able to support navigation, and how human impacts on a river system alter legal definition of navigability.

Modifications to Arizona's Streambed Bill (H.B. 2594) by the 1994 Arizona Legislature clarifies the definition of navigability, which effectively answers some of the questions about navigability criteria raised in the CH2M Hill/SWCA report. The bill also sets up a presumption of non-navigability for Arizona streams (except for the Colorado River), establishes a state-funded ombudsman to represent the rights of private property owners against claims by the State based on river navigability, and requires approval of the general legislature prior to acting on decisions. ANSAC has not convened hearings or held public meetings since passage of H.B. 2594. Therefore, no final decision on navigability has been made and the problem of clouded titles on Arizona streambed lands remains.

BEYOND ADJUDICATION: DE FACTO CONJUNCTION OF SURFACE AND GROUND WATER[1]

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ABSTRACT: In the spring of 1994 there was significant debate, public and private, concerning four separate areas of water management. These were: (1) the creation of the Santa Cruz AMA; (2) public comment sessions on the draft Riparian Protection Report issued by DWR; (3) concerns about the settlement provisions of an implemented Adjudication of some 60 years, Globe Equity 59 (adjudicating the Safford Valley, San Carlos Irrigation Project and San Carlos Apache Community), and (4) the rehearing on Issue No. 2 (surface-groundwater interaction) in the General Adjudication.

While unrelated in origin, the first three discussions seem to converge toward a set of common concepts which may become increasingly significant in the future of water management in Arizona. The most important common concept is that in some specific geohydrological environments, the distinction between surface and ground water should not be maintained, despite the separation which has existed in previous adjudications and which the Arizona Supreme Court has reaffirmed to be a principle in the Gila River Adjudication. This paper discusses the evolution of the common concepts and some implications.

INTRODUCTION

The Groundwater Management Act of 1980 was developed to implement management over groundwater mining in the areas of the state which contained almost all of the population and almost all of the agriculture. The continuing overdraft had implied a crisis of water supply at some time in the future. The CAP had early been conceived as a partial solution to the continuation of population and agricultural growth, but in return for funding the CAP the Federal Government demanded that groundwater mining and the continual overdraft be managed.

The imposition of management was not and has not been easy. The apocryphal story of the creation of the 1980 law was that representatives of the mining interests, municipalities, and agriculture had to be locked in a room until agreement was reached. Neither hydrologists nor environmentalists had sufficient economic nor political power to have much impact on the shape of the Act.

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

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The three overdrafted areas, in Maricopa, Pinal and Pima counties, each consisted of a regional basin aquifer which had contained large quantities of water in storage, with a proportionately small component of annual recharge (very small in the Eloy area). However, as rules began to be made to implement the management goals of the Act, it began to appear that some areas within the AMAS did not conform to the broad picture of groundwater overdraft mining. One of the first of these was in the Buckeye area, which although in the AMA, suffered from waterlogging. DWR agreed that special conditions existed there, and it is now possible to obtain Certificates of Groundwater Oversupply for such areas.

DWR has continued to develop the realization that special hydrogeologic conditions may exist in certain areas, both within and outside of AMAs, which may require appropriate water management policies developed for these conditions. The purpose of this paper is to discuss two such areas, Santa Cruz County and the upper Gila Valley (Safford/Duncan-Virden Valley). These are areas in which some consideration is being given to the concept that there is a single alluvium from which wells produce water, and so the distinction between groundwater and surface water is a fiction. Appropriate water management therefore requires management of "use of water, other than stored water, withdrawn from a well" (Senate Bill 1380: this act created the Santa Cruz AMA).

SANTA CRUZ COUNTY

In January 1988 the example of the Hassayampa Valley (west of the White Tank Mountains, west of Phoenix and within the Phoenix AMA) was raised with DWR as a case where any development of the water supply could have no physical effect on the overdraft of West Salt River Valley. We were informed that while that was recognized, unutilized recharge into the Hassayampa sub-basin could be counted as a credit to PAMA, thus mitigating the Salt River Valley overdraft. This made no hydrologic sense, since underflow out of the Hassayampa simply contributed to waterlogging at Arlington, but it made clear that progress toward "safe yield" in the overdraft areas was measured in part by "paper water" accounting of safe yield areas or even more by counting those areas with "plus safe yield", with rising water tables.

Beginning in 1982 our firm conducted a series of hydrogeologic investigations for various clients along the Santa Cruz River north to the Santa Cruz County Line. The data obtained led us to conclude that the Santa Cruz Valley upstream from the County Line was in a condition of "plus safe yield", with substantial discharge moving into the overdraft area of Pima County. Conversations on this subject with Duke Petty, then Manager of Citizens Utilities led him and John Ellinwood of Tubac to convene a meeting in Nogales in 1984 to discuss these facts publicly. In early 1988 the Santa Cruz County Board of Supervisors, particularly Ron Morriss, whose district includes the Rio Rico-Tubac area, commissioned our firm to produce a report describing the hydrogeologic situation in the upper basin of the Santa Cruz River.

The conclusions of our 1988 report (Halpenny, L. C., and Halpenny, P. C., 1988) were reported to the members of AHS at the first meeting in September 1988. The general conclusions were that even prior to the construction of the Nogales wastewater treatment plant, underflow from Santa Cruz County into the overdrafted part of the Tucson AMA was on the order of 10,000 acre-feet per year, and that with construction of the plant that amount became considerably more. Therefore Santa Cruz County was in a condition of "plus safe yield", contributing water which could be used for the development of Santa Cruz County (one of the poorest counties in the state) to offset the overdraft caused by the development of Pima

County. Moreover, the well test data indicated that there were substantial reserves of groundwater in the Older Alluvium which could be utilized. Transmissivities in the Older Alluvium were such that massive overdrafting caused by pumping large capacity wells would be improbable.

The fact that nondevelopment in Santa Cruz County contributed a water surplus to Pima County, both in physical fact and in terms of "paper water" accounting, led Santa Cruz County to seek legislation to separate the County from the management goals of the AMA and consequent management restrictions on groundwater development. The concept was to establish a separate "Nogales sub-basin" with a different safe yield goal.

DWR responded by publishing the "Santa Cruz County Water Issues Report" (October 1989. TAMA). It was noted that creation of a separate AMA "would have a negative impact upon other water users in the [Tucson] AMA by reducing the amount of groundwater recharge which could be used outside of Santa Cruz County when the AMA is in a safe yield condition" (p. ii) because "...safe-yield would allow certain parts of the [Tucson] AMA to experience groundwater declines as long as the water table rises in other areas to compensate" (p. i). The last major objection was to link surface and ground water through geology:

"....an expression of the interconnection which exists between surface water and groundwater systems... There is a strong possibility that much of the water that is pumped from wells in Santa Cruz County could be legally characterized as surface water....the outcome of the adjudication could have significant implications regarding the legal ability to pump from wells in Santa Cruz County. (p. ii)."

For whatever reason, the legislation creating the "Nogales sub-basin" did not pass.

Simultaneously with the publication of the Water Issues Report Bruce Babbitt had been retained by Ralph Wingfield to advise him in the sale of the water rights at Guevavi Ranch to the City of Nogales (Halpenny, L. C., and P. C. Halpenny, 1991). Babbitt advised him to consolidate all of his claims into surface water claims because the geology at Guevavi was such that they would probably be considered surface water under the Adjudication (most well owners in the Santa Cruz Valley had filed both surface water and groundwater claims for the same well/same water). Some historical research was done to show that, because of the bedrock constriction at Guevavi Narrows which allowed irrigation, claims of priority for this site would be the most ancient on the river.

DWR did eventually develop guidelines, possibly partly from the Guevavi experience, which would allow surface water supplies to be considered for proof of 100-year adequacy if it were hydrogeologically clear that the water supply would be considered surface water under the Adjudication, and if priority claims were sufficiently strong. However Nogales had not secured approval of 100-year adequacy by February 1994. A hydrogeological investigation had been conducted (Cella Barr Associates, 1991) which concluded that there were substantial groundwater reserves in storage west of Nogales Wash.

Santa Cruz AMA

In early 1994 a window opened politically whereby Nogales and Santa Cruz County were provided the opportunity to reintroduce legislation separating Santa Cruz County from the management restrictions of the AMA. Duke Petty by this time was retired and on the City

Council and he seized the opportunity, as did Ron Morriss of the County. One factor had emerged in the preceding years, and that was that CAP usage was going to be the major component of water management in AMAs. The physical cost of construction of a supply system from the Tucson terminus of the CAP meant that Santa Cruz County would not have access to that alternative. Because CAP was not available, the City of Nogales felt that they could not comply with the regulations which required CAP recharge in exchange for the right to pump groundwater. The first draft of what became SB 1380 therefore was written, primarily by City of Nogales attorneys and representatives of Rio Rico, to allow recharge credit for the vast amount of effluent (which included wastewater from Nogales, Sonora, with a population of over 200,000) so that groundwater could be withdrawn and the City obtain proof of 100-year adequacy. What reportedly was a 4 page bill then had some 38 pages added. Senate Bill 1380 in final form addressed many of the concerns raised in the 1989 DWR "Water Issues Report" (space considerations here limit the discussion to surface-groundwater relations).

The concern in 1989 over whether water might be classified as surface water or groundwater by 1994 had been resolved. Perhaps based partly upon our description of the hydrogeology at Guevavi, by 1994 the general consensus of those drafting the Bill seemed to be that the Santa Cruz consisted of a shoestring aquifer with limited storage, where all water is surface water because of hydrologic bedrock surrounding the Inner Valley. Therefore for water management purposes, water from one well would not be counted twice but would, following the Guevavi example, be counted once. To avoid having to make priority evaluations or decisions as to whether under the Adjudication the well would be classified as surface or groundwater, water was defined in SB 1380 as "use of water, other than stored water, withdrawn from a well". Full conjunction of groundwater and surface water had taken place:

> <u>§45-411.04</u>
> B. The Legislature also finds that the coordinated management of surface water rights and groundwater rights set forth in this enactment has been specifically designed to address the unique problems for water resource management that are described in subsection A [A. The Legislature finds that the hydrology and water resource management issues ...are unique due to the international nature of the river basin..a new active management area is needed...to facilitate binational negotiations for coordinated management of the water resources of the Santa Cruz River.] of this section and that are posed by the hydrology of the upper Santa Cruz River. Coordinated management of surface water rights and groundwater rights is necessary in the area designated as the Santa Cruz Active Management Area for public health, safety and welfare reasons.

Rather than the achievement of safe yield, <u>maintaining safe yield</u> was the goal: "C. The management goal of the Santa Cruz Active Management Area is to maintain a safe-yield condition in the active management area and to prevent local water tables from experiencing long-term declines" (§45-562).

Water interests elsewhere in the state insisted on limiting the implications: "§45-411.04 It is the express intent of the Legislature that the creation of the Santa Cruz Active Management Area is not to affect the definition of, or rights to, the surface waters and the groundwaters within this state, or to establish any precedent that could be used in a court of law ...to define or limit the legal distinction between surface water and groundwater in this state...". Despite the caveats, the practical effect is that surface water is brought under the Groundwater Management Act of 1980.

For the first time, an AMA has been created specifically for hydrogeological reasons: "§45-411.04.A...It is the further finding of the legislature that the proposed boundaries designated for the Santa Cruz Active Management Area are based on hydrologic parameters...".

The relation with the Tucson AMA is to be very close. The management plans for SCAMA must include an "evaluation of the potential impact of the plan on the Tucson Active Management Area." (§45-566.12). The Pinal AMA does not require such data from the Tucson AMA. The management goal of continuation of safe yield means that surface and subsurface flow will continue to flow into Pima County to offset the overdraft, so that in terms of physical supply little will change. The DWR 1989 "Water Issues Report" estimated that in 1987 surface/subsurface outflow from Santa Cruz County to Pima County was 28,600 acre-feet (Table 4, p. 22). This is water in excess of safe yield. It would be difficult for SCAMA to recover much of this excess for local use.

The conjunction of surface water to groundwater depends on the local hydrogeology. For the upper area from the International Boundary to the Nogales Wastewater Treatment Plant the Santa Cruz River is constrained by hydrologic bedrock to the Inner Valley where water can be considered surface water (for definition of "Inner Valley" see General Adjudication Order, June 30, 1994 p. 59: "...the weight of this evidence supports the saturated floodplain Holocene alluvium as the 'subflow zone'".). However the hydrogeologic situation downstream from the NIWWTP is considerably different (we call this the "I-19 Corridor"). There are substantial areas on both sides of the River which consist of Older Alluvium, an aquifer which lies between the bedrock mountains and the Inner Valley, as described in our 1988 report. Osterkamp (1973) found that the amount of water entering the valley of the Santa Cruz in Santa Cruz County as annually renewable mountain front recharge is 12,900 acre-feet per year. Mountain front recharge is a renewable water source. It quite clearly is "ground water" or "tributary percolating" water, not "surface water" nor "underflow" as those terms are used in the legal arena. This is renewable water which is available for use in Santa Cruz County.

Hydrogeologically then the I-19 Santa Cruz basin is not a system where "all water" is Inner Valley surface water but it is a system where mountain front recharge constitutes a large component of the available water supply, which also consists of a limited but significant amount of storage in Older Alluvium, and a small Inner Valley saturated aquifer. The contrast with the regional aquifer basins with great amounts of Basin Fill storage in comparison to a relatively small proportion of annual recharge, recharge which is through mountain front and ephemeral flood/snowmelt runoff (not perennial/intermittent riparian flow), cannot be more striking.

THE DWR DRAFT RIPARIAN REPORT

There was no public discussion officially held on SB 1380 but there was some discussion in a GUAC meeting in Tucson and at a State Parks meeting held at Rio Rico on March 16. TAMA representatives at both meetings mentioned that a major advantage of SB 1380 was that water management policies would aid in preserving the riparian character of the Santa Cruz River, which was not possible in overdraft AMAs which had the goal of attainment of safe-yield in many cases through replenishment district CAP exchanges. Current AMAs could control only groundwater, but with no control over surface water there was no protection for riparian areas.

Riparian protection is not listed as a management goal in SB 1380 and there is no use of the word. However, following the meeting at Rio Rico, on March 17, 1994 there was a briefing

at TAMA on the DWR Draft Riparian Protection Report (DWR, February 1, 1994) which was to be submitted to the Legislature as a guide for future legislation. The Santa Cruz River in Santa Cruz County was one of three study areas.

The Draft Riparian Report provided the framework for what had been said at Rio Rico. The riparian areas in the state are few, they are almost all outside of current AMAs and because of the need to maintain surface flow, special management is required in these small areas. The Report lists several different possible frameworks for managing these areas, mainly requiring specific legislation in each case. Far more interesting to DWR is the concept of management of these riparian areas by separate Active Management Areas, in which if surface water and groundwater are conjoined complete management is possible. The Report devotes considerable space to the economic impact of such tightly managed resources. Because of the need to have water flow through the area rather than be utilized by water-use development, there would to an extent be a negative impact on the inhabitants of the riparian AMAs. On the other hand, development of ecotourism (birdwatching in Santa Cruz County, for example, is of increasing economic importance) could offset and even transcend the negative impact. The point was made that in addition relatively few people live in these areas, in contrast to the overdrafted central valleys. The water which is not taken out by communities upstream but left to flow to preserve riparian habitat eventually reaches the overdrafted valleys where in terms of the public welfare of the state it benefits a greater population.

Given the difference from the current AMAs actively striving to attain safe yield, perhaps a better name for AMAs in which the goal is maintenance of safe yield is Inactive Management Areas.

In the analysis of Santa Cruz County in the Draft Report, the area upstream from the Nogales Wastewater Treatment Plant (NIWWTP) is distinguished from the area downstream. The upstream river is perennial only at Guevavi Narrows. Downstream "There is no scientific dispute that absent the discharge of effluent into the Santa Cruz River at the NIWWTP, the Santa Cruz River today could not support either a thriving riparian plant and dependent wildlife community, nor fish (Hugh Holub, Appendix VIII, p. 3 in Cella Barr Associates, 1991) The current flow in the Santa Cruz River downstream is legally not riparian. According to A.R.S. §37-1101.11 (House Bill 2589, 1994), a "riparian area does not include...man-made water or effluent transportation...systems." The Santa Cruz downstream from the NIWWTP is an "effluent-dominated" stream, whose surface and subsurface flow in the winter extend to and enter Pima County at the Pima County Line. In the summer phreatophyte transpiration is so great that the water sinks into the ground at approximately Chavez Siding Road (the relation between phreatophyte growth and river flow is inverse). However, fieldwork in July 1994 indicates that in the summer the flow of effluent may be intermittent because on July 10 we observed flow at Santa Gertrudis Lane and at Tubac, while the river was dry north of Carmen until flow resumed at an instream spring south of Tubac.

Conclusion

Because of the complexities caused by the limited but significant amount of groundwater in storage, renewable groundwater sources and by a non-riparian effluent-dominated stream, in fact Santa Cruz County provides a poor example of the concept developed in the Draft Riparian Report. The other two areas studied, the upper San Pedro and the Verde Valley, are similar to the Santa Cruz. However, there is one area in the state which does seem to be much more an example where surface and ground water can be conjoined, managed possibly by an AMA framework, and in which downstream parties are interested in maintaining riparian flow.

SAFFORD

Hydrogeologically, the Safford Valley on the Gila River seems to fit the DWR paradigm of a local area where practically all available well water is legally surface water. In general the valley is relatively narrow and outside of the Inner Valley consists of steeply terraced lakebed deposits with poor transmissivity (In 1976 Water Development Corporation conducted exploration drilling at Frye Mesa (Cactus Flat) for the City of Safford. This is a limited area which does not contradict the generalization). The water quality of the Gila River flow and underflow is very poor. As a result, the City obtains drinking water from a pipeline from Bonita Creek, some 21 miles northeast, and from reservoirs on the slopes of Mt. Graham.

The area was settled extensively in the 1870s and major diversions began. At the same time downstream, Florence was settled and diversions began there. As a result, flow reaching the farms of the Gila River Indians was diminished. To ameliorate the Indian water problem Coolidge Dam was planned. The farmers in the Florence area had to be incorporated into the Project, because the dam would impound their divertible water. At the same time diversions in the Safford and Virden valleys had to be regulated. The result was an Adjudicated settlement, Globe Equity 59, which apportioned water to each of the parties: the upper valleys (Upper Valley Districts), the Gila Indians (Gila River Indian Community, GRIC) and the Florence/Coolidge/Casa Grande farmers (San Carlos Irrigation District, SCIDD), the latter two being administered by the San Carlos Irrigation Project (SCIP). Another entity, the San Carlos Apache Tribe (SCAT) was also involved, with a very small allocation.

A few years after the 1935 Decree, wells began to be drilled in the Safford area for supplemental water. A drought beginning in 1942 intensified well water usage (Cushman, R. L., and Halpenny, L. C., 1955). The relation of well water to surface diversions is shown in Figure 1.

In 1983 GRIC sued to clarify and enforce certain aspects of the Decree. In 1990 SCAT intervened on the basis that well pumpage was not included in the adjudicated apportionment of the Upper Valley Districts but constituted pumpage of subflow (DWR, 1993, pp. 69-70).

The major issue of interest here is that surface diversion and well pumpage is reminiscent of the "double-dipping" filing of both surface water Claims and groundwater Rights in Santa Cruz County: the same water is being counted twice. Presumably if well pumpage were included as part of the apportionment, there would be additional surface flow in the Gila River thereby constituting maintenance of and adding to the riparian character of the stream.

In this case, instead of flowing through the upstream area to replenish an overdrafted downstream aquifer as in the Santa Cruz County example, the surplus water is stored above-ground behind Coolidge Dam. The surplus water is unallocated and available to the most successful claimant. As "new" water it is somewhat analogous to Nogales effluent: a "new" source for downstream users.

If Safford were to become a "locally managed AMA" it would have to be melded into the requirements of Globe Equity No. 59, with possible changes in the duties of the Gila Water Commissioner.

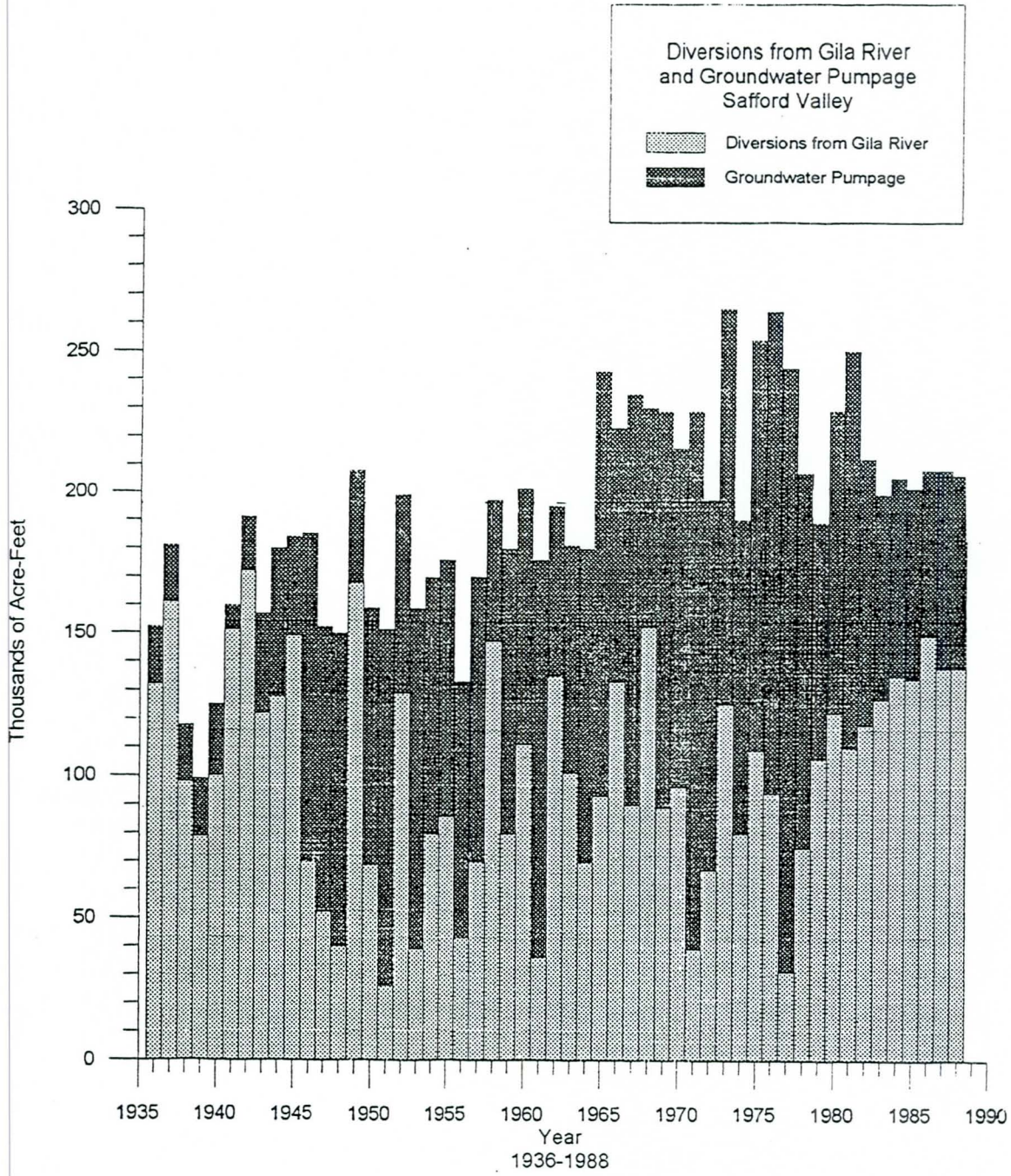

Figure 1. **Surface diversions/well pumpage in Safford Valley, 1935-1990.**

Source: Black, K. R., 1991, *Maps showing groundwater conditions in the Gila Valley sub-basin of the Safford Basin, Graham and Greenlee Counties, Arizona-1987*: DWR, Hydrologic Map Series Report No. 20, Table 1.

THE GENERAL ADJUDICATION

There is an obvious problem in the Globe Equity 59 litigation of the fact that the General Adjudication is ongoing (see ibid. p. 70) which is the major reason the 1993 Briefing Report was commissioned. Judge Goodfarb issued his Opinion on June 30, 1994 which determined that all wells within "the lateral limits of the 'subflow' zone" are subject to adjudication as are wells where the cone of depression "by continual pumping will cause a loss of such 'subflow' as to affect the quantity of the stream" (Order, Conclusions Nos. 7 and 8).

Still not specified is what level of effect on a stream will be considered appreciable.

Just as there is a problem in determining the effect of the General Adjudication on the special adjudication of Globe Equity 59 (which has been in operation for almost 60 years) so there is the question of the applicability of the distinction between ground water and surface water in the Adjudication to SCAMA where it has been conjoined.

The Arizona Supreme Court in its remand order reminded the Legislature that the power of determining the distinction between ground water and surface water lay in legislation. The conjunction of groundwater and surface water in SB 1380 was an attempt to solve what appeared to be an immediate and local problem, the Nogales 100-year adequacy. The alternative apparently was to continue in limbo until the General Adjudication is finally and fully resolved. SCAMA is an attempt to move ahead of the long Adjudication process, to solve a local problem.

CONCLUSIONS

It has been the purpose of this paper to note that SB 1380 and the creation of SCAMA was not an isolated, unique event in water management policy.

1. Beginning in 1983 DWR has progressively realized the significance of local hydrogeological conditions, and the concept of local AMAs to manage riparian areas contained in the Draft Riparian Report provides a mechanism to account for specific and special hydrogeological situations.

2. The original goal of the creation of a separate water management entity in Santa Cruz County (the "Nogales sub-basin") was to obtain local management of excess water caused by the state of being in safe yield, for development of the County. The evolution of SB 1380 and the creation of SCAMA reflect in large part the concerns presented in the DWR 1989 Santa Cruz County Water Issues Report.

3. The concept of riparian management, maximization of surface flow, provides for maximum delivery of water to downstream users. In the case of SCAMA, the delivery recharges the overdrafted cone of depression in Pima County. In the case of the Verde Valley water is delivered to the dams on the Verde for ultimate use in the Salt River Valley. In the Safford case, water is delivered to storage behind Coolidge Dam, to an ultimate user yet to be determined.

4. Hydrogeologically, the Santa Cruz River valley from Rio Rico to the Pima County Line does not provide the best example of a valley where all water can be considered flow and subflow. There are considerable areas of "groundwater" supply, capable of limited but significant development and based on renewable mountain front recharge. The Santa Cruz example is also distorted because of the effect of Nogales effluent.

5. The Safford Valley may provide a better example than either the upper Santa Cruz, Verde or upper San Pedro, of hydrogeologic conditions where surface water and ground water could be considered a conjoined system.

6. Creation of a "locally managed AMA" in the Safford area raises the issue of the relation of the AMA to the 60-year old Globe Equity No. 59 Adjudication. There is already concern as to the effect of the General Adjudication on Globe Equity No. 59. The creation of SCAMA raises the issue of the relation of the General Adjudication, especially the distinction between groundwater and surface water, to the conjoined definition in SB 1380. The Legislature has the power to define the relation between surface and groundwater, but the caveats concerning the applicability of general water rights and water law of the state to SCAMA seem to leave the question open.

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TECHNICAL ASSESSMENT OF SUBFLOW: AN UPDATE[1]

Charles R. Cullom[2]

ABSTRACT: On July 6, 1994, Judge Stanley Z. Goodfarb issued a decision addressing the groundwater-surface water interaction issue, by defining subflow in the General Adjudication of the Gila River System and Source. His decision generally defined subflow as: 1) existing adjacent to and beneath a perennial or intermittent stream that maintains a hydraulic connection with groundwater, excluding tributary aquifers, 2) occurring in a geologic unit where groundwater flow direction, water level elevations, and chemical composition are substantially the same as the stream. The saturated portions of the geologic unit containing subflow define a subflow zone. All wells located within the lateral limits of a subflow zone are subject to the jurisdiction of the adjudication, unless the well owner can show that his well is perforated below a confining layer that precludes the cone of depression from reaching the subflow zone. The Court determined that a well located beyond the subflow zone may be included in the adjudication if the well's cone of depression reaches the subflow zone.

INTRODUCTION

On July 6, 1994, Judge Stanley Z. Goodfarb ruled on the groundwater-surface water interaction issue by defining subflow in the Gila River General Stream Adjudication. His ruling is the culmination of a process that began with the subflow hearings held in October, 1987. Those hearings led to Judge Goodfarb's September 9, 1988 order establishing the 50%/90 day subflow test. The 50%/90 day test used the Jenkins equation to establish a two-dimensional zone within which wells were presumed to pump subflow. This test was appealed to the Arizona Supreme Court and accepted for interlocutory review by the Court on December 11, 1991. The Supreme Court, in its July 27, 1993, decision (Interlocutory Appeal Issue No. 2), overturned the 50%/90 day subflow test and remanded the issue back to Judge Goodfarb. The Supreme Court, in its decision, alluded to a two tier subflow test. The first tier of the test was to define a presumptive geographic boundary within which all wells are presumed to pump subflow. The second tier, identifies wells found outside the presumptive zone whose cones of depression impact the stream.

[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.
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Judge Goodfarb held an evidentiary hearing in January and February, 1994, hearing testimony from expert witnesses. The Court then took a two day field trip to the San Pedro River in March, 1994. The Court held a final evidentiary hearing in June, 1994, again hearing testimony from expert witnesses. The Court also received expert reports from the parties and DWR.

DECISION SUMMARY

The Court, in its July 6, 1994, decision, defined subflow, ruled on four proposals defining the presumptive geographic zone (subflow zone), and ruled on cone of depression tests. The Court also found the following:

1) subflow is a legal concept with no hydrologic meaning, therefore, one must apply hydrologic principals to find a reasonable factual basis to enwrap the legal concept of subflow,

2) the San Pedro River surface water flow is a minor component of the watershed's water budget when compared to the groundwater system, so the river system's value as a water resource is largely in its storage capacity rather than its surface flow.

Definition of Subflow

The Court defined subflow following the characteristics outlined by the Supreme Court:

1) subflow flows in same general direction as the stream,

2) subflow has groundwater gradients with the stream rather than toward or away from the stream,

3) subflow has the same general elevation with the stream,

4) subflow has the same general chemical composition as surface water in the stream.

The Court then added the following characteristics to the definition of subflow:

5) subflow is located adjacent to or beneath a perennial or intermittent stream,

6) subflow is not located adjacent to or beneath an ephemeral stream, unless the ephemeral stream is a reach of a perennial or intermittent stream and the ephemeral reach is caused by surface water diversions or groundwater pumping, however, there must be a saturated zone beneath the reach similar in nature to that found in the perennial or intermittent reaches of the stream,

7) except for the forgoing, a hydrologic connection must exist between the aquifer and the perennial or intermittent stream,

8) subflow must be distinguished from tributary or basin fill aquifers,

9) subflow must not include "inliers" (basin fill outcrops within the saturated floodplain alluvium),

10) wells located in the subflow zone but perforated below the saturated floodplain alluvium are included unless the well owner can show the well is perforated below some confining layer, preventing the well's cone of depression from reaching the subflow zone,

11) wells located outside of the subflow zone are not included unless the well's cone of depression reaches the subflow zone and the drawdown on surface and subflow is measurable.

SUBFLOW ZONE TESTS

The Court then reviewed four proposed tests for defining the subflow zone. The tests were proposed by the parties in the case. The four tests included: the edge of the principal channel boundary test, "post-1880 entrenchment" and deposition test, the riparian test, and the saturated floodplain holocene alluvium test.

Edge of Principal Channel Test

The edge of the principal channel boundary was proposed by Don Young for the State of Arizona, and Bill Wellendorf for the City of Benson and others. The edge of the principal channel boundary is the narrowest definition of the San Pedro River channel and therefore the narrowest proposal for subflow. The principal channel is the channel that contains the river during low and moderate flows.

The Court rejected the edge of the principal channel boundary. The Court cited the lack of stability of the channel, lack of consistent vertical component, and lack of wells within the boundary. Studies by DWR and other parties showed that the principal channel boundary has shifted significantly since 1935. The fact that few if any wells are located within the principal channel requires every well in the watershed to be subject to a cone of depression test.

"Post-1880 Entrenchment" and Deposition Test

The "post-1880 entrenchment" and deposition test (post-entrenchment test) was proposed by Dr. Errol Montgomery and Dr. Stanley Schumm for the groundwater users (including mines, agricultural interests and some municipalities). The "post-1880 entrenchment" is a slightly broader channel than the principal channel boundary. The "post-1880 entrenchment" is the channel formed after climatic and cultural changes in the Southwest caused channel cutting along major streams in southern Arizona. The channel scouring was completed by 1937 and since that time, from 3 to 14 feet of alluvium has been deposited within the entrenchment channel. Dr. Montgomery stated that the hydrologic properties of the "post-1880 entrenchment" alluvium were significantly different than the surrounding holocene alluvium.

The Court rejected the post-entrenchment test. First, the Court cited the instability of the entrenchment channel. Studies by DWR and other parties showed that the "post-1880 entrenchment" channel has shifted up to 1,000 feet since 1935. The Court noted that hydrologic examination of the "post-1880 entrenchment" alluvium showed that the post entrenchment alluvium was not significantly different from the holocene alluvium. The Court also cited the lack of vertical consistency in the post entrenchment test. Dr. Montgomery suggested that the wells completed in the holocene alluvium but located in the entrenchment channel be included in the subflow zone. Finally, the Court recognized that a post-entrenchment test captures few if any wells, therefore almost all wells in the watershed would have to be examined individually by a cone of depression test.

Riparian Test

The riparian test, proposed by Dr. Tom Maddock for the Nature Conservancy, used the extent of riparian vegetation under predevelopment conditions as the definition of a subflow zone. The test would require the determination of predevelopment conditions of a watershed and the estimation of the riparian vegetation under those conditions.

The Court rejected the test due to a lack of available data and the difficulty in accurately determining the extent of riparian vegetation without the aid of historical aerial photography. The San Pedro River and most watersheds in Arizona were moderately developed before the advent of high quality aerial photography in 1935.

Saturated Floodplain Holocene Alluvium Test

The saturated floodplain holocene alluvium test proposed by John Ford for Salt River Project, and Oliver Page for federal interests, and Alan Gookin for the Gila River Indian Community, uses the saturated portion of the floodplain saturated holocene alluvium as the subflow zone. The holocene alluvium has been deposited during the past 10,000 years and is a stable, distinct geologic unit.

The Court accepted the saturated floodplain holocene alluvium test. The Court stated that the saturated portion of the alluvium meets the elevation, gradient, and flow direction definition of subflow suggested by the Supreme Court as well as those characteristics added by the Court. The Court defined the saturated floodplain holocene alluvium as that portion of the floodplain holocene alluvium that is saturated, and must be set back 200 feet from the connection to tributary aquifers, and set back 100 feet from "inliers" of basin fill material in the floodplain holocene alluvium.

The inliers of basin fill are outcroppings of basin fill deposits within the saturated floodplain holocene alluvium. It is believed that these inliers could cause local deflections of the groundwater gradient toward the stream, and thus no longer meet the definition of subflow. Therefore, the Court proposed a 100′ setback distance from the edge of the inlier to allow for the minor fluctuations in gradient.

Cone of Depression Test

The Court found that a cone of depression test must be used for wells outside of the subflow zone. The Court noted that any well outside of the subflow zone that now pumps any percentage of water either from the

stream itself or its subflow zone should be included in the adjudication and the total amount of pumpage withdrawn subjected to the proceeding. However, the Court left the type and parameters of the test to the discretion of DWR, stating "whatever test ADWR finds is realistically adaptable to the field and whatever method is the least expensive and delay-causing, yet provides a high degree of reliability, should be acceptable."

Finally, the Court ruled that the determinations by DWR should be subject to a presumption in favor of DWR. However, the weight of that presumption should be a burden of proof of preponderance, due to the uncertainties inherent in hydrologic investigations and determinations.

COURT'S CONCLUSIONS

The Court reached the following conclusions:

1) a subflow zone exists adjacent to and beneath a perennial or intermittent stream, and not an ephemeral one,

2) there must be a hydraulic connection between the stream from the saturated subflow zone,

3) tributary and basin-fill aquifers are not part of a subflow zone,

4) the subflow zone must be that part of the geologic unit where the flow direction, the gradients of the water level elevations, and the chemical composition of the water in that particular reach are substantially the same as those of the stream,

5) the subflow zone must be set back from the connection with tributary aquifers and inliers (200 feet from tributary aquifers, and 100 feet from inliers),

6) riparian vegetation may be useful to determine the limits of subflow, however, riparian vegetation cannot be used as an indicator on tributary aquifers or inliers,

7) all wells located within the lateral limits of the subflow zone are subject to the jurisdiction of the adjudication, no matter how deep the well is, unless the well owner can prove the perforations are below a confining layer that precludes the cone of depression from reaching the subflow zone or the stream,

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

IMPACT OF DECISION

The decision establishes a technically accurate, stable geographic zone in which wells can be managed as surface water users. The test can be efficiently and consistently implemented across the Gila River system. Because the general geology is well established, mapping the limits of the floodplain holocene alluvium is a straightforward process using available geologic maps, aerial photography, and field examinations. The determination of the extent of the saturated portion of the floodplain holocene alluvium will require detailed analysis of DWR's well database, USGS data, and field surveys. Once the limits of the saturated floodplain holocene alluvium are established, wells within the zone can be managed conjunctively with surface water uses, with the exception of wells perforated solely below a confining layer.

The cone of depression test will provide for wells located beyond the boundary of the subflow zone to be managed as subflow wells, based on their impact on subflow. The determination of which wells outside the subflow zone impact the subflow zone will require extensive data collection and analysis, and may require modeling efforts in some watersheds. The parameters of a cone of depression test have not been established by DWR. The parameters critical to determining the number of wells that will be managed as subflow wells include the level of drawdown at the subflow boundary and the duration of pumping.

IN SEARCH OF SUBFLOW: ARIZONA'S FUTILE EFFORT TO SEPARATE GROUNDWATER FROM SURFACE WATER[1]

Robert Jerome Glennon and Thomas Maddock, III[2]

ABSTRACT: Cottonwood-willow forests and mesquite bosques, characteristic desert riparian habitats, once lined many rivers in Arizona, including the Salt and Gila Rivers in the Phoenix valley, and the Santa Cruz and Rillito Rivers in the Tucson area. The trees and accompanying associated shrubs and herbaceous vegetation gradually died of thirst as groundwater pumping and surface water diversions for domestic and irrigation purposes disrupted surface flows and lowered the groundwater table below the root zone of these plants. Sadly, surface water diversions and groundwater pumping have contributed to the degradation of 90% of Arizona's once perennial low desert streams and rivers, and about an equal amount of its riparian habitat.

Many people look at washes and arroyos, dry except during rainstorms or snow melt, and do not understand that, despite the lack of surface flow, water is not far below the surface. The presence of sub-surface water - a high water table - sustains the remaining desert vegetation which has deep tap roots. Unfortunately, unrestricted groundwater pumping of water hydrologically connected to surface water flows will inexorably hasten the demise of the remaining free flowing streams and associated riparian habitats, and interfere with the vested property rights of surface water rights holders. On July 27, 1993, the Arizona Supreme Court sanctioned these consequences in In re the General Adjudication of All Rights to Use Water in the Gila River System and Source, Interlocutory Review, Issue No.2.

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[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994. The paper is scheduled for publication in a future issue of the Arizona Law Review.

[2] Robert Jerome Glennon is a Professor of Law at the University of Arizona. Thomas Maddock, III is a Professor of Hydrology and Water Resources at the University of Arizona.

(hereinafter Issue No. 2). The Court reaffirmed a 1931 ruling that rested on hydrologic concepts contained in a legal treatise published in 1912 and, in the process, futher obfuscated the legal interpretation of the 1931 ruling.

This article analyzes the 1993 ruling against a backdrop of current hydrogeologic principles. We begin, in Part II, by setting the context of Issue No. 2 through an overview of water law general adjudication. We then discuss the Court's ruling in Part III. Part IV presents the general principles of hydrogeology that govern a section of the Southwest known as the Basin and Range Lowlands Province, while Part V applies those principles to the San Pedro River, a tributary of the Gila River. In Part VI, we analyze the array of problems generated by Issue No. 2, especially its failure to protect surface water rights. We also analyze the trial courts June 1994 ruling on remand from the Arizona Supreme Court.

Regardless of how Arizona courts ultimately apply Issue No. 2, other issues generated by the Gila River Adjudication offer hope of protecting the State's remaining riparian corridors. In March 1994, the Arizona Supreme Court established a briefing schedule for interlocutory review of two such issues. In Part VII, we comment on these questions and conclude that the federal reserved rights doctrine will protect surface flows in the San Pedro River from pumping od hydrologically-connected groundwater.

SESSION 3B:

GROUNDWATER CONTAMINATION AND ENVIRONMENTAL LIABILITY: SEARCHING FOR A MORE MEANINGFUL SUPERFUND PROGRAM

Moderator: Floyd Marsh
City of Scottsdale

THE 1994 CERCLA AMENDMENTS:

CHANGE FOR THE BETTER?[1]

Keith S. Watson[2]

ABSTRACT: The Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA") was enacted by the United States Congress in 1980 and significantly amended in 1986. Known as Superfund, CERCLA is intended to provide a cost-effective mechanism for promptly identifying and remediating sites where historic hazardous substance disposal practices have created environmental and public health risks.

Since CERCLA's enactment, the United States Environmental Protection Agency ("EPA") has targeted more than 1200 sites requiring remediation on a priority basis and has identified as many as 25,000 additional sites which may present environmental concerns. The typical priority site now costs an estimated $25 million to remediate and the entire process -- involving site investigation, feasibility study, agency decision, public comment and implementation of required remediation -- consumes an average of 8 to 10 years. To date, remediation has been completed at less than 100 priority sites.

CERCLA is a no-fault, retroactive liability statute. That is, parties which either owned, operated, transported materials or arranged for the disposal of hazardous substances at a site are each liable for the site's remedial costs. Liability attaches regardless whether the party's actions were lawful or permitted when undertaken and regardless whether other liable parties can not be found or are financially insolvent. Responsible parties may be ordered to remediate a site by EPA or EPA may itself remediate a site and then bring legal action seeking recovery of its costs.

Although the CERCLA program has a number of successes to its credit, critics of the program abound. Some are critical that relatively few sites have been remediated, that remediation too often takes the form of containment in lieu of "permanent" solutions, and that many responsible parties have evaded all or a fair share of their liability. Others (particularly those from the business community) argue that CERCLA has unnecessarily spawned enormous paperwork and other "transaction costs", gold-plated remedial solutions, unfair allocations of financial responsibility, and a diversion of resources from more pressing environmental needs.

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[1] Extended abstract of paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] Keith S. Watson is a partner in the Litigation Department of Wiley, Rein & Fielding, Washington, D.C.

In 1994, the Congress must reauthorize CERCLA. This has afforded critics of the program an opportunity to propose changes to the program and a number of interested parties (including the Clinton Administration) have proposed significant amendments to CERCLA. These proposals may be summarized as follows:

Remedial Goals

The Administration and others have proposed that uniform, risk-based clean-up levels be established for various media. Some believe one risk level should be utilized in establishing these levels; others prefer use of a risk range. With regard to the EPA selection of remedies to address groundwater contamination, the current House bill sets forth a number of factors to be "balanced", including the remedy's reliability, the risks being addressed, the affected community's views, and the cost of the remedy. Where contaiminated groundwater is a potential source of drinking water, the bill imposes the following "minimum" requirements:

- Prevent human injestion of drinking water having contaminant levels which are either i) in excess of "the maximum contaminant level or non-zero maximum contaminent goal level" established under the Safe Drinking Water Act (including, if appropriate, the provision of an alternate water supply), or ii) in excess of levels needed to protect human health;

- Unless "technically impracticable from an engineering perspective", prevent impairment of any surface water designated use under the Federal Water Pollution Control Act;

- Assure that "source areas" of groundwater contamination are "contained to the extent technically feasible", using treatment which reduces contamination as "necessary to ensure the long-term reliability" of the containment remedy;

- Assure that groundwater exceeding specified contaminant levels is contained unless "technically infeasible from an engineering perspective"; and

- Provide for long-term monitoring of contaminated groundwater.

A number of issues remain unresolved. For example, as presently drafted, the bill expands CERCLA's current scheme to require remediation of "contaminants" and "pollutants" as well as hazardous substances. It is unclear, however, whether this provision will survive the legislative process. Another issue has arisen because, under the Administration's proposal, some CERCLA programs may be delegated to State environmental agencies, including remediation of facilities owned by the federal government. It has yet to be resolved whether State-directed remediation may utilize clean-up standards more stringent than those required by CERCLA or whether only state funds may be used in these circumstances.

Liability

Under the Administration's proposal, responsible parties could theoretically remain strictly and jointly liable. However, mechanisms would be established to allocate a "fair share" of financial responsibility among various waste generators and to require use of up to $300 million of public, CERCLA-generated monies to fund that portion (known as "orphan shares") of remedial costs attributable to parties who cannot be found, are financially incapable of paying, or simply refuse to do so. Those in the later group would be subject to EPA cost recovery actions for all outstanding costs. In addition, current proposals would exempt or limit the liability of certain parties such as remedial contractors, recyclers, and municipal governments. By these amendments, the retroactive liability aspects of CERCLA would remain, but some of its inequities would be mitigated.

Funding

Under the Administration's proposal, responsible parties with liability insurance coverage would be entitled to have 20% to 60% of their financial liability paid by a new $8 billion fund to be financed by assessments on liability insurance companies. The percentage entitlement varies by state; for Arizona sites, it is 40%. In exchange, the responsible parties would be barred from claiming reimbursement from their insurance carriers. The result would be a significant reduction in contentious litigation between many insurers and their policyholders who are responsible parties under CERCLA.

Congressional adjournment is scheduled for late September or early October. At this time it is unclear whether, or to what extent, proposed amendments to CERCLA will be enacted during this Congressional session.

PRIVATE COST RECOVERY OF ENVIRONMENTAL[1] INVESTIGATION/CLEANUPS

Edward D. Ricci[2]

Overview of Cost Recovery Issues

Class action lawsuits, cost allocation, and cost recovery are buzz words in the sectors of the environmental industry that service Superfund work. Due to the increasing enforcement of hazardous substance incidents and the reality that such incidents may represent prohibitive remedial costs, parties involved in investigations or cleanups are turning to cost recovery from other "responsible" parties in order to recoup the potentially exorbitant costs. Therefore, cost recovery actions are filed against parties who may be linked to the evidenced contamination in some way. These parties include:

- Neighboring or even distant property owners,
- Past operators, lessees or owners of the subject property,
- Present day operators, lessees, or owners of the subject property,
- Third parties who disposed of hazardous wastes on the subject property,
- Generators who arranged for the disposal or treatment of a hazardous substance,
- Transporters of hazardous substances to the subject property or facility.

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]Edward D. Ricci is Southwest Area Manager of Environmental Services, Brown and Caldwell, Phoenix, Arizona.

This article focuses on the evidentiary information needed to construct an effective private cost recovery case. Since a responsive cost recovery case is usually based on provisions of Federal Superfund law, key aspects of these provisions will be reviewed. Superfund law, in a number of states, has typically been modelled after the federal act. Individual state law will not be discussed herein.

The reauthorization of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) being pushed through Congress during the summer of 1994 will have serious ramifications regarding cost recovery qualification and mechanisms. The proposed development of an Environmental Insurance Resolution Fund (EIRF) would provide a source of cleanup monies for Potentially Responsible Parties (PRPs) to draw upon if they first agree not to sue their insurance providers to recover their cleanup costs. There is also great momentum to abolish or at least limit retroactive liability although such amendments seem doomed.

Other disincentives for cost recovery do exist. The Supreme Court ruled in June 1994 that individuals or companies cannot recover their legal expenses when they successfully sue others for contributing to the pollution. This decision creates a significant disincentive for private litigation under the federal Superfund. However, fees paid to lawyers or other advisers hired to identify PRPs may be recovered. Under President Clinton's proposed "fair share approach", a neutral party with expertise in Superfund issues would allocate the cleanup cots among PRPs at multi-party sites. If a PRP rejected the allocation and pursued cleanup contributions from other parties through lawsuits, the PRP would be subject to joint and several liability.

Section 107 of the Federal Superfund law or the CERCLA provides for private parties to bring cost recovery suits. Government cost recovery suits are also addressed under Section 107, although this will not be the topic of this article. The collection and formulation of evidentiary information is critical to both private and government suits, as well as common law claims.

The key liability premise for cost recovery as stated in Section 107(a) is that when a release or threatened release of a hazardous substance from a facility causes the incurrence of response costs, certain parties associated with the facility shall be responsible for any or all costs of response, removal, or remedial action incurred by the U.S. Government, States, or any other person, if those costs are consistent with the National Contingency Plan (NCP). Other procedural prerequisites exist. These include standing as evidenced by some response activity having actually already occurred. Response activities broadly

include monitoring or testing to evaluate the extent of contamination, planning and implementation of a response action, and actual cost recovery action.

Conformance with the NCP

The NCP, contained in CERCLA Section 105, is the procedural document for the conduct of investigations and cleanups under CERCLA.

In summary, the NCP provides very generalized methods for discovery, investigating, and evaluating facilities at which hazardous substances have been disposed or otherwise have come to be located. The applicable requirements include the following general categories:

- Worker health and safety,
- Documentation and cost recovery,
- Determination of the need for a Super Fund-Financial action,
- Permit requirements,
- Identification of and compliance with applicable or relevant and appropriate requirements (ARARs), including established drinking water standards,
- Report of releases to the National Response Center,
- Site evaluation for removal action versus remedial action,
- Remedial investigation and feasibility study (RI/FS),
- Remedial design and action in accordance with the Record of Decision (RD/RA),
- Community relations,
- Designation of public comment period.

The requirements that must be met in connection with the recovery of costs incurred for "removal action" are significantly less stringent than those requirements associated with "remedial action". A removal action, which is short term, is undertaken in response to an immediate threat to the

environment or public health. Depending on the circumstances, it may be in a party's best interest to characterize its investigatory and remedial measures as a removal action rather than remedial action, particularly if the completed scope of work has been limited to an assessment and short-term mitigation of the immediate hazard.

It should be noted that the above listed requirements may not have to be universally met in order to show consistency with the NCP. For example, a property owner who discovers that contaminated runoff has entered his site from an adjacent property may realistically file suit after only evaluating the nature and extent of the contamination via a formalized sampling and analyses program that includes health and safety and defensible quality control/quality assurance techniques. As related in the preamble to CERCLA, the plaintiff's key demonstration should be that in the process of substantially complying with the NCP, a "CERCLA-quality" cleanup is (or will be) achieved. CERCLA quality includes a remedial action protective of health and the environment, employment of permanent solutions and resource recovery technologies, and cost effectiveness.

The Environmental Protection Agency (EPA) and numerous courts have approached cost recovery issues permissively in favor of plaintiffs, encouraging increased private-party response action. In regards to NCP compliance, the more lenient "substantial compliance" standard has been adopted rather than adhering to the "strict compliance" standard. However, in regards to government suits, two recent decisions by the U.S. Courts of Appeal for the Third and Fifth Circuits have created new opportunities for defendants to reduce their liability exposure by evaluating the Government's cost claims for unallowable costs or for improper selection of a remedy.

Construct of Evidentiary Information

In concert with NCP consistency being proven, a cost recovery case focuses on plaintiff's demonstration that another party is truly responsible (partly or fully) for response costs incurred. This demonstration typically includes key items which are the result of records review; personal interview; aerial photographic analysis; sampling and analysis programs; and quantification of the amount and toxicity of the hazardous substances involved. Additionally, since the NCP is only a general road map for the completion of technical work, EPA guidance documents and accepted state of the practice professional methodologies must be employed to arrive at a defensible project scope. This section of the paper describes types of key evidentiary information and presentation of that information.

Site Investigation

The technical information valuable to the cost recovery effort will address the questions of has contamination been caused by another party and what is the extent of that contamination. The issue of whether cost recovery is being sought from a previous occupant of the site versus an off-site party will largely dictate the type of information that will be constructed. In general, the strategy is similar. There are two coalescing paths that may be travelled in constructing the evidentiary information - conduct of a site investigation and conduct of a comprehensive records review.

The site investigation focusses on the lateral and vertical extent of contamination caused by another party, and possibly by plaintiff's own actions. The investigative work is oriented so that it can be shown that the work progressively moves towards a "remedy". An effective qualitative screening method that has been used successfully in defining lateral contamination is soil vapor testing of volatile organic compounds (VOCs) in soils. The VOCs include the chlorinated solvents often used in industrial applications (such as tetrachloroethane (PCE), trichlorethene (TCE), trichloroethane (TCA), and the freons), as well as the aromatic solvents which may also be components of gasoline products (benzene, toluene, ethylbenzene, and xylenes). The challenge often centers on separation of parties and distinction of chemical mixes in a comingled plume.

The investigation often may focus on the identification of a conduit to the groundwater contamination. Such conduits include dry wells, sumps, underground storage tanks (USTs), drains, water wells, and buried dumps. Such facilities may be identified through reconnaissance at the ground surface but geophysical techniques such as electromagnetics are often necessary.

Subsequent to an investigative screening technique, more aggressive means of investigation are typically employed. These include sampling and analyses programs. Soil borings are drilled to evaluate residual concentrations of contaminants laterally and vertically. Depending on the type of soil, a residual "finger print" in the soil may not be present.

If the vertical extent of soil contamination reaches the groundwater table, or the soil matrix is permeable such as for gravels and cobbles, monitor wells are typically required in order to gauge groundwater impacts. If representative wells are not already located in the subject area, at least three wells may be required in order to establish the groundwater flow direction beneath the subject property. At least one well must be placed in an upgradient location, characterizing potential contamination from off-site sources. In addition,

locations of wells near the subject property afford the site investigator additional important information regarding plume dynamics and potential comingling. Decisions on well construction must take into consideration whether the contaminants are more or less dense than water. Wells completed at various vertical intervals are intended to capture solubilized contaminants in various geologic strata or lenses.

Monitoring of a contaminant plume particularly when dealing with chlorinated volatile or aromatic compounds should be accomplished at least semi-annually and preferably quarterly while a suitable and representative data base (typically 4 to 8 sampling events per well at a minimum) is established. Groundwater elevations and flow direction should be measured monthly on a continuous basis to gauge seasonal variations.

Characterization of a contaminant release as a historical on- or off-site problem rather than a present discharge on the plaintiff's property may be proven through a development of the records review information described below. Field data that is critical to these arguments includes a detailed evaluation of the mix of chemical constituents in the soil, water or air. The ratio of the various contaminants may typify the product waste stream of a neighbor or historical operator. This same analysis holds true for an evaluation of the degradation products of a particular contaminant. For example, equivalent concentrations of PCE and TCE may signal an old solvent release of PCE, since TCE is the first order degradative product of PCE and degradation would occur over time. The same holds true for the relationship between TCE and T-1,2-DCE, and between 1,1,1-TCA and 1,1-DCE. Natural characteristics of waters, such as a trilinear plot of major cations and anions, can yield valuable information about groundwater sources. The types of chemical constituents which are the subject of the field sampling and analysis program will typically be tied to the information provided in the records review of the background activities on the subject site and in the surrounding area.

Surface water runoff influences should not be disregarded from suspect adjoining or nearby properties. Potential impacts during seasonal rainfall events should be evaluated.

Records Review

Information gleaned from existing documents and records is critical to the cost recovery effort. Comprehensive data sources should be evaluated, particularly EPA, Arizona Department of Environmental Quality (ADEQ) and Arizona Department of Water Resources (ADWR) records. Key evidentiary information is often found due to the savvy and experience of the investigator. Key

sources of historical information are listed below:

- Municipal records of utility additions, improvements, or servicing,
- Facility productions and purchase records,
- Water usage and discharge records,
- Raw materials inventory records,
- Waste manifests and waste handling company records,
- Aerial photographs focussing on tanks, pits, discoloration, building additions, vehicular parking patterns, paved versus unpaved areas,
- Personal interviews and depositions,
- Federal, state, county, city incident records of contaminant violations, nuisances, permits, registrations, inspections,
- Compliance reports, including Superfund Amendments and Reauthorization Act (SARA) reports,
- Identification of transporters and report areas of historical waste products,
- Hydrogeologic information based on data from groundwater wells in the area including historical groundwater flow direction,
- Drillers' records.

An often overlooked or underestimated source of information is from property neighbors and previous owners, operators, or employees. Depending on the particular client, personal interviews may best be handled by an expert in this field.

Presentation of Information

First and foremost, the work product has to be legally defensible. As previously discussed, the provisions of the NCP should be adhered to. In order to validate adherence to the NCP, you have to realize at what step of the CERCLA process you are in. All documents including field notes and observations and telephone notes should be properly dated. An organized file

and accounting system should be implemented at project inception. The presented information should be clear, concise yet comprehensive, and supported by documentation that allows the work to be understood by a broad audience. Technical discussions in text will be supported by tables and figures. Conclusions and opinions are supported by presentation of the technical results found in the sampling and analysis programs and the records review. Reports will be typically generated as draft documents so that plaintiff and plaintiff's representatives may review the work prior to its final issue.

Compilation of detailed and accurate field records is essential to the cost recovery effort. These field records include field notes, daily trip records, equipment calibration information, logs of stratigraphic borings and well installations, chain-of-custody records and quality control documentation. Quality control is typically completed on a 10-percent basis for field and laboratory samples. In other words, for every 10 samples collected in the field or analyzed in the laboratory, at least one duplicate sample may be analyzed for estimates of accuracy. Laboratory accuracy measurements are also completed on at least the 10-percent level.

Since records review information is interpretative to some degree, it is important that the investigator make a proper accounting of the dates, condition, source, representativeness, and accuracy of the records that are reviewed outside of the office. Whether the records are written or typed should be noted. Records should be copied and maintained in the project file if possible. Supporting information that complements other key records is important to the construct of evidentiary information. Information should be packaged and presented so that plaintiff's arguments and legal position are appropriately supported.

The application of a contaminant transport model may often be utilized to characterize the extent of contamination (typically when accurate source terms are known). Contaminant transport models may also be fitted with existing groundwater contamination data to verify model results and to evaluate the presence of additional sources. Such data input to the model should be comprehensive and reflect an adequate data set. This information not only provides a framework for the sampling and analysis program but may provide the details that implicate a previously unidentified responsible party or strengthen the case against already known parties.

Because of the legal ramifications of this type of work, environmental counsel should be conferenced regarding potential document status as attorney-client privileged and confidential, or as an attorney work product. Counsel may request that draft documents are not maintained in the file.

HOW CLEAN IS CLEAN: RECOMMENDATIONS CONCERNING THE ENVIRONMENTAL CONSULTANT'S STANDARD OF CARE[1]

Denise H. Troy, Esq.[2]

INTRODUCTION

Although the first environmental laws were adopted as early as 1899,[1] and the Clean Water Act was enacted almost forty years ago,[2] Congress only began to pay serious attention to environmental protection in the last twenty years.[3] While federal law may now encompass most aspects of environmental protection, the list of substances that are deemed harmful, and therefore come within the ambit of this law, continues to grow. Moreover, as technology advances, lower levels of pollutants may be detected and government agencies, such as the Environmental Protection Agency ("EPA") and the Arizona Department of Environmental Quality ("ADEQ"), may impose regulations that require the clean up or prevention of these very low level pollutants. In addition, new methods of remediation are appearing rapidly, permitting more extensive clean up. As a result, what is environmentally "clean" today may not be "clean enough" tomorrow.

This paper illustrates the possible risks to environmental consulting, in light of the explosion of environmental regulations and technology. It explains the legal standards that apply to environmental consultants, and also makes recommendations on how consultants can limit their

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[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

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potential liability in the event that the work they perform today does not, in hindsight, meet the standards of tomorrow.

A RECENT CASE IN POINT

A case recently decided by the Arizona Court of Appeals illustrates how environmental consultants can be haunted by work they performed a number of years earlier.[4] In 1983, Western Technologies ("WTI") entered a contract with Southwest Savings and Loan Association ("Southwest") to perform geotechnical services for a proposed office complex in Phoenix. As specifically defined in its contract, the scope of WTI's services was to

> evaluate subsurface soil and groundwater conditions, recommend procedures for grading and underslab treatment in the building and parking areas, recommend bearing pressures and estimate settlements for the moderately shallow spread footings and belled caissons, present surface and subsurface drainage recommendations, and recommend flexible pavement design thickness(es) for the at-grade parking lot.[5]

At the time WTI performed its work, the site contained two gas pumps and four underground storage tanks ("USTs"). One of the businesses on the site also fueled its own street sweeping vehicles at the site. WTI did not make note of the USTs in its report. During construction, the contractor removed two of the USTs.[6]

In 1988, an environmental assessment of the site revealed petroleum contaminated soil ("PCS"), and other hazardous substances. Southwest was unable to sell the complex, due to this contamination. In June 1990, more than seven years after WTI had entered its geotechnical services contract with Southwest, it was sued for breach of contract and negligence by the Resolution Trust Corporation ("RTC"), the receiver for Southwest.

The case against WTI was dismissed only after it presented the affidavits of three other geotechnical engineers who affirmed that, at the time WTI performed its services for Southwest, the standard of care for geotechnical engineers did not include the responsibility to locate and identify USTs or contaminated soil. Therefore, WTI had not breached the standard of care in performing its services. The RTC was unable to present expert testimony of its own to contradict this position.[7]

In the *Western Technologies* case, WTI was able to avoid a jury trial and potential liability because the RTC was unable to find a geotechnical engineer who was willing to give an opinion that, in 1983, a geotechnical engineer had a duty to discover and report the presence USTs.

If the RTC had been able to present expert testimony that a geotechnical engineer had a duty to discover and report on USTs and PCS in performing standard geotechnical services in 1983, WTI may still have been able to avoid liability. In 1983, neither federal nor state law included UST regulations. Congress first adopted the federal UST statutes in November of 1984.[8] The Arizona legislature enacted the Arizona statute in 1986.[9] Therefore, even if WTI had reported the presence of USTs and PCS, it is open to speculation whether Southwest Savings would have taken any action to remove them from the site, or would have decided not to construct the buildings on the site.

Even though WTI was completely successful in defending itself against the RTC's claims, it was put to the expense and aggravation of litigation. WTI may have been able to avoid even this expense if it had included certain provisions in its contract which would have limited its liability to Southwest.

THE LEGAL BASIS OF A CONSULTANT'S LIABILITY

To fully appreciate the breadth of his or her potential liability, an environmental consultant should understand the basic legal concepts of: the standard of care; duty; causation; and strict liability.

The Standard Of Care

In Arizona, as in most states, professionals such as environmental consultants, whether they are professional engineers, geologists or hydrologists, are only liable if they breach the "standard of care." The standard of care is defined as whether the consultant "exercised the degree of skill, care, and diligence as [consultants] ordinarily exercise under like circumstances."[10] This rule applies regardless of whether the claim is alleged as a breach of contract, negligence or negligent misrepresentation.[11]

To prove that a consultant breached the standard of care, the party suing the consultant must present "expert testimony establishing the prevailing standard and the consequences of departing from it in the case under consideration."[12] As described above, WTI was able to escape any liability to the RTC because the RTC was unable to present expert testimony that WTI had breached the standard of care. The only time

expert testimony is unnecessary is when the breach of the standard of care "is so grossly apparent that a lay person would have no difficulty recognizing it."[13]

To ensure compliance with the accepted standard of care, environmental consultants must keep abreast of changes in the technology and the law, and government interpretation of the law. Membership in professional organizations is probably the most efficient means of learning of these changes and determining whether new methods have become widely accepted within the consulting community, or are still deemed experimental. Under most circumstances, following generally accepted principles within the professional community will be sufficient to comply with the standard of care.

Duty

The law also defines a consultant's liability in terms of "duty." A consultant is only liable to those persons to whom he or she owed a duty. If the consultant does not owe a duty to the claimant, he or she should not be liable, even if the standard of care was breached.

The consultant always owes a duty to his or her client. Duty to third parties, however, is limited by whether the third party is "a foreseeable victim[]."[14] In *Hoffman*, the court ruled that unless the professional was aware that a report would be relied upon by people in Hoffman's position, the professional owed no duty to Hoffman, and therefore was not liable to him.[15]

In the environmental consulting context, if an environmental consultant performs an environmental risk assessment for the owner, knowing that the owner intends to provide any report to potential purchasers, the environmental consultant owes or could owe a duty to the potential purchasers. On the other hand, if the consultant provides a report for the sole use of the owner, and a potential purchaser is permitted to review the report, the consultant does not owe a duty to the third party. Nonetheless, if the owner is found liable to the third party, he or she may seek reimbursement from the consultant if the consultant is at fault.

Causation

Environmental Risk Assessments And Remediation

To be held liable for damages, a party must have been the cause of the damages. With environmental risk assessments and remediation, the environmental consultant's liability to the

owner may be limited, because the consultant probably did not cause the environmental problem. As illustrated by the *Western Technologies* case, it is unlikely that WTI caused Southwest Savings' damages. First, WTI was not responsible for the placement of the USTs on the property, nor the releases of petroleum that resulted in contamination. Second, even if it had reported the presence of USTs and PCS, at that time Southwest may not have acted on the information.

Circumstances may occur, however, that would impose liability on the consultant. For example, if the consultant designs or oversees a particular course of action for remediation, which is later disapproved by the government, the client may seek reimbursement from the consultant for the penalties, costs and damages it incurred for the disapproved or unsuccessful remediation. A consultant might also be responsible for damages if the contamination migrated and leached into the groundwater, or onto a neighboring property, greatly increasing the cost of clean up.[16]

The consultant may also cause other damages not solely attributable to remediation. For example, if the environmental consultant causes a delay in obtaining government approval and this delay unduly disrupts the client's business, or prevents the client from leasing the property, the environmental consultant may be responsible for these indirect or "consequential" damages the client incurred from those losses. The client would, however, have to demonstrate that the consultant was aware that the damages would accrue if a delay occurred.

While an environmental consultant may not cause direct damages to his or her client when performing environmental risk assessments or remediation, he or she may cause damages to a third party, such as a purchaser. If, when deciding to purchase the property, the purchaser relied on the consultant's report that the property was not contaminated, or all contamination had been remediated, and is later forced to clean up contamination at the site, the purchaser will claim the cost of clean up from the consultant, asserting that he or she would never have purchased the property if it was contaminated.

Permitting And Environmental Impact Statements

Environmental consultants are more likely to "cause" damages when assisting in permitting and environmental impact statements ("EIS"). In performing these duties, clients are relying on their consultants to assess, prevent or remedy the possible extent of environmental harm. If the consultants' recommendations are erroneous, the consultant may be deemed to

have caused the damage, and both the client and affected third parties may seek compensation from the consultant.

Strict Liability

Many of the environmental statutes impose liability on owners, generators, and transporters of hazardous substances without any regard to the party's fault in causing the environmental hazard.[17] Liability that is imposed regardless of fault is "strict liability."

Some courts, such as the Seventh Circuit Court of Appeals, have not embraced the inclusion of environmental consultants as parties who are strictly liable under the federal statutes.[18] In ruling that an environmental consultant was not liable under CERCLA for designing a facility that discharged hazardous wastes, the Court stated:

> the statute does not fix liability on slipshod architects, clumsy engineers, poor construction contractors, or negligent suppliers of on the job training. . . . The liability falls on owners and operators; architects, engineers, construction contractors, and instructors must chip in only to the extent that they have agreed to do so by contract."[19]

Other courts, however, have found consultants may be responsible under CERCLA, if they have arranged for transportation of hazardous substances off the site.[20] For example, in a case currently pending, owners of property near a superfund site seek to impose liability on the environmental consultants who designed a closure plan for the site. These neighboring owners allege that the consultants are liable under CERCLA for arranging for the transportation of lead off the site.[21]

LIMITATIONS ON LIABILITY

The best method of limiting liability is well drafted contracts and reports. While many consultants' contracts and reports contain some liability limiting language, those documents do not always contain all the provisions that may reduce potential liability. Consultants should review their form contracts to determine whether they contain the following types of provisions.

Scope Of Work

The provision over which an environmental consultant has the most control is the scope of work provision. As the *Western Technologies* case demonstrates, a scope of work provision that specifically excludes the services for which the client seeks to impose liability can preclude the imposition of liability on the consultant.

The scope of work provision should be as limited as possible. It should also expressly exclude work for which the consultant is not responsible. In addition, it should define the intended or permitted users of any report that the consultant may prepare, limiting the potential rights non-clients who may claim that they relied on the report. Although a third party is not bound by the terms of the contract, courts will review contract language in determining whether a consultant owed a duty to the third party, and such a limitation in the contract should preclude a finding of such a duty.

Similarly, consultants' reports should specifically describe the work the consultant performed, and should detail the work that was not performed. The report should also clearly state the purposes for which the consultant was retained. Again, the reports should designate the intended users of the report, for the same reasons that intended users are named in the contract.

Standard Of Care

Any consulting contract should also include a standard of care provision that states that the consultant will render his or her services in accordance with the generally accepted practices at the time and place where the services are performed.

With the rapid changes in environmental consulting, including the time the services were performed is of great importance. If the consultant is sued many years later, being able to demonstrate that he or she rendered services appropriate for the time, and used the available, proven technology, no liability should be imposed, even if new, more effective methods have been created in the interim.

The "place" language in the provision is also very important, given the particular geologic conditions in the Southwest. Generally accepted practices here are likely to be different than in other regions of the country. By limiting the standard of care to the place where the services were rendered, the consultant may make it more difficult for the

potential claimant to find an expert to testify that the consultant breached the standard of care, because consultants from other regions of the country may be unable or unqualified to testify concerning local practice.

Sophisticated clients may request that the consultant agree to a "highest and best" standard of care. Consultants should take care to avoid such provisions, because the client may later claim that the consultant breached this standard of care by failing to use state of the art methods. For example, pump-and-treat ("PAT") methods of ground water restoration are currently very popular remedies for groundwater remediation. They are expensive, take a long period of time, and may not always be effective. Consultants are now introducing new methods that are used in conjunction with PAT methods, and may increase PAT effectiveness.[22] If a consultant must comply with the "highest and best standard of care," unassisted PAT methods may not be enough to meet that higher standard, and the consultant may have to try experimental means of dealing with groundwater contamination. If the consultant must only comply with the general standard of care in the community, it probably will not breach that standard of care by using PAT methods alone.

The only time when a consultant may have to go beyond the practices generally accepted by similar consultants is when the work involves permitting. In Arizona, to obtain permits for environmentally hazardous operations, ADEQ often requires state of the art design elements or the "Best Available Demonstrated Control Technology" ("BADCT") to protect groundwater.[23] BADCT is normally site specific, and must be determined through negotiations with ADEQ. Government approval of the BADCT should be sufficient to protect the consultant from claims that he or she breached the standard of care, because it demonstrates that the government agreed that the proposed methods were the best available. Moreover, by its very definition, BADCT requires that the methods used be proven reliable. Accordingly, while meeting the BADCT requirements may demand more than generally accepted practices, the consultant will not breach the standard of care by excluding experimental methods of preventing environmental harm.

Liability Limitations

Another method of reducing a consultant's risk is to include a Liability Limitation provision in the contract. This provision will limit any damages the consultant must pay to the client if the consultant is found liable to the client. The provision will provide a specific sum, often the contract price paid by the client, or an errors and omissions insurance

policy liability limit. Although not required by Arizona law, any such provision should probably be conspicuous, that is, in bold or large point type. While a liability limitation provision will set a specific amount the client can recover from the consultant, third parties are not bound by the contract, and can recover more than this specific sum.

This provision should also provide that the consultant is not responsible for "consequential damages." As described above, consequential damages are those damages for which a consultant is not directly responsible, such as lost profits or lost rent. Any language limiting responsibility for consequential damages probably should also be conspicuous.

Site Information

The consultant's contract should also state that the consultant is relying on the site information provided by the client, and that the client is providing all known site data and information to the consultant. The client should also warrant that it has provided the consultant with all available information. This clause should also state that the consultant is not responsible for existing conditions at the site that the client did not reveal in the site information provided to the consultant.

Disposal and Transportation

Due to the possibility that a consultant may be held strictly liable under CERCLA if he or she arranges for the transportation or disposal of contaminated material, the contract should spell out that the client is responsible for the final determination of the means of transportation and method of disposal of any material.

In addition, any contract to remediate, transport or dispose of contaminated material should be between the client and an independent contractor unrelated to the consultant. If the consultant has no control over this independent contractor, he or she cannot be held responsible for the independent contractor's actions.

Indemnification

An indemnity clause in a contract requires one party to the contract to defend, indemnify, and hold harmless the other party from liability and damages, including attorneys' fees and litigation expenses. Arizona permits broad indemnification clauses in contracts.[24] However, a party may not be indemnified if its sole negligence is the cause of the liability.[25] Inserting an indemnity provision in the contract

that requires the client to defend and indemnify the consultant can completely relieve the consultant from even the expense of litigation, if the consultant is only partially at fault.

Most sophisticated clients, however, will require mutual indemnity clauses. A clause indemnifying the client will not only make the consultant responsible for damages he or she may have caused, but will also impose liability for damages for which he or she would otherwise not be responsible.

Time Bar To Legal Action

In Arizona, the statute of limitations for contract claims is four years,[26] and for tort claims is two years.[27] Arizona, however, has a "discovery" rule.[28] Under the discovery rule, the statute of limitations does not begin to run until the injury has been discovered by the plaintiff.[29] In the *Western Technologies* case described above, the discovery rule permitted the RTC to bring its claims against WTI more than seven years after WTI performed its work, because the PCS was not discovered until 1988. In addition, due to the Arizona Constitution's bar on legislative limits on damages, statutes of repose, which cut off liability after a certain number of years whether the injury has been discovered or not, have been struck down by the Arizona Supreme Court.[30] Accordingly, in Arizona, it is unclear how long potential liability may exist.

In an effort to limit the time in which the client can bring a lawsuit against a consultant, the consulting contract should contain a provision that precludes the client from taking action against the consultant beyond a certain number of years after the consultant has completed his or her work, and without regard to when the client discovers the injury. The clause should be broad enough to encompass all provisions of the contract, including the indemnity provisions, and all types of claims, including torts. This clause may limit the consultant's liability to the client, but third parties will not be bound by the provision.

Insurance

The insurance industry has responded to the expansion in the environmental laws by expressly excluding pollution coverage in most general commercial liability policies. Instead, it has created special riders and policies that deal exclusively with pollution. For example, some insurance companies now offer environmental efficacy policies that provide coverage if a pollution prevention design does not work. All environmental consultants should review both their

errors and omissions policies and commercial general liability policies on a regular basis and make sure that not only are their policy limits adequate to protect against the potential risks, but that all potential risks are covered by some form of insurance.

CONCLUSION

Even with rapidly changing law and technology, an environmental consultant can limit his or her future liability by keeping abreast of these changes, and careful contract drafting. While a consultant may not be able to persuade a client to accept all the contract provisions that have been suggested in this paper, the inclusion of some, especially a limited standard of care provision, should prevent the imposition of liability on consultants who are performing their work in conformance with currently accepted practices.

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SESSION 3C:

COMPUTER APPLICATIONS IN WATER RESOURCE STUDIES (PART 1)

Moderator: Bradley M. Hill
Arizona Department of Water Resources

GROUNDWATER MANAGEMENT AND RIPARIAN ECOSYSTEMS OF THE UPPER SANTA CRUZ RIVER[1]

J. C. Stromberg, J. Fry, P. McCraw, and D. Patten[2]

ABSTRACT. Stream flows and groundwater depths have varied greatly over time in the Santa Cruz River, due to variations in precipitation and stream flow and in anthropogenic water uses. These hydrologic changes, in turn, have caused the abundance and condition of cottonwood-willow forests and other riparian vegetation types to fluctuate over time. Remote sensing analysis, in combination with ecological field studies and hydrological studies, provide the necessary tools to understand these changes. These studies indicate that effluent discharged into the Santa Cruz River channel from the Nogales International Wastewater Treament Plant, in combination with above-average stream discharge and peak flows in recent decades, has allowed for development of an extensive young cottonwood-willow riparian forest. This forest is continuing to expand farther downstream over time as groundwater tables continues to rise. However, some riparian forests upstream of the NIWTP are in degraded condition, due to the combination of groundwater pumpage (the ultimate source of some of the effluent) and insufficient recharge. Actions that could be taken to restore eco-hydrological "balance" to the upper Santa Cruz watershed include restoring a more equitable spatial overlap of groundwater pumpage and aquifer recharge.

INTRODUCTION

The Upper Santa Cruz River supports one of the last remaining large stands of Fremont cottonwood - Goodding willow riparian forest, as well as other riparian vegetation types. The stream-aquifer system that sustains these ecosystems, however, is greatly influenced by human actions in Arizona, USA and Sonora,

[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

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Mexico. The towns of Nogales, Arizona and Nogales, Sonora, for example, obtain much of their water supply from aquifers connected to the Santa Cruz River, as do many other smaller communities including Rio Rico. Irrigated agriculture also uses water from the floodplain aquifer. Some of the groundwater that is pumped from the upper Santa Cruz River stream alluvium (and from another river basin in Mexico) is returned to the Santa Cruz River channel farther downstream near Rio Rico as effluent, from the Nogales International Wastewater Treatment Plant (NIWTP). In addition to these human influences, climatic fluctuations cause river flows and groundwater recharge rates to fluctuate greatly over time in the Santa Cruz River basin.

METHODS

Protection of functions and values of riparian ecosystems calls for an interplay of science, regulation, and public participation. We describe approaches that provide a scientific framework for riparian protection for the Upper Santa Cruz River. Effects of climatic and anthropogenic changes in site hydrology on the upper Santa Cruz riparian ecosystems were assessed by using research methods that differed greatly in their scale of analysis. At the landscape scale, LandSat satellite imagery and aerial photography (1973 and 1990) were incorporated into a Geographic Information System, to allow detection of areas with reduced riparian plant cover. Time-series analysis of groundwater data from multiple alluvial wells were analyzed to determine whether groundwater depletion was a cause of the reduced vegetation cover. Ecological field studies including analysis of cottonwood age structure, cottonwood radial growth rate, and vegetation density and composition, were performed to detect riparian stress and to determine groundwater needs for maintenance and enhancement of various types of riparian plant communities (see ADWR 1994 for additional detail).

RESULTS

Riparian Degradation

Our studies indicate that water uses have resulted in varying degrees of riparian degradation and enhancement in different reaches of the upper Santa Cruz River. In some areas, pumpage of groundwater from the Santa Cruz River aquifer has caused groundwater depression and/or loss of perennial surface flow. One such area lies near the Santa Cruz/Pima County line, where the combination of aquifer characteristics (i.e., high transmissivity) and high rates of pumpage for mining and agricultural activity have caused water tables to decline substantially. Murphy and Hedley (1984), for example, observed that water levels near Continental and Green Valley declined by 120 feet (36 m) from 1953

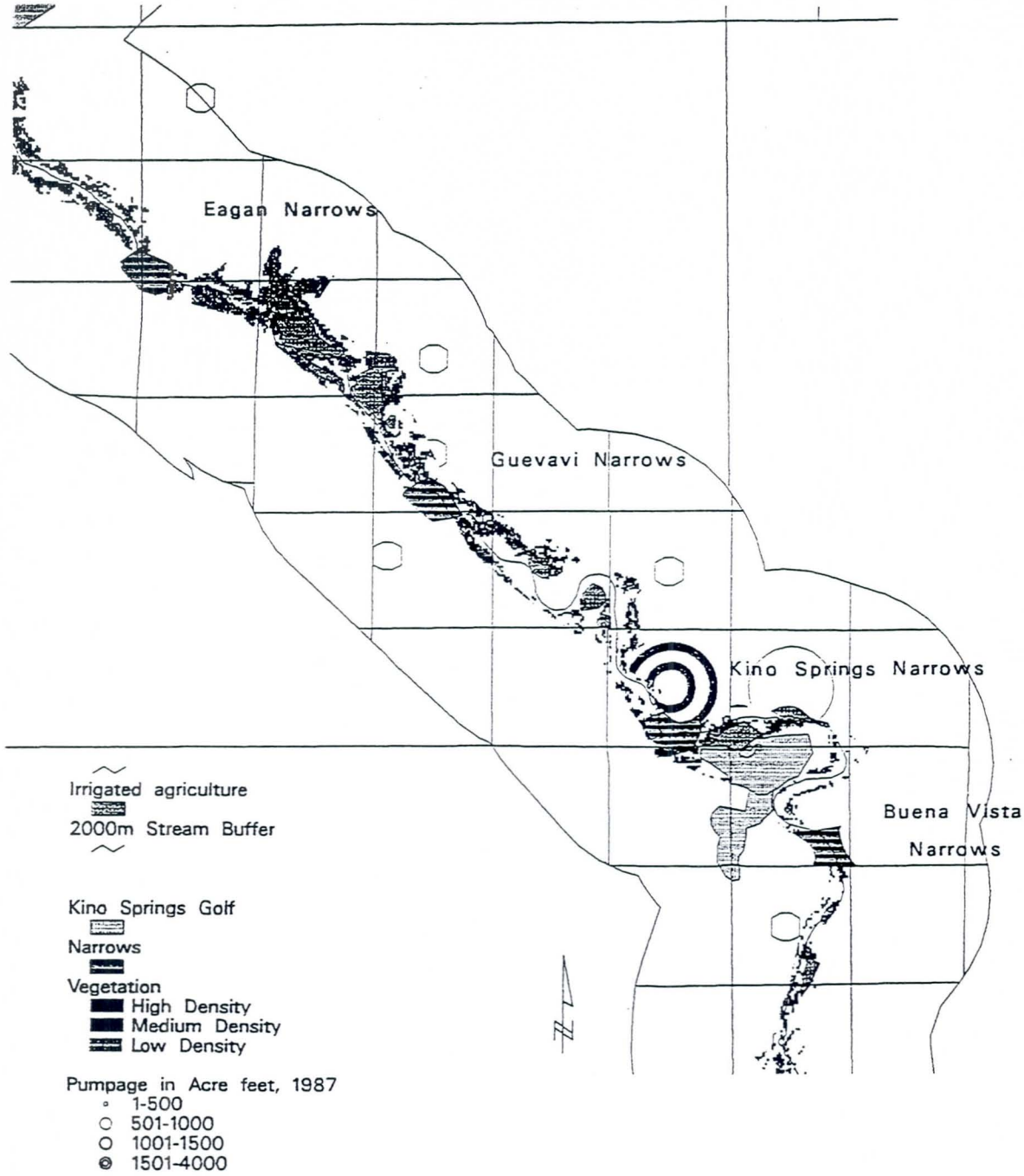

Figure 1. LandSat satellite imagery of a portion of the upper Santa River floodplain, indicating riparian vegetation density, groundwater pumpage (acre-feet pumped in 1987 per 1 mi^2 section of land), and location of "narrows", or hardrock constrictions that force subflow near the surface.

through 1982. In these areas of greatest groundwater depression, riparian forests have been completely eliminated.

Riparian areas also are locally degraded upstream of the Nogales International Wastewater Treatment Plant (NIWTP) (Figure 1). Fremont cottonwood-Goodding willow forests are discontinuous in this reach, and persist in good condition only in localized areas where geologic constrictions produce shallow, stable water tables. The stable water tables in these localized areas has allowed for the persistence of old-growth (about 100-yr) cottonwood stands. In contrast, the forest is either absent or in poor ecological condition in sub-basins with deeper alluvium and high rates of groundwater pumpage. Near the City of Nogales Highway 82 well field (located near the Kino Springs Narrows), for example, the depth to groundwater is at a threshold range for Fremont cottonwoods (5-6 m, or 15-20 ft and more below the floodplain surface), and the forest stands have low tree density, low canopy cover (i.e., low canopy foliage area) (Figure 2), and low growth rates. Riparian forests in these areas also have high ratios of Fremont cottonwood to Goodding willow trees, reflective of the greater sensitivity of willow to water stress. The limited age-class diversity of the cottonwood forests also in an indicator of degradation. Some reaches, for example, support only one age-cohort, which established after the 1983 floods. This young cohort persists in the heavily pumped reaches only because of above average stream flows in recent years.

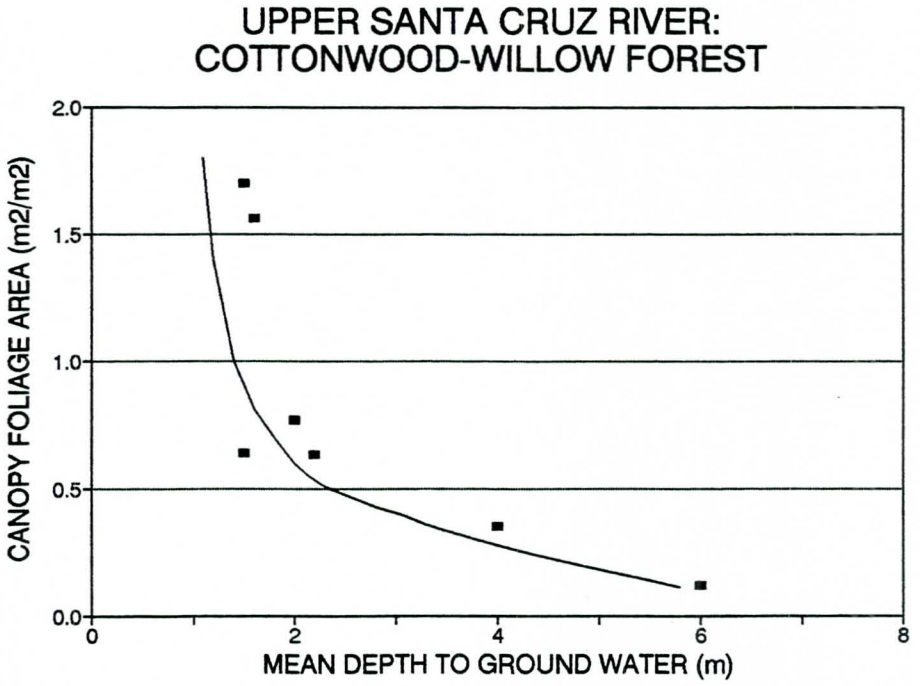

Figure 2. Canopy foliage area of Fremont cottonwood-Goodding wilow forests in relation to mean depth to groundwater in the upper Santa Cruz River floodplain.

Riparian Enhancement

Riparian enhancement is apparent in the perennial reach of the Santa Cruz River located downstream of the NIWTP. In the 1950s and 1960s, high rates of groundwater pumpage and low rates of recharge caused groundwater in this reach to decline to depths below the survivorship range of Fremont cottonwood and Goodding willow trees (5-6 m, or 15-20 ft and more below the floodplain surface). This factor, together with clearing of trees, and subsequent flooding in the 1970s and 1980s, eliminated most of the cottonwood-willow forests that existed at that time. Over the past few decades, however, increasing amounts of effluent have been released into the Santa Cruz channel, resulting in substantial increase in streamflow and groundwater recharge, both of which have beneficial effects on riparian vegetation. The effluent discharge, in combination with above-average surface flows, has allowed for re-development of an extensive Fremont cottonwood-Goodding willow forest downstream of the NIWTP in recent decades. Large winter floods, which occurred frequently in the 1970s, 1980s, and 1990s, stimulated germination of the cottonwood and willow trees (Figure 3), while raised water tables allowed for their survivorship.

The cottonwood-willow forest has been extending farther downstream of the NIWTP over time as water tables sequentially have become shallow enough to sustain the riparian forest. For example, cottonwood-willow forests near Tubac are mostly less than 30 years old while those near the Pima/Santa Cruz County Line are mostly less than 10 years old (Figure 4). The highest density cottonwood-willow forests are located in the river reach nearest the NIWTP (i.e., Tubac/Rio Rico area) where flow is perennial and water tables are shallowest (about 2 m, or 7 ft below the floodplain surface). Forest density declines with increasing distance from the NIWTP. Low-density cottonwood-willow forests now grow near the Santa Cruz/Pima County line where stream flow is not perennial but groundwater tables are shallow. In the reaches where the forest is most dense, however, the young cottonwood trees have undergone high rates of mortality in recent years due to the activities of a native wood-boring beetle (*Lochmaeocles marmoratus*). Although the beetle is distributed over the length of the upper Santa Cruz riparian zone, beetle abundance and cottonwood mortality are greatest in the effluent-dominated reach. This may be due to a combination of factors including rapid tree growth rates, high tree density, and lack of old-growth trees that might provide nesting sites for natural avian predators of the beetles.

Besides affecting cottonwood-willow forests, effluent discharge also is affecting opportunities for restoration of other riparian vegetation types. Cienegas (marshes), for example, are a rare type of wetland community that were historically abundant on the upper Santa Cruz (Hendrickson and Minckley 1984). Because these communities require very shallow water tables (i.e., near or above the ground surface) they were reduced to tiny remnants along the

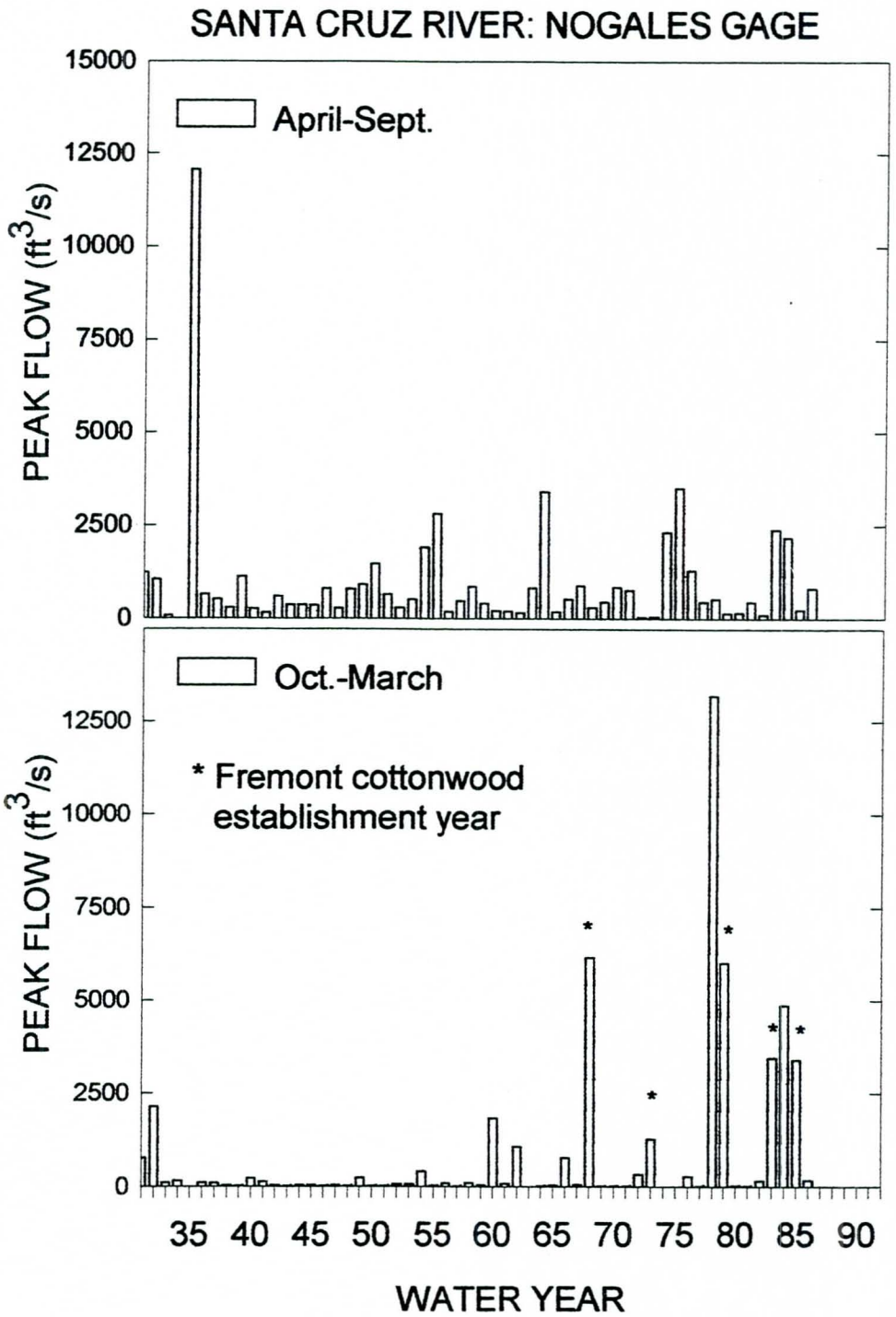

Figure 3. Fremont cottonwood establishment years in relation to flood magnitude and seasonality.

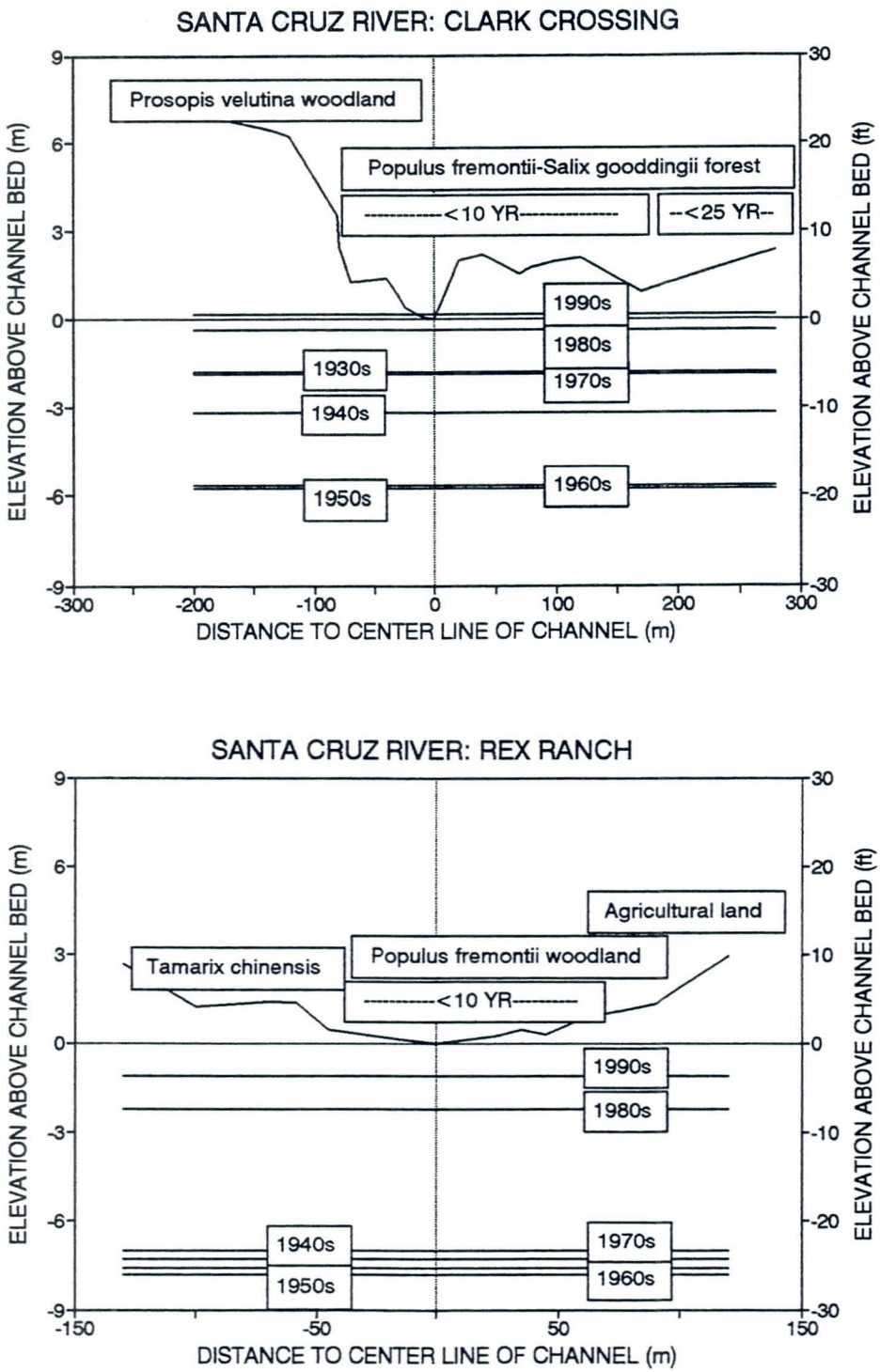

Figure 4. Profile of the Santa Cruz River floodplain at sites located approximately 15 km (Clark Crossing) and 30 km (Rex Ranch) downstream from the Nogales International Wastewater Treatment Plant. Mean depths to groundwater, by decade, and dominant vegetation types also are indicated.

Santa Cruz River by past water table declines. Potential for restoration of this rare vegetation type is enhanced by raised water tables resulting from effluent discharge. Mesquite (*Prosopis velutina*) woodlands (bosques) are another type of riparian community that has undergone much loss on the upper Santa Cruz River. Although they remain as the dominant riparian forest type along the high floodplain terraces of the Santa Cruz River, over 40% of their habitat has been cleared for agriculture (ADWR 1994). Due to changing land use patterns, many of the agricultural fields along the Santa Cruz River now lie fallow. Raised water tables in the effluent-dominated reach of the Santa Cruz river are facilitating restoration of the mesquite forests to these fallow fields. Sacaton (*Sporobolus wrightii*) grasslands are yet another type of riparian plant community that were historically abundant along the higher floodplain terraces of the Santa Cruz River. Sacaton grasslands are essentially nonexistent along the river today, and are not naturally regenerating in response to the raised water tables. Sacaton restoration may depend upon maturation of the cottonwood-willow forest, which may presently be too young to create the ecological conditions necessary for sacaton establishment.

FUTURE OUTLOOK

Although the Upper Santa Cruz River study area is located within the newly created Santa Cruz Active Management Area (SCAMA), additional development of water resources is expected to occur in the USA as well as in Mexico (El Colegio de la Frontera Norte 1992). This could result in additional changes in riparian ecosystem quality and abundance. For example, if groundwater pumpage from the floodplain aquifer continues at equal or higher rates upstream of the NIWTP, the riparian forests will most likely degrade upon return of inevitable drought periods. Some cottonwood mortality, for example, has occurred in recent years in heavily pumped areas upstream of the NIWTP. Downstream of the NIWTP, if effluent release continues at equal or higher rates, the cottonwood-willow forests will continue to expand farther downstream over time; fallow fields will continue to recover to mesquite bosque; and wetland vegetation will be enhanced. If effluent release is discontinued, if groundwater pumpage is increased in order to recapture effluent recharge credits, or if additional floodplain land is developed, recent gains in riparian ecosystem abundance will be lost.

Although effluent discharge has contributed to riparian re-development in portions of the Santa Cruz Active Management Area, this gain does not entirely "compensate" for riparian degradation in other reaches. Many of the functions and values of riparian ecosystems are optimized when the riparian corridor is continuous, rather than interrupted (Ohmart and Anderson 1986). For example, continuous riparian corridors provide more effective routes for wildlife travel, and provide more effective flood flow attenuation. Additionally, although the young

forests that exist downstream of the NIWTP have high value, the old-growth cottonwood forests that exist at some sites upstream of the NIWTP have unique biodiversity values. For example, many types of bird species depend on the old-growth riparian forests for their existence (Rosenberg et al. 1991). Finally, because there are unresolved concerns over effects of nutrient-rich effluent on riparian ecosystem composition, productivity, and disease interactions, there is a need to maintain hydrological conditions that allow for high quality riparian ecosystems in non-effluent dominated reaches, as well as in effluent-dominated reaches.

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MEXICO BORDER ISSUES AND GIS APPLICATIONS[1]

Jana Fry, Juliet Stromberg, and Duncan Patten[2]

ABSTRACT: A geographic information system (GIS) database has been used to address water quality and quantity issues on the border and within the binational Santa Cruz River watershed. These issues include water quality problems in Nogales Wash, water quantity issues, and consequences of effluent released from an International Wastewater Treatment Plant (IWWTP). The GIS has been used to map results from several different water quality studies, changes in land use, well pumpage and levels over time, and riparian vegetation. Overlay analysis techniques have been used to correlate areas of high pumpage with areas of reduced vegetation, and groundwater contaminants with industry locations. The database has been used for a statewide riparian inventory effort and for a Nogales Wellhead Protection Program as well.

INTRODUCTION

Water is a natural resource that is shared by the U.S. and Mexico in the form of surface water, groundwater, and in some instances, treated effluent. Such is the case in the binational Upper Santa Cruz watershed. The Santa Cruz River is the primary source of water in the watershed, providing water for agricultural, domestic, industrial, and municipal uses. The river begins in Arizona in the San Raphael Valley and drains the Patagonia Mountains to the west, Canelo Hills to the north, and Huachuca Mountains to the east. It flows south into Mexico, making a 35 mile loop, and reenters the United States just east of Nogales. The river continues to flow north to Tucson, then turns northwest to join the Gila River about 12 miles southwest of Phoenix. Its length is over 225 miles (Schwalen and Shaw 1957). Because political boundaries do not align with hydrologic and physical boundaries, it is important that Mexico and the U.S. work together

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to manage these resources in a responsible manner. Maintaining a reliable, clean source of water is of critical importance to both countries.

Issues

Multiple issues related to water quality and water quantity are of concern in the watershed. Water quality problems exist in Nogales Wash, a drainage that flows from Nogales, Sonora through Nogales, Arizona into the Santa Cruz River. Water quantity problems exist, especially for Nogales, Sonora, which supports four times the population on 1/4 the water as does Nogales, Arizona (COLEF 1992). An International Wastewater Treatment Plant (IWWTP) located at the confluence of Nogales Wash and the Santa Cruz River has exceeded US Environmental Protection Agency (EPA) water quality standards on several occasions (Udall Center 1993) and recently cholera was found at the treatment plant (Associated Press 1994). However, effluent released from the plant has increased groundwater recharge and enhanced a riparian ecosystem downstream from the plant (Stromberg 1993).

Water Quality

Several water quality sampling efforts have been undertaken in the Nogales Wash area. Nogales Wash originates in Sonora and flows through Nogales, Sonora and Nogales, Arizona (commonly referred to as Ambos Nogales). The wash then flows into the Santa Cruz River near Rio Rico. In 1988, a study conducted by Prescott College and the Border Ecology Project found high levels of tetrachloroethylene (PCE) and other volatile organic compounds (VOCs) on the Sonoran side of the border in the wash (Humes and Voelker 1988). Similarly, studies conducted by the Udall Center at the University of Arizona in conjunction with Colegio de la Frontera Norte (COLEF) and Instituto Tecnologico de Sonora (ITSON) in 1993 (Udall Center 1993), by Earth Technology for the Arizona Department of Environmental Quality (ADEQ) in 1990 (Earth Technology 1990), and in a cooperative effort conducted by the International Boundary Water Commission (IBWC), ADEQ, the Santa Cruz County Health Department, the City of Nogales, and the University of Arizona Department of Microbiology and Immunology in 1990 (ADEQ 1994), found high levels of VOCs such as PCE, trichloroethylene (TCE), dichloroethylene (DCE), and trichloroethane (TCA) present in the wash.

A 1991 sampling from sewers located in Sonora found high levels of toluene, ethylbenzene, xylene, methylene chloride, and benzene (Sanchez and Kamp 1990). This year, a binational sampling effort for the United States and Mexico is set to be conducted by IBWC and ADEQ upon final

agreement by the Mexican government, which is still pending (Castenada 1994). Thirteen wells in Nogales Wash, six on the Sonoran side, and seven on the Arizona side of the border will be sampled for the presence of VOCs and other chemicals. The Union of Concerned Scientists is also considering sampling the wash (Kamp 1994).

Water Quantity

Groundwater provides the main source of water for human use and consumption, and runoff from precipitation provides the main source for groundwater recharge in the Upper Santa Cruz watershed. Nogales, Arizona and Nogales, Sonora rely, in part, on well fields located along the Santa Cruz River for municipal water supplies.

Rapidly growing populations in Nogales, Arizona, and Nogales, Sonora prompt the search for water to supplement current supplies. Development in Nogales, Arizona and surrounding Santa Cruz County is limited by state groundwater protection laws established in 1980 (ADWR 1990). No parallel legislation exists in Nogales, Sonora, however, where a population four times greater than that of Nogales, Arizona, exists on 1/4 the water per capita (COLEF 1992). Over 20% of the population in Nogales, Sonora does not receive water from the main water distribution system, and nearly 60% of the population that is serviced by the system endures frequent and prolonged interruptions of water service (Lara and Sanchez 1993). Of the population that does not receive water from the main distribution system, many rely on private water suppliers that deliver water in trucks. This water is more costly and may be of questionable quality.

In response to a growing population and chronic water shortages, Nogales, Sonora, is currently pumping water from the adjacent Los Alisos basin to supplement supplies from the Santa Cruz basin (COLEF 1992). Water that is obtained from the Alisos basin and released into the Santa Cruz basin as effluent constitutes an interbasin transfer. This interbasin transfer adds a new dimension to water budgets for the Upper Santa Cruz River and the Alisos basins. The city is also recommending use of graywater and water conservation to address future water needs (COLEF 1992).

To satisfy projected population growth through the year 2005, the city of Nogales, Arizona plans to drill four additional wells that will pump 4.5 mgd each, by the year 2005 (The Planning Center 1992). Locations for these wells has not been determined. The city currently maintains wells on the Santa Cruz River and on Potrero Creek for their municipal water supply. Wells along Nogales Wash are no longer used by the city.

Binational Effluent

Unique and complex water quality and quantity issues are of concern in relation to the IWWTP. The plant is located at the confluence of Nogales Wash and the Santa Cruz River, in Arizona. Over 12 million gallons of sewage from Ambos Nogales, (approximately 8 million from Nogales, Sonora and 4 million from Nogales, Arizona) is treated and released into the Santa Cruz River per day. As the IWWTP approaches 75% capacity, this figure is likely to increase (Holub 1993). Although Arizona owns the majority of the remaining 25% capacity, it is likely that it will be used by Sonora whose population is growing more rapidly.

The 1944 Water Treaty between Mexico and the U.S. guarantees Mexico the right to retain effluent originating in Mexico. Although Mexico does not currently require that treated water be returned to Mexico, it may do so in the future. A small capacity 'eco-parque' that will treat effluent in Nogales Sonora is currently being designed by COLEF. The treated effluent will be reused by industry in the city. Treating effluent in Sonora could preclude use of the IWWTP if treatment facilities of sufficient magnitude are constructed in Mexico. This scenario is somewhat unlikely at present because Mexico currently treats only 15% of its wastewaters (Garza 1994). However, if Mexico were to reclaim the 6,000 acre/feet of effluent per year that it currently relinquishes to Arizona, critical riparian habitat downstream from the plant could be negatively effected and groundwater recharge substantially diminished (Stromberg 1993). Additionally, Arizona state law ARS 45-804 allows Nogales, Arizona to receive recharge credits for effluent recharged in the Santa Cruz River. In essence, Nogales, Arizona has the right to purchase water from Nogales, Sonora (Holub 1993).

Groundwater quality concerns surrounding the treatment plant stem from treated effluent that has exceeded water quality standards and from untreated effluent that occasionally flows from Nogales Wash past the treatment plant into the Santa Cruz River. Fecal coliform has been found above 160,000,000 counts per 100 ml in Nogales Wash, and at levels reduced to 9,000 counts per 100 ml below the plant (Udall Center 1993). Chloride levels are higher downstream from the treatment plant due to effluent flows that transport chloride with them. The treatment plant was out of compliance with several water quality standards from 1980 to 1990 (Udall Center 1993).

METHODS

In order to examine the complex issues that are of concern in the Upper Santa Cruz River basin, a GIS database was employed. Use of a GIS allows a wide variety of data to be compiled in a compatible format.

Spatial analysis using overlay techniques, 'unioning' and scientific modeling is also facilitated by GIS.

Data Collection and Compilation

The database created for the Upper Santa Cruz River basin utilizes data from many sources. The Arizona Lands Resource Information Systems (ALRIS) division of the Arizona State Lands Department (ASLD) provided a majority of 'background' information such as quadrangle boundaries, cadastral information, major transportation routes, and surface hydrology, in digital format. This information facilitated the development of additional 'covers' (layers of thematically related spatial and tabular data).

Tabular data from the U.S. Geologic Service (USGS) for well locations and pumpage rates were averaged and projected from longitude and latitude coordinates Aerial photos at 1:20,000 scale were georeferenced and digitized to portray land use and riparian vegetation on the U.S. side of the basin. Photos from a Soil Conservation Service (SCS) soil survey were digitized to delineate soil series and assign attributes for soil conductivity and permeability. Digital data for geology, satellite imagery, and well pumpage amounts were provided by the Arizona Department of Water Resources (ADWR). Digital covers for non-point source pollution discharge (NPDES) sites and a cover that indicates aquifer vulnerability were provided by ADEQ.

For the Mexican side of the watershed, COLEF provided maps from Instituto Nacional de Estadistica Geografia e Informatica (INEGI - the Mexican equivalent of USGS) for vegetation, soils, geology, and hydrology. Digital data were acquired for climate, vegetation, geology and soils. Aerial photos at 1:75,000 scale were also obtained from INEGI by COLEF. An agreement between ASU and COLEF has facilitated exchange of data between the two countries and greatly increased the efficiency of acquiring documents from various agencies within the Mexican government.

Additional data for the Mexican side were obtained from the University of Utah. Land use for Ambos Nogales, maquiladora locations, shallow alluvium and roads covers were obtained from researchers in Utah.

Analysis

Most analyses to date have been achieved by use of overlay techniques. By overlaying covers for riparian vegetation, satellite imagery indicating vegetation density and pumpage rates, for example, it is possible to spatially correlate areas of reduced vegetation cover with areas of greater pumpage. By overlaying groundwater levels with vegetation, it is possible

to show the relationship between increasing water levels, due to increased groundwater recharge, and younger riparian growth further downstream. Similarly, it is possible to see how recharge has increased water levels over time and space using overlay techniques.

By 'unioning' two or more covers it is possible to create a new cover that reflects a combination of the spatial and tabular features of the original covers. For example, by unioning the covers for shallow alluvium, aquifer vulnerability, soil permeability and land use, it is possible to delineate areas that could be most susceptible to groundwater contamination.

GIS can also be used for scientific modeling applications. Models for surface runoff and surface elevation modeling in conjunction with non-point source pollution concerns can be executed using grid functions. Using models of this type would make it possible to trace urban, agricultural, or industrial related runoff and recommend placement for riparian vegetation or other buffers that may help to protect surface water quality in the river. By adding attributes for static well levels, aquifer thickness, hydraulic conductivity, and porosity of different geologic units, groundwater modeling can also be executed using grid functions. The GIS database housed at the Center for Environmental Studies (CES) lays a foundation that can be enhanced in order to perform these more complex modeling analyses.

GIS Applications

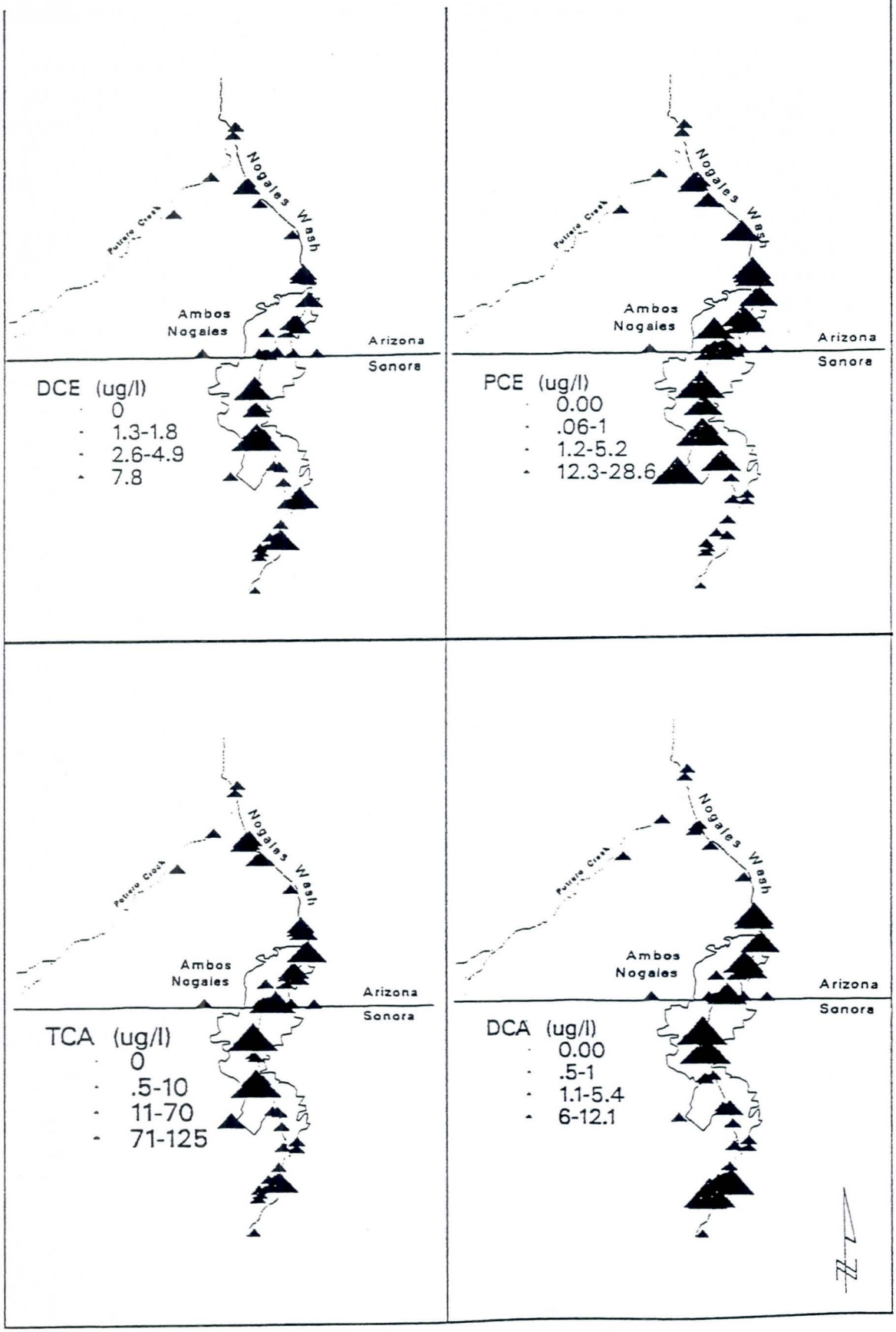
Although originally created for watershed planning applications, the GIS database has been used for a variety of applications. Water quality and water quantity applications have been explored as follows.

Water Quality

Sampling efforts from the Udall/COLEF study, the Earth Technology study and the ADEQ cooperative study have been mapped using GIS. Results from the Prescott College study were not mapped, but results from the study show one well violates PCE and TCE U.S. Maximum Contaminant Levels (MCLs) in Sonora. Findings from the studies are consistent in that VOC levels were higher in sections of Sonora and tended to diminish in concentration to the north (Figure 1).

Water quality sampling efforts tested for different chemicals and used different measurements. Sampling locations from different studies were mapped at different scales and in some instances, sites were not mapped in a standard format, or were not produced on a map at all. Using GIS to compile the results of these studies allows the results to be housed in a uniform spatial orientation that is considerably easier to visually interpret,

Figure 1. VOC Concentrations in Nogales Wash



query, and/or update. Overlaying maquiladora locations and water quality results partially validates the hypothesis that VOC contaminants originate, in part, from maquiladora facilities in Mexico. However, further investigation is required in order to verify this.

Cancer rates for bone cancer, lupus, and multiple myeloma in Nogales, Arizona are five times the normal cancer rate according to the American Cancer Society (Hernandez 1993). Studies to examine elevated cancer rates are being undertaken by the Arizona Department of Health Services (ADHS) and by the Arizona Department of Environmental Quality (ADEQ) which is initiating air, water, and soil monitoring activities (Castenada 1994). Although there are no studies that correlate cancer rates and locations with known areas of groundwater contamination, GIS provides a framework to aid in analysis of such spatial relationships.

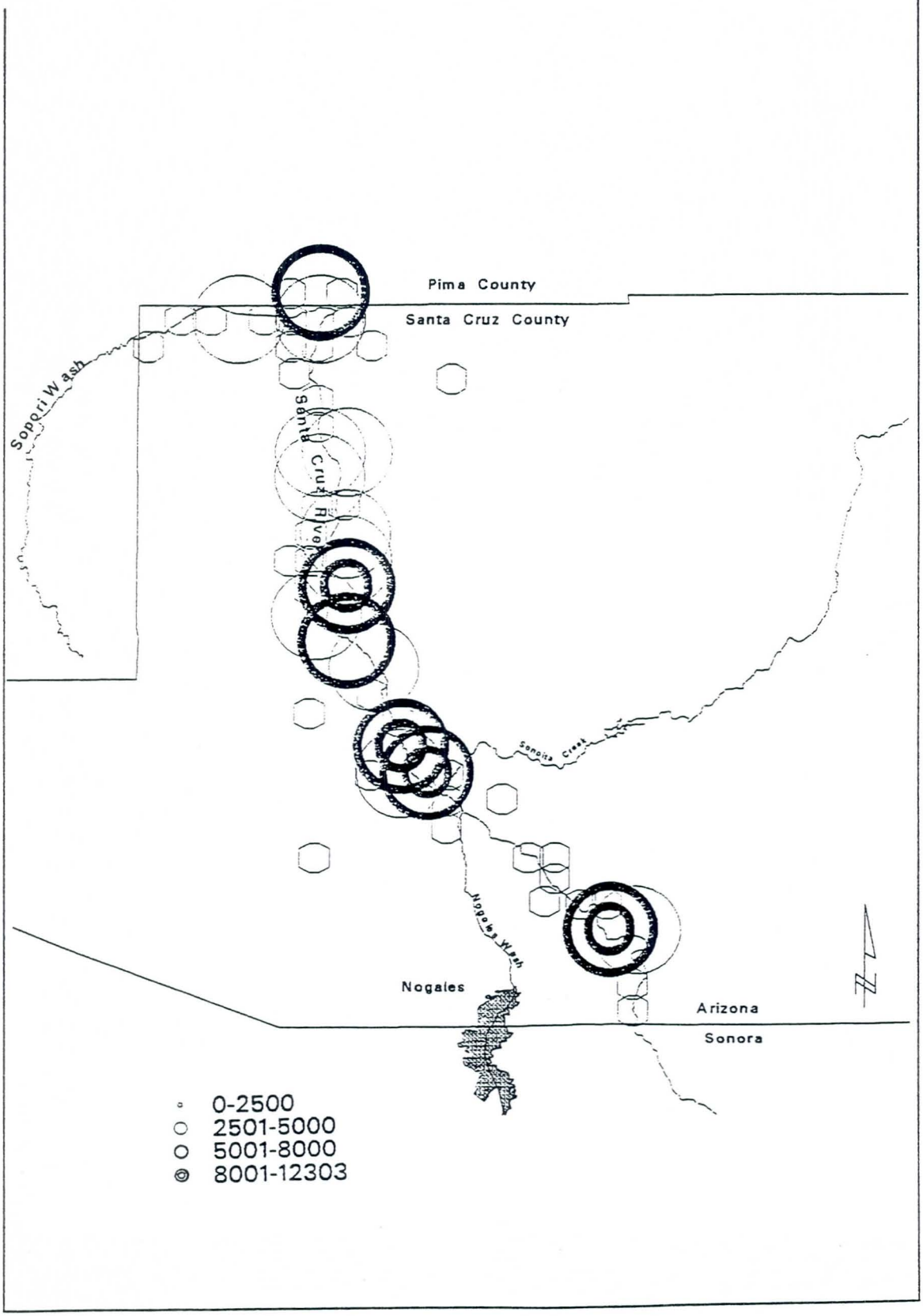
Attempts are being made to link water quality in the Santa Cruz River with land use; including agricultural, industrial, residential, tributary inputs, discharge rates, superficial geology, and riparian vegetation. By creating a land use index based on weighted scores for different land uses, it is possible to make predictions concerning water quality. For example, an area with much riparian vegetation and little industrial or agricultural use would receive a lower land use index rating and the hypothesis would be that non-point source pollution would be lower in this instance. Conversely, an area with little vegetation adjacent to paved areas would be given a higher index rating and correlate to greater non-point source pollution potential.

The database is being utilizing for a Nogales Wellhead Protection Program. The program was established under the Safe Drinking Water Act in order to protect groundwater that supplies public drinking water wells. Each state is required to develop a Wellhead Protection Program. ADEQ and CES are working cooperatively to provide technical assistance for the Nogales program. Databases from both facilities are being combined to provide the elements necessary to determine wellhead protection areas. Data for land use, leaking underground storage tanks, hazardous waste sites, and recharge areas will be used to aid the local community in determining wellhead protection areas and formulating land use recommendations to protect local drinking water supplies.

Water Quantity

Pumpage data for the U.S. side of the border, along with well locations and water levels over time have been mapped using GIS (Figure 2). This has allowed for areas of high pumpage to be determined, and for changes in groundwater levels, due to effluent recharge, to be mapped. By comparing areas of high pumpage and changes in groundwater levels, it is possible to speculate as to which areas might have historically been

Figure 2. Pumpage in Acre Feet, 1984-1991
Upper Santa Cruz River



cienegas or small wetlands because of consistently high groundwater levels, even in times of high pumpage. Rio Rico represents such an area.

The database lays part of the groundwork necessary for groundwater modeling analysis. The GIS software in use; Arc/Info, can be used as an interface with groundwater modeling software such as FEFLOW, a groundwater modeling program that is capable of estimating VOC movement in the aquifer. Groundwater modeling analyses can aid in predicting future impacts to groundwater quality.

In conjunction with examining riparian vegetation supported by effluent from the IWWTP, the GIS database has been used to spatially delineate types of riparian vegetation present, track changing well water depths, track land use changes over time, compare satellite imagery of vegetation density to groundwater pumpage, and delineate areas of high groundwater pumpage. The database is being used for a research project titled 'Development of Best Management Practices for Water and Riparian Resources Along the Santa Cruz Watershed, U.S./Mexico Border,' funded by SCERP. This research project is focused specifically on the relationships among water use (e.g. pumping), water quality (e.g. effluent) and riparian vegetation. GIS could help to plan optimal locations for future wells to reduce riparian degradation.

Complete well location, water level, and pumpage data for the Mexican side has not yet been obtained for the database. However, with the addition of this information it may be possible to create a water budget for the watershed, rather than for individual countries. In order to understand the hydrologic resource the cities of Ambos Nogales share, it is necessary to have complete and accurate hydrologic data. GIS provides a means through which to integrate information from both countries concerning water availability and use.

Water quality and quantity issues in Ambos Nogales are being summarized in a non-technical bilingual manual for a Border Environmental Action Team (BEAT) project, funded by the Southwest Center for Environmental Research and Policy (SCERP). The manual will use the GIS database to generate maps and will also provide a tool for general education purposes. The database also has the potential to be made available to the public through use of PC platform Windows compatible software.

CONCLUSION

GIS presents a unique format within which many different types of data, traditionally stored in different formats at different scales, can be joined together in a single format that is spatially referenced to real earth coordinates. This format allows faster, easier graphic display than has been

possible in the past and lends new meaning to the phrase 'a picture is worth a thousand words.'

Because two countries, two states, and two cities along with two sets of federal, state, and local agencies must manage hydrologic resources that know no political boundaries, it becomes important to work within a format that can provide easy data exchange, update and access. GIS provides this format.

ACKNOWLEDGMENTS

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INTEGRATION OF LANDSAT IMAGERY AND GIS FOR ENVIRONMENTAL APPLICATIONS IN THE SALT AND VERDE WATERSHED[1]

Michael H. George and Rebecca A. Ruckman[2]

ABSTRACT: The traditional approach to information flow between remote sensing and GIS has been unidirectional. Classified images are created in image analysis systems, then are moved into the GIS environment. GIS information is not typically used in image analysis. As the spectral and spatial resolution of image data increases, it is necessary to use additional ancillary data to improve product interpretation and accuracy. Toward this end, an ongoing project at Salt River Project to produce land use and surface geology classifications for the Salt and Verde River watersheds is using a modified methodology including digital elevation models and low resolution maps in image interpretation. The current results of this ongoing project are presented.

INTRODUCTION

Remote sensing is defined as the "collection and interpretation of information about an object without being in physical contact with the object" (Sabins, 1987). Remote sensors, carried by airplane or satellite, provide access to spatial information at scales previously impossible. Spatial resolution is continually improved with advances in remote sensing technology. For example, a Landsat 1 scene from the 1970's represents an area of approximately 34,000 square kilometers, with about 5,000,000 pixels (80m pixel size). Landsat 5, the most recent NASA satellite, produces

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a scene of the same area with an increased spatial resolution of 70,000,000 pixels (25m pixel size). In addition, spectral resolution has improved from 5 bands recorded by Landsat 1 to 7 bands by Landsat 5.

This increased detail is especially attractive because it provides improved tools for the analysis of the environment and anthropogenic activities. Increased spectral and spatial resolution, however, is not without its price. Not only is it necessary to upgrade computer system capabilities for processing the improved images, it is also imperative to formulate more rigorous methodologies for the analysis of digital imagery. Conventional image processing approaches based on trial-and-error and field verification will be inadequate for the complexity inherent in higher resolution data.

Geographic information systems (GIS) provide the capabilities necessary to address the methodological issues. GIS arose out of efforts by land managers to formalize the ways in which attributes of property were combined with spatial data. This approach of relating information to points, lines, or polygons on the earth's surface facilitates the combination of disparate, yet related, data (Dobson, 1993).

The interaction of remote sensing and GIS has most often been based on this traditional role of GIS as a data integrator. The raw digital files are processed and analyzed through the Image Analysis System (IAS) where a classified image is produced. The information is then brought into the GIS environment to be consolidated with the appropriate database. Walsh et al. (1990) discuss this situation as follows:

> Traditionally, the link between remotely sensed data and GIS has been perceived as unidirectional, with remote sensing data being used as an input into the GIS. The use of GIS thematic overlays as an aid in the interpretation of remotely sensed data is not widely utilized, though its application has great potential.

METHODOLOGIES

The aim of a pilot project at the Salt River Project (a water and power provider in Phoenix, Arizona) is to use digital imagery for large-scale data collection in creating ARC/INFO GIS raster and vector data sets of land use and surface geology for the Salt River and Verde River watersheds. This endeavor is intended to provide information to support a more holistic approach to watershed management, particularly water quality applications.

Traditional

Initially, the traditional approach to remote sensing and GIS integration was used. The steps in this approach are as follows:

1). Data selection/definition
After extensive evaluation, Landsat Thematic Mapper (TM) digital images have been selected as the primary data source, and, where available, aerial photos are to be used as ancillary information for verification. Four images were purchased to cover over 90% of the Salt and Verde River watersheds.

2). Digital preprocessing
The scenes were ordered map oriented, and the initial grid size has been retained. Atmospheric effects are deemed minimal. Non-watershed portions of each scene are removed before interpretation begins.

3). Select training sites
Spectrally homogenous areas are identified through analysis of true color composites and unsupervised classifications. A portion from each unique homogenous area is established as a training site. Statistics derived from the training sites over each band form a unique spectral signature which represents the land use or geology class. The site signatures (Fleming, 1988) are used to "train" the IAS to distinguish land use and geologic categories during the supervised classification. Supervised classifications have been completed for two of the scenes. 20 unique areas have been identified for the north scene and 27 for south scene.

4). Training site validation and assignment of class
Training sites are first compared with aerial photos and classes are assigned where possible. For training sites where questions remain, field checking is required. A total of twelve days of field work has been necessary to date for the two scenes.

5). Supervised classification and evaluation
A training file is then created and a supervised classification produced. This is again spot checked against aerial photos in areas that were not used for training sites. There are often anomalies that must be addressed. Urban areas are frequently troublesome, particularly in arid regions such as Arizona. They are often

misclassified as riparian as they are usually the only deciduous vegetation in the area. Most urban areas have been classified manually. The final products resulted in land use classifications with 13 categories.

6). Move to GIS
In this case, the data are moved to an ARC/INFO database where the images may be stored in digital (raster) format or converted to a vector format for additional applications.

Integrated

This traditional approach provides good products, however, concerns regarding the accuracy of the classification remain. Other techniques that are often used in image analysis with regard to land use, such as principal components analysis, have been considered to address this issue. Principal component analysis can improve the supervised classification stage, however, to achieve greater accuracy, fundamental changes to the traditional methodology are necessary. Incorporation of available resources, particularly through GIS, should improve image interpretation by better training site selection, reducing field work, and aiding quality control of the classifications. The modified procedure is as follows:

1). Data selection/definition
This process must now include geographic information. For this project digital elevation models (DEM) and a 1:375000 classification is used.

2). Digital preprocessing
There is no change to this phase.

3). Registration of GIS data to image
It is necessary to register the image to the GIS coverages. This is done for this project in ARC/INFO.

4). Select training sites
Additional ancillary information can be useful in this task when the landscape is quite heterogeneous. The DEM have been particularly useful in this work since the watershed is mountainous and slope, aspect, and elevation effects combine to create an often complex vegetative situation.

5). Training site validation and assignment of class
It is possible to lessen the amount of field checking substantially with the utilization of additional information. The ability to interpret a class based on terrain, as well as the previous classification effort should result in more positive identifications

6). Supervised classification and analysis
Once again areas not designated as training sites are compared to the ancillary data. The integration of image data with GIS now allows such analysis to be automated, and thus much more comprehensive and rigorous. Boolean operators are used in ARC/INFO's GRID to pinpoint classification anomalies associated with terrain.

CONCLUSION

In conclusion, although this modified approach to image processing and analysis is still in its early stages, it is felt that it will produce a better product in less time once it is fully developed and tested. This increase in efficiency can be further improved as this methodology is designed to allow automation of the process.

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INTEGRATION OF A GIS SYSTEM AND MODFLOW TO HELP ARIZONA'S UNDER UTILIZATION OF CENTRAL ARIZONA PROJECT CANAL WATER[1]

by
Bradley M. Hill, R.G., Frank G. Putman and James E. Swanson[2]

ABSTRACT: The U.S. Bureau of Reclamation and Arizona Department of Water Resources entered into a cooperative project to identify areas within the Phoenix metropolitan area to potentially recharge Central Arizona Project canal water. These areas might correspond to locations where excessive groundwater declines are predicted to exist in the future. A Geographic Information System (GIS) was integrated with a MODFLOW groundwater flow model to better simulate hydrologic conditions into the future. The GIS was used to take advantage of detailed water use and supply data to more accurately calculate critical components of groundwater inflow than was available in the past. The MODFLOW model predicted several regions within the Phoenix metropolitan area that may develop excessive groundwater level declines by the year 2025.

INTRODUCTION

The State of Arizona is at risk of losing a portion of its Colorado River entitlement to the neighboring states of Nevada and California because of the under utilization of this renewable water resource. Many municipalities within the Phoenix metropolitan area do not use their full Central Arizona Project (CAP) water entitlement. The U.S. Bureau of Reclamation and Arizona Department of Water Resources (ADWR) entered into a cooperative project to identify areas within the Phoenix metropolitan area to potentially recharge CAP water utilizing a MODFLOW groundwater flow model developed by Corell and Corkhill (1994). These recharge areas might correspond to locations where the model projects areas of excessive groundwater declines.

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1. Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994

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The model was used to simulate hydrologic conditions between 1995 and 2025 with projections of population, water use and supply, and other hydrologic inputs estimated at 5-year intervals (eg., 1995, 2000, etc). The year 1991 was selected as a base year from which to make projections since sufficient data exists for that year. A Geographic Information System (GIS) was used to track the number of agricultural acres, water applied to those acres, population projections, municipal water demand and potential water supply sources to satisfy this demand.

PURPOSE AND OBJECTIVE

The purpose of the cooperative project is to develop a future prediction of hydrologic conditions within the Salt River Valley (SRV) and identify areas where excessive groundwater declines might exist. To accomplish this the project takes advantage of detailed water use and supply data that are reported to the ADWR by utilizing a GIS and integrating these data with a numerical MODFLOW model (McDonald and Harbaugh, 1988).

Important objectives of the project were to develop a realistic estimation of deep percolation recharge from irrigated agriculture and develop the ability to track projected urban growth, water demand and the various sources of water supply. The goal of the project is to evaluate each alternative management action identified and determine which would be best in alleviating potential groundwater declines.

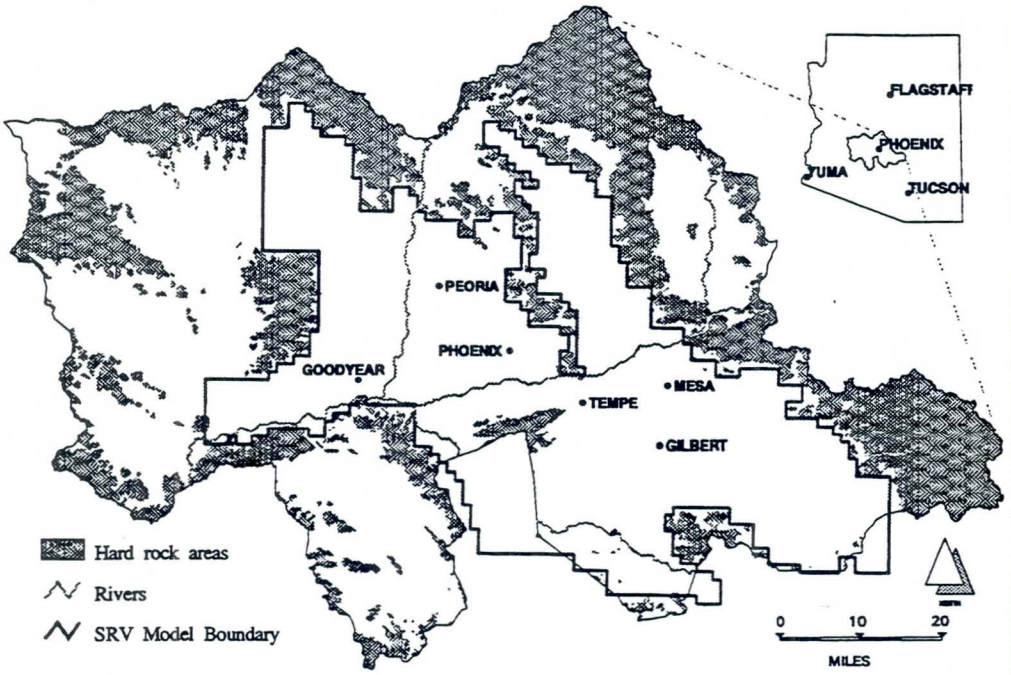
OVERVIEW OF SALT RIVER VALLEY NUMERICAL MODEL

The Salt River Valley lies within the central portion of Arizona and incorporates all of metropolitan Phoenix's population of 2.2 million (Figure 1). The Phoenix metropolitan area is subjected to intensive groundwater management by the ADWR due to the historical high levels of groundwater pumping. The climate of the SRV is semi-arid with hot summers, mild winters and an average annual precipitation of 7 inches (ADWR, 1991). The Salt River Valley is drained by three major streams - the Salt, Gila and Agua Fria Rivers. However, these rivers now only flow in response to precipitation or releases from upstream dams.

The Salt River Valley model was developed to provide an analytical tool capable of quantifying the effects of various groundwater management and conservation scenarios on the groundwater supplies within the study area. The modeled portion of the Salt River Valley is 2,240 square-miles in area (Figure 1). The model was calibrated for both steady-state and transient-state conditions. Pre-development steady-state conditions were calibrated and are representative of hydrologic conditions circa 1900. Transient-state

Figure 1

GENERAL LOCATION OF THE SRV MODEL



hydrologic conditions were calibrated between 1983 and 1991 since there were sufficient data available for this time period.

The SRV model is comprised of equi-dimensional model cells one mile in length and width totaling 62 rows and 90 columns with three layers. Model boundaries were simulated as constant flux to simulate groundwater underflow into the model and as constant head cells to simulate underflow out of the model.

Three model layers were used to represent the three hydrogeologic units that have been identified within the Salt River Valley. The uppermost layer, Layer 1, corresponds to the Upper Alluvial Unit (UAU) and is modeled as an unconfined aquifer. The middle layer, Layer 2, corresponds to the Middle Alluvial Unit (MAU) and is modeled as a confined/unconfined aquifer. The lowermost layer, Layer 3, corresponds to the Lower Alluvial Unit (LAU) and is also modeled as a confined/unconfined aquifer. The thickness of each model layer is defined by the elevation of each hydrogeologic unit contact.

Model Inflows and Outflows

Recharge represents the major inflow to the modern groundwater system in the Salt River Valley. The sources of recharge identified and simulated in the model include deep percolation of agricultural irrigation and urban flood irrigation, seepage from canals

and artificial lakes, treated effluent discharged into river channels, artificial recharge, and naturally occurring recharge from flood flows along the major drainages and along mountain fronts and groundwater underflow from adjacent basins.

The greatest recharge to the groundwater system is from irrigated agriculture. Approximately 212,000 acres were under cultivation using 900,000 acre-feet of water within the Salt River Valley in 1991 (ADWR, 1994). Estimating recharge from agricultural irrigation is very important in the success of predicting future hydrologic conditions.

Outflows from the groundwater system that were identified and simulated include groundwater pumpage, evapotranspiration from phreatophytes, groundwater discharge to rivers and underflow out of the basin. The greatest outflow from the groundwater system is from pumpage. Approximately 950,000 acre-feet of pumpage in the SRV was reported to the ADWR in 1991.

USE OF A GEOGRAPHIC INFORMATION SYSTEM

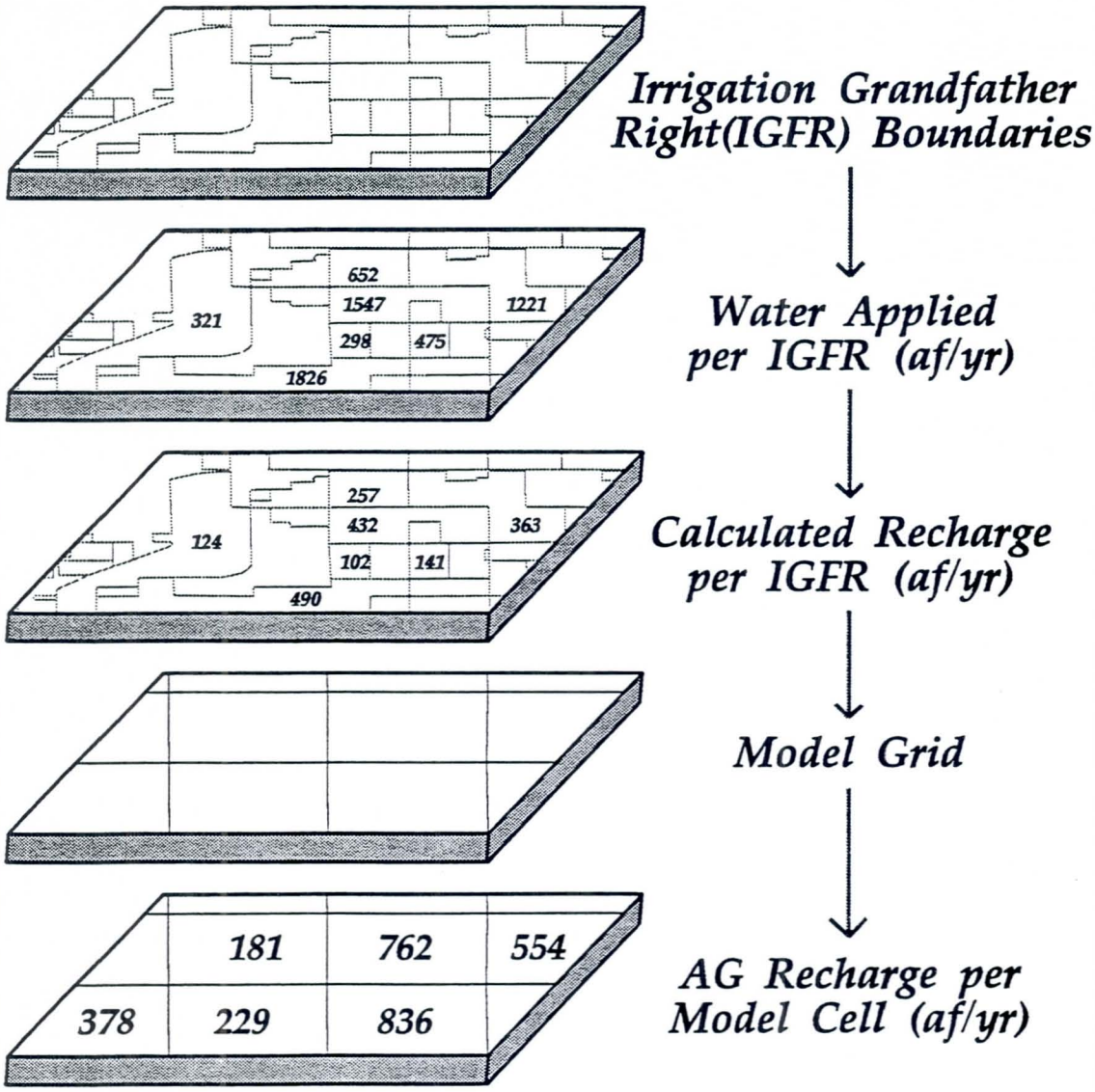
The Geographic Information System (GIS) ARC-INFO was used to achieve four primary objectives. First, the GIS was used to take advantage of detailed data reported to the ADWR to better estimate recharge from agricultural irrigation for the base year of 1991. Second, the GIS was used to estimate future agricultural water demand and groundwater recharge based upon population projections. Thirdly, the GIS was used to identify agricultural wells and subsequently remove them from future simulations as these cultivated lands become urbanized. Finally, the GIS was used to estimate future municipal water demand based upon population projections and to track the various sources of water supplies used to satisfy the municipal demand. Linkage of these different data by their geographic location is vital to the success of the modeling effort.

Figure 2 illustrates conceptually how the GIS system links the different data from various GIS "covers" with the MODFLOW model grid. The example presented represents the spatial correlation of estimating recharge from deep percolation of agricultural irrigation.

Recharge from non-Indian agricultural irrigation was estimated for 1991 using actual farm boundaries and reported water applied to each farm. Each farm is spatially identified by their Irrigation Grandfathered Right (IGFR) boundary and each IGFR is required to report their total annual water use to the ADWR. The GIS permitted the spatial correlation of each IGFR boundary with the groundwater flow model grid. This allowed for a more accurate distribution of water applied for agricultural purposes throughout the SRV model domain than was possible in the past. This information was then coupled with historic farm efficiencies, estimated farmed acres, and crop consumptive use for each IGFR. Deep percolation recharge from agricultural irrigation for each IGFR was calculated by subtracting the annual water use from the total estimated annual crop consumptive use. Recharge for each IGFR was then linked spatially to each

Figure 2

GIS Covers Used to Calculate Recharge From AG Irrigation



model cell to derive the total recharge used within the MODFLOW groundwater flow model. Deep percolation recharge for 1991 from non-Indian agricultural irrigation for the entire SRV was estimated at approximately 324,000 acre-feet.

The GIS was then used to estimate future agricultural recharge dependant upon urbanization projections. Population projections for each 5-year interval (eg., 1995, 2000, etc) were provided by the Maricopa County Association of Governments and are the official estimates for the Salt River Valley. It was assumed that an area was urbanized if the area had a projected housing density greater than one house per acre. The GIS was used to link these urbanization projections with IGFR boundaries to determine when an agricultural area was projected to convert to urban uses. Recharge estimated for those IGFRs that were projected to convert to urban uses was subsequently removed from future simulations. Recharge from the remaining IGFRs was calculated for each 5-year interval using the assumption that water applied, crop mixture grown and farm efficiencies for each IGFR would remain constant at 1991 levels. The GIS then linked these remaining agricultural areas with the groundwater flow model grid deriving at a new distribution of recharge per model cell. This methodology allowed for the spatial reduction of deep percolation recharge from agricultural irrigation due to urbanization projections. Recharge was estimated to be reduced approximately 53% by the year 2025 to 212,000 acre-feet.

In conjunction with urbanization, wells that provide groundwater for agricultural purposes needed to be removed from future simulations. The GIS was used to link the IGFR boundaries with the spatial location of each well within the model domain. Pumpage from an agricultural well was removed from future simulations if the well was located within an IGFR boundary that was projected to convert to urban uses. This methodology permitted the parallel reduction of groundwater pumpage due to the urbanization of agricultural lands throughout the model domain. Groundwater pumpage for agricultural purposes was estimated to be reduced by 190,000 acre-feet in 2025.

The last application of GIS was to track future municipal water demand and supply sources based upon population projections and supply source assumptions. Municipal water demand for 1991 was calculated based upon the actual reported water used for each city within the Salt River Valley. A gallons per capita per day (GPCD) value for each city was calculated to determine future water demand based upon the population projections. The GPCD for 1991 was calculated for each city by dividing the total annual reported water use of that city by its total population. Total future water demand for each 5-year interval was then calculated by multiplying the 1991 GPCD for each city by their projected population. The GIS was then used to track the growth of municipal water demand throughout the model domain. Total municipal water demand was predicted to increase by 52% by the year 2025 from 566,000 acre-feet in 1991 to approximately 1.2 million acre-feet in 2025.

In conjunction with the growth in water demand is the need to track the source of the water to satisfy the new demand. ADWR planners identified 32 zones within the Salt River Valley that delineated spatially which type of water source (eg., groundwater, surface water, or Central Arizona Project canal water) would be supplied to those areas in the future. Future municipal groundwater demand was estimated to increase by

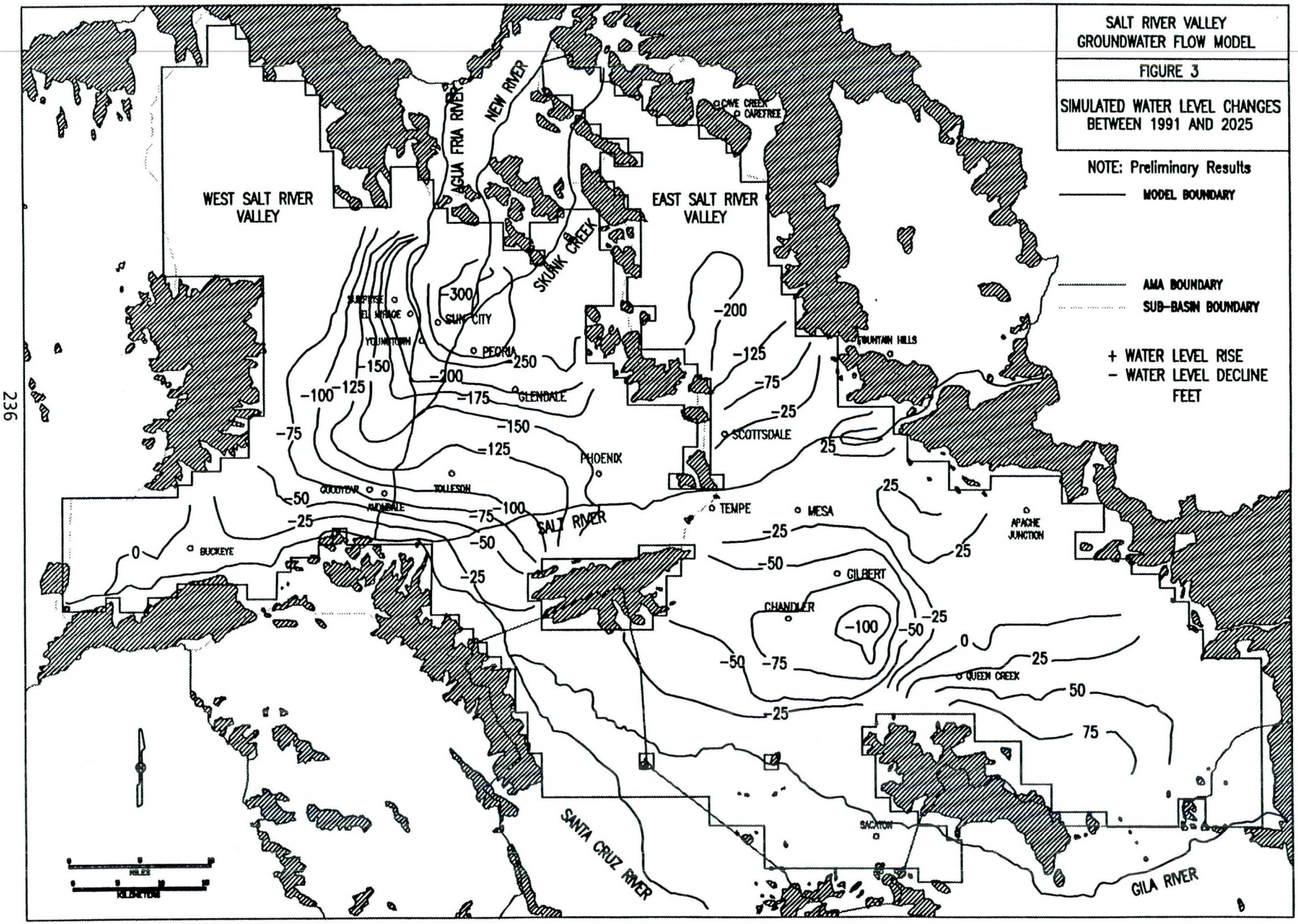
494,000 acre-feet by 2025. This new demand was linked by the GIS with the groundwater flow model grid and then simulated in the model as new pumpage. The ability to track the different sources of water along with the projected water demand is critical to ensure future water demand and supply projections are reasonable.

MODFLOW RESULTS FOR PREDICTING GROUNDWATER CONDITIONS IN THE SALT RIVER VALLEY

The MODFLOW model predicted extensive water level declines throughout most of the Salt River Valley. Figure 3 illustrates the simulated water level changes between 1991 and 2025. The greatest declines were predicted to occur within the northern portion of the West SRV and southeastern portion of the East SRV (Figure 3). These declines can be attributed to several factors including increased groundwater pumpage due to increased municipal water demand and decreased recharge from agricultural irrigation due to the urbanization of cultivated lands.

IDENTIFICATION OF FUTURE MANAGEMENT ALTERNATIVES

The projected groundwater level changes between 1991 and 2025 indicate a maximum water decline rate of over 8 feet/year within the western portion of the SRV. The ADWR and U.S. Bureau of Reclamation are currently studying water resource management alternatives in an attempt to alleviate these projected water level decline problems. One water resource management alternative might be to increase the use of Central Arizona Project canal (CAP) water. To minimize these water level declines, CAP canal water could be used directly or artificially recharged since many cities within the West SRV presently do not utilize their full entitlement of CAP canal water. Direct use would benefit the hydrologic system by decreasing the regions reliance on groundwater as a source of water. However, insufficient infrastructure currently exists in the West SRV to transport the water from the canal to each city's water distribution system. Artificially recharging CAP water would benefit the hydrologic system in the vicinity where the cities currently pump groundwater. This alternative looks favorable since the canal is only a few miles to the north of most West SRV cities, permeable sediments exist in the nearby Agua Fria River and aquifer storage space exists since the depth to water is several hundred feet below land surface.


SALT RIVER VALLEY
GROUNDWATER FLOW MODEL
FIGURE 3
SIMULATED WATER LEVEL CHANGES
BETWEEN 1991 AND 2025
NOTE: Preliminary Results
MODEL BOUNDARY
AMA BOUNDARY
SUB-BASIN BOUNDARY
+ WATER LEVEL RISE
- WATER LEVEL DECLINE
FEET
WEST SALT RIVER VALLEY
EAST SALT RIVER VALLEY
AGUA FRIA RIVER
NEW RIVER
SKUNK CREEK
SALT RIVER
SANTA CRUZ RIVER
GILA RIVER
CAVE CREEK
CAREFREE
SUN CITY
PEORIA
GLENDALE
PHOENIX
SCOTTSDALE
TEMPE
MESA
GILBERT
CHANDLER
QUEEN CREEK
APACHE JUNCTION
FOUNTAIN HILLS
GOODYEAR
AVONDALE
TOLLESON
BUCKEYE
SACATON
-300
-200
-125
-75
-25
25
50
75
-100
-150
-175
250
0

CONCLUSION

The integration of a Geographic Information System (GIS) system and MODFLOW proved to be successful in developing a realistic prediction of hydrologic conditions within the Salt River Valley (SRV) between 1995 and 2025. The GIS permitted the ability to analyze detailed data that are reported to the ADWR and more effectively estimate than was possible in the past the spatial distribution of projected water demand and supply, and deep percolation recharge from irrigated agriculture.

The results of the MODFLOW model indicated that excessive groundwater declines may exist in certain locations within the SRV by 2025. One management alternative to alleviating this potential problem is the direct or indirect use of Central Arizona Project canal water.

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POSTER PRESENTATIONS

RECHARGE AND MIXING IN GROUND WATER ALONG THE LOWER SALT RIVER[1]

Eric J. Zugay[2]

ABSTRACT: Recharge and mixing in ground water, via intermittent flows along the 70 km lower Salt River, have transformed the flow and chemical composition of the multi-layer aquifer system in the Salt River Valley, especially in areas within 5 km of the river. As seen in cross-sectional view, the accretion of Salt River water onto the water table has caused the formation of semi-elliptical equipotential lines about the water table, with hydraulic head decreasing horizontally and vertically away from the Salt River. When the lower Salt River is not flowing, that recharge signature is not necessarily present below the Salt River.

The ground-water flow direction in the multi-layer aquifer system does not necessarily coincide with the hydraulic gradient, since significant anisotropy exists within each layer and between layers. Since field measurements of hydraulic conductivity tensors are few, it is sometimes difficult to estimate the direction of ground-water flow based only on hydraulic gradient. In some cases, the flow direction can be estimated or verified with chemical tracers. Salt River water is a potential tracer, since its chemical composition locally differs from that of ground water. The spatial and temporal distribution of dissolved species in the aquifer have represented, to some extent, the effects of advection and mixing of Salt River water into the aquifer. The flow of that mixture through the aquifer has been mostly horizontal, even though the vertical hydraulic gradient has been locally much larger than the horizontal gradient.

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]Eric J. Zugay is a master's degree candidate in the Department of Hydrology & Water Resources at the University of Arizona, Tucson.

INTRODUCTION

The lower Salt River, formerly a perennial stream and located within metropolitan Phoenix, Arizona, has been transformed by water reclamation projects into an ephemeral stream. Streamflow is regulated by seven dams on the Salt River and its tributary, the Verde River. Pulsed episodes of surface to ground-water recharge have occurred as floodwaters were released past the penultimate dam (Granite Reef Dam) of the upper Salt River. Due to both climatic and water management controls, the annual release into the lower Salt River since 1978 has varied from 0.2 to 5090 million cubic meters (MCM). For about 75 percent of the time from 1978 to 1993, there was little or no water in most of the lower Salt River.

When surface-water is released to the riverbed, it percolates through the undersaturated zone below the riverbed and accretes onto the water table. Eventually, this recharged water spreads laterally and vertically and mixes with the older ground water. This process affects the flow and chemical composition of the ground water.

PURPOSE

Each release of pristine surface water into the lower Salt River has significant consequences for metropolitan Phoenix, since ground-water contamination is an important issue in areas near the Salt River. Within 5,700 meters of the lower Salt River, the aquifers beneath fifteen state-regulated sites and five federal-regulated sites are locally contaminated with compounds derived from solvents, fuels, waste oils, metals, pesticides, landfill materials, and other sources.

Recharge and mixing in ground water along the lower Salt River is pertinent to those sites because it affects:

- the direction and magnitude of the flow of contaminants in ground water
- the positions of aqueous contaminant plumes and efforts to define their extents

- efforts to determine the sources of ground-water contamination
- the rising of the water table and its contacts with contaminants in the unsaturated zone
- the temperature, pH, and ionic strength of the ground water, as well as the solubilities of dissolved compounds
- the dilution and spreading of contaminants in ground water

OBJECTIVES

Measurements and samples taken at wells have provided abundant hydraulic head and inorganic chemistry information since 1978. That information has been organized and used during this project to study the flow of ground water in more detail than was previously possible. The objectives of this project are to provide the following observations and interpretations:

- estimate the hydraulic gradient matrices in selected areas and provide the statistical uncertainties of those estimates
- determine ground-water flowpaths based on hydraulic gradient matrices; qualify those determinations with evidence provided by changes in the inorganic chemistry of ground water in depth-specific wells
- simulate chemical reactions and mixing along selected ground-water flowpaths
- examine the stratigraphy and the measured hydraulic properties of the aquifer matrix; qualitatively explain the nature of ground-water flow in the context of those aquifer properties

PRELIMINARY RESULTS AND DISCUSSION

The area between Granite Reef Dam and the Salt and Gila confluence has been investigated to meet the objectives of this project (See Figure 1). Over 22,000 monthly hydraulic head values, measured at wells within the study area from 1978 to 1994, have been organized into an electronic database for this project. The majority of those measurements were conducted from 1987 to 1993.

From January to April, 1992, 927 MCM of water were released past Granite Reef Dam. Although nearly 20% of that release was recharged and evaporated in the 29 km Salt River stretch leading up to the Salt and Indian Bend Wash confluence, the effects on ground water beneath that confluence were dramatic.

Figure 2 shows the hydrologic conditions in cross-sectional view across the Salt River, prior to the 1992 release. An unsaturated zone was present beneath the dry riverbed. A downward vertical hydraulic gradient was ubiquitous across the three main layers of the aquifer, i.e. the Upper Alluvial Unit (UAU), the Middle Alluvial Unit (MAU), and the Lower Alluvial Unit (LAU). The vertical gradient was largest across the MAU, which is the finest-grained layer, composed mostly of sandy clayey silt.

Figure 3 shows the effects of surface to ground-water recharge during the fourth month of the Salt River release in April, 1992. A saturated zone, at least 15 meters thick, developed above the initial water table as recharged water accreted onto the water table below the Salt River; the saturation status of the 5 meter zone below the Salt River during April, 1992 is not known. The accreted zone thinned laterally away from the Salt River; its thickness approached zero at a distance of 2 to 3 km north of the Salt River.

In cross-sectional view, the equipotential lines after four months of Salt River flow appear as semi-ellipses about the water table, centered below the point of recharge at the Salt River. Those semi-elliptical equipotential lines occurred mostly in the upper part of the MAU, and disappeared at approximately the same horizontal extent as the accreted zone. The increase in MAU hydraulic head during the 1992 release, as represented by the semi-elliptical equipotential lines, was probably induced as the UAU

applied greater stress on the MAU (the accretion process increased the saturated thickness of the UAU).

Hydraulic head measurements from a cluster of wells, located approximately 3 km north of the Salt River near Indian Bend Wash, have been selected to study the effect of ground-water recharge on the hydraulic gradient. Figure 4 shows the changes in the horizontal hydraulic gradient from 1987 to 1993 at the water table, i.e. in the UAU. In general, ground-water flowed more northerly and at greater gradients in response to Salt River releases from March, 1991 to May, 1993. Those responses usually occurred 2 to 3 months after the beginning of the Salt River releases. Figure 5 shows that the horizontal hydraulic gradient of the upper part of the MAU was probably not significantly affected by those Salt River releases.

The vertical hydraulic gradient from the water table to the upper part of the MAU decreased markedly during Salt River releases, as shown in the uppermost panel of Figure 6. That decrease may be caused by at least two different processes. First, the stress applied on the MAU by the accreted portion of the UAU not only increased pore water pressure in the MAU below the river, but probably also in the laterally outward portions of the MAU. That process would increase hydraulic head in the outer portions of the MAU to a level closer to that of the water table, thereby diminishing the vertical hydraulic gradient. Second, as the accreted portion of the UAU below the river pushed laterally outwards, ground water in the outer portions of the UAU may have had a greater tendency to flow horizontally. Vertical components of the gradient from the UAU to the upper part of the MAU may have been diminished during this second process.

Some uncertainties about the direction and magnitude of ground-water flow should be alleviated by comparing the chemistry of Salt River water to that of the older ground water. Preliminary evaluation of chemical distributions has failed to provide conclusive evidence about ground-water movement, because measurements of chloride and other inorganic parameters from ground water samples are too infrequent. As such, primarily hydraulic gradient information will be used in the determination of ground-water flowpaths; chemistry information will be used to confirm or confute those determinations.

Recharge and mixing in ground water along the lower Salt River has proven to be a measurable process. The formation of an accreted zone and semi-elliptical equipotential lines about the water table are conclusive indicators of recharge below the Salt River. Hydraulic gradient matrices have provided clues about the flow of accreted water and its mixtures with older ground water. Work on flowpath determination and mixing along flowpaths will continue through the end of 1994. Completion of this project is expected in January, 1995.

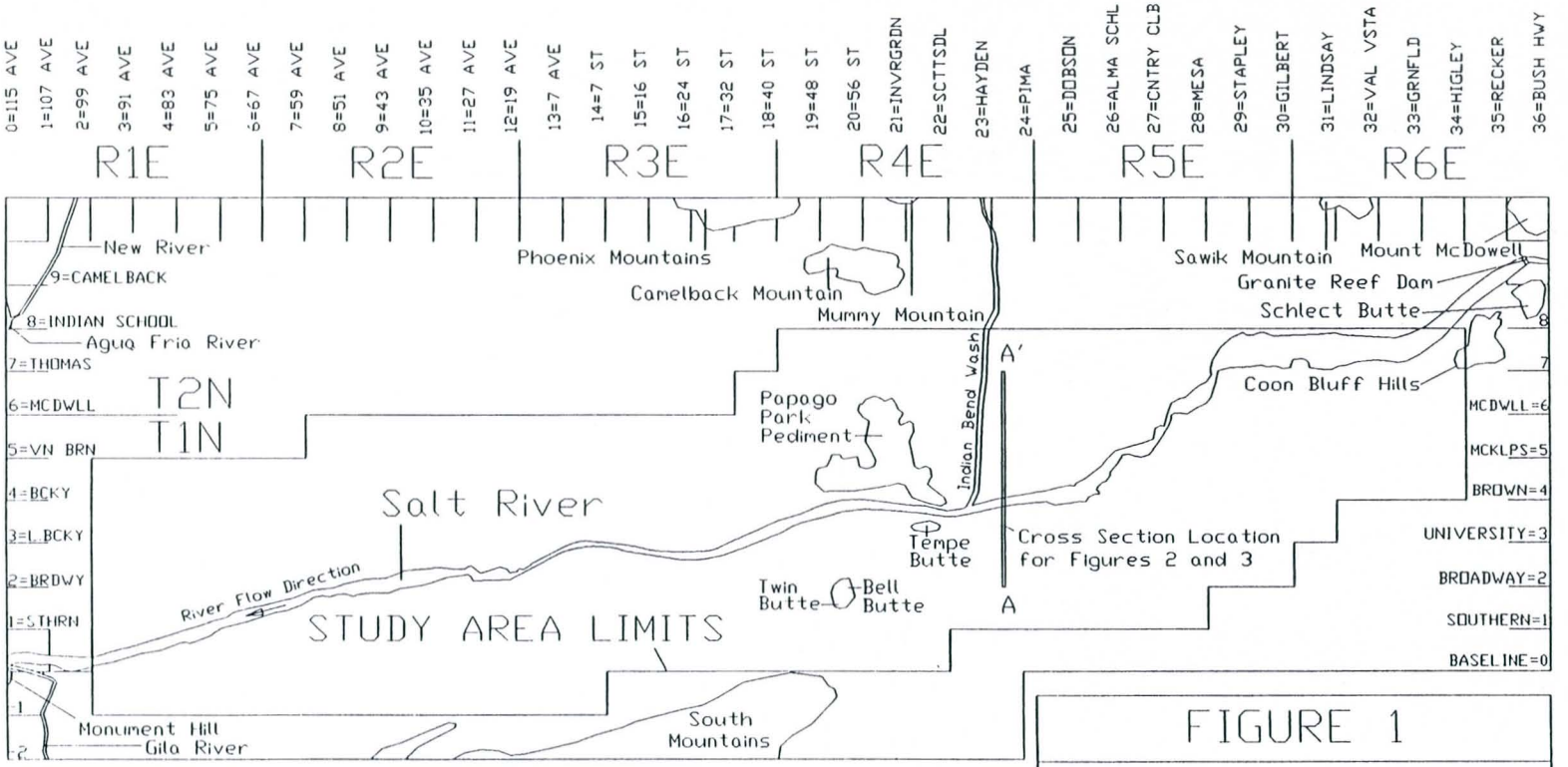


FIGURE 1

STUDY AREA

September, 1994 | Eric J. Zugay

APPROXIMATE SCALE

5 4 3 2 1 0 5 KILOMETERS

3 2 1 0 3 MILES

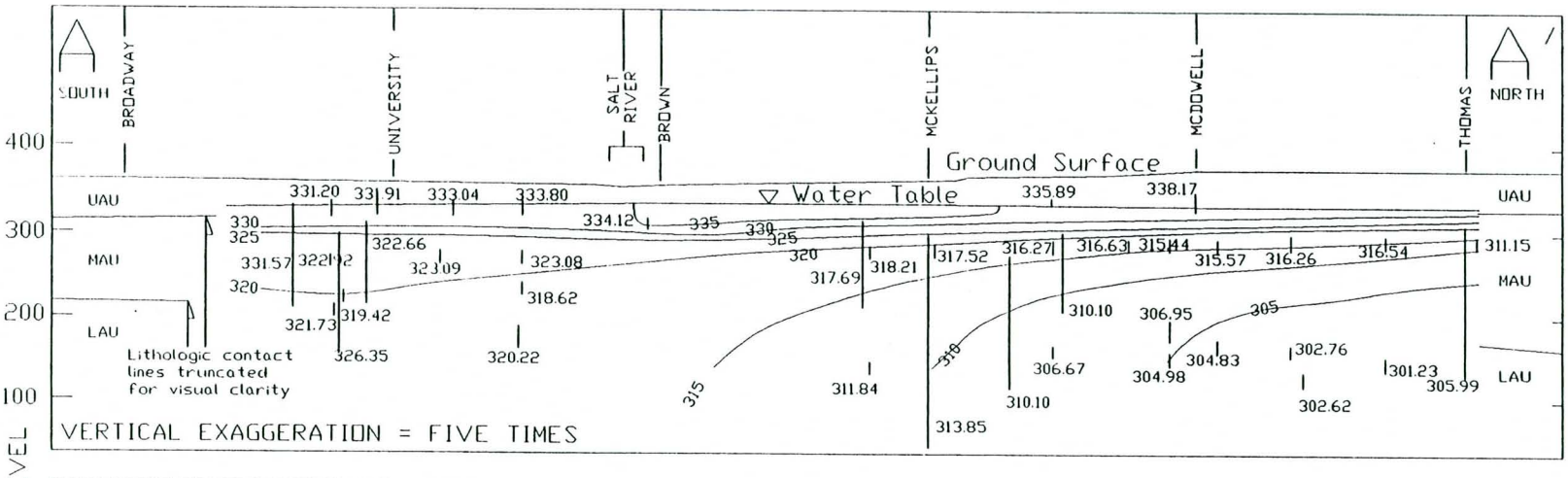
NORTH

LEGEND

R6E	Range 6 East (Cadastral coordinates notation)
T1N	Township 1 North (Cadastral coordinates notation)
0=115 AVE	Cartesian coordinate and abbreviated street name

CAPTION

The study area is located within the Phoenix, Arizona metropolitan area and generally encompasses 6 km on each side of the lower part of the Salt River. The lower part of the Salt River generally refers to the stretch from Granite Reef Dam to the Salt and Gila confluence.



LEGEND

315 Equipotential Lines in Contour Intervals of Five Meters

320.22 Location of Screened Interval and Hydraulic Head Measurement

UAU Upper Alluvial Unit

MAU Middle Alluvial Unit

LAU Lower Alluvial Unit

CAPTION

This cross section represents the hydrogeologic conditions prior to a Salt River release that began in January, 1992. Refer to Figure 1 for the location of the cross-section line. Most of the plotted wells are located within 250 meters of the cross-section line; some of the wells with screened intervals greater than 35 meters are located greater than 250 meters from the cross-section line. The depth-specific wells with screened intervals less than 35 meters were used to contour the hydraulic head measurements.

FIGURE 2

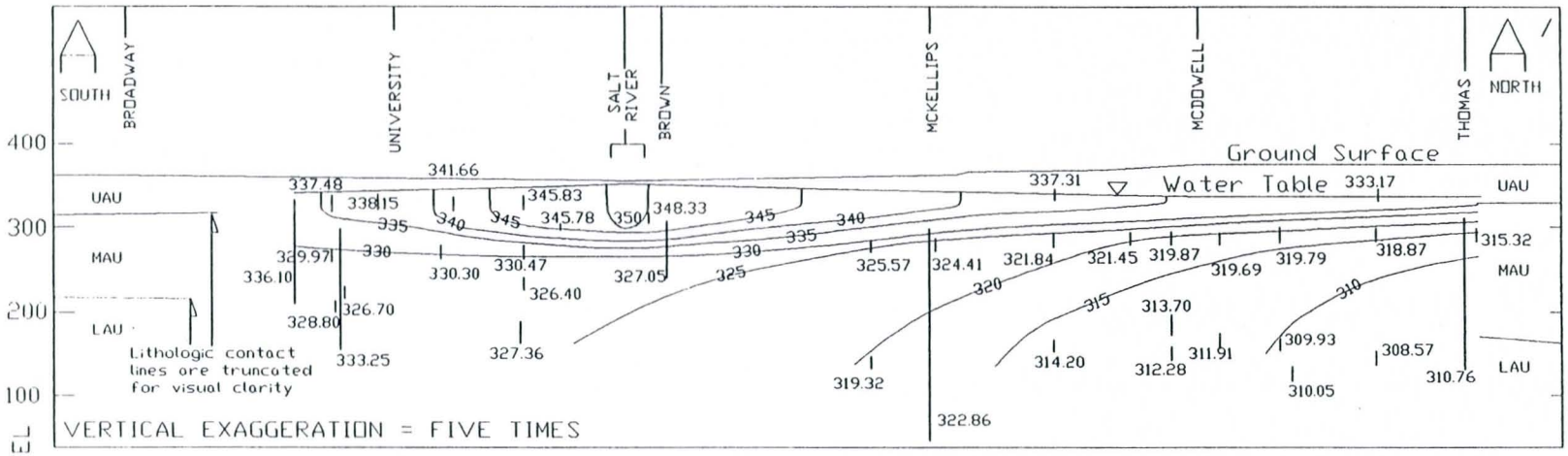
NOVEMBER, 1991 HYDROLOGIC CROSS SECTION

September, 1994 | Eric J. Zugay

APPROXIMATE HORIZONTAL SCALE

1000 500 0 1000 METERS

4000 2000 0 4000 FEET



LEGEND

315 Equipotential Lines in Contour Intervals of Five Meters

320.22 Location of Screened Interval and Hydraulic Head Measurement

UAU Upper Alluvial Unit

MAU Middle Alluvial Unit

LAU Lower Alluvial Unit

CAPTION

This cross section represents the hydrogeologic conditions during a Salt River release that began in January, 1992. Refer to Figure 1 for the location of the cross-section line. Most of the plotted wells are located within 250 meters of the cross-section line; some of the wells with screened intervals greater than 35 meters are located greater than 250 meters from the cross-section line. The depth-specific wells with screened intervals less than 35 meters were used to contour the hydraulic head measurements.

FIGURE 3

APRIL, 1992 HYDROLOGIC CROSS SECTION

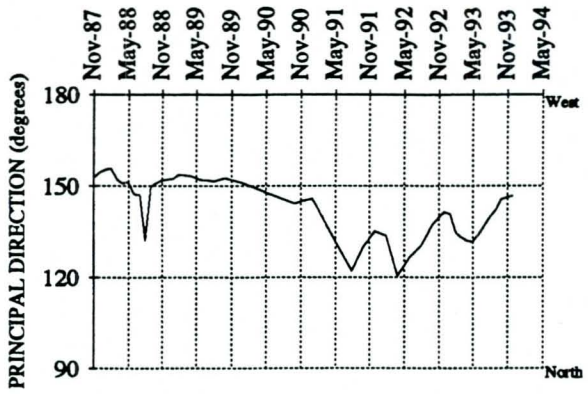
September, 1994 | Eric J. Zugay

APPROXIMATE HORIZONTAL SCALE

1000 500 0 1000 METERS

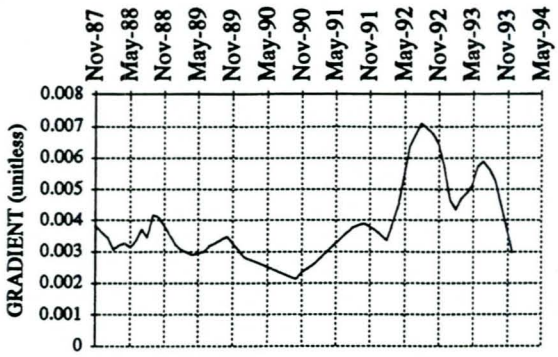
4000 2000 0 4000 FEET

FIGURE 4. HORIZONTAL HYDRAULIC GRADIENT FOR 3 WELLS SCREENED NEAR AN ELEVATION HEAD OF 335 METERS ABOVE MEAN SEA LEVEL (UAU), NORTH INDIAN BEND WASH STUDY AREA, APPROXIMATELY 3 KILOMETERS NORTH OF SALT RIVER



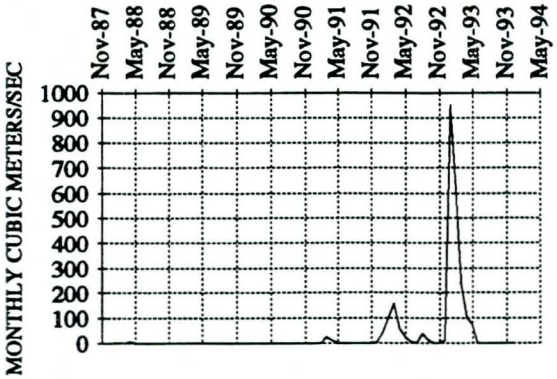
PRINCIPAL DIRECTION OF HORIZONTAL HYDRAULIC GRADIENT

	Degrees counter-clockwise from east
Mean	143
Geometric Mean	143
Median	146
Standard Deviation	10
Maximum	156
Minimum	120



MAGNITUDE OF HORIZONTAL HYDRAULIC GRADIENT (ALIGNED WITH PRINCIPAL DIRECTION OF HORIZONTAL GRADIENT)

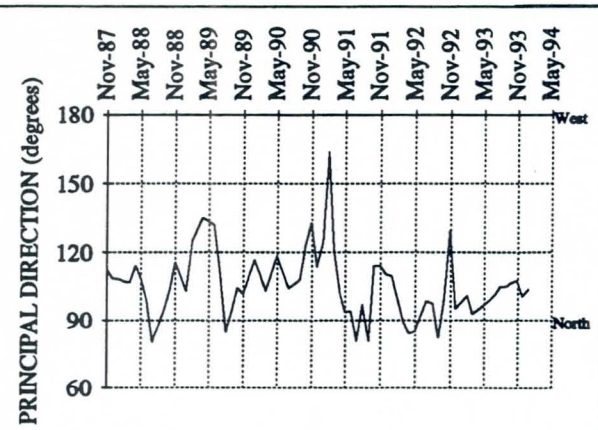
	Unitless
Mean	0.00407
Geometric Mean	0.00391
Median	0.00371
Standard Deviation	0.00123
Maximum	0.00709
Minimum	0.00212



SALT RIVER FLOW PAST GRANITE REEF DAM AND DRAINS (AVERAGE CUBIC METERS PER SECOND FOR EACH MONTH)

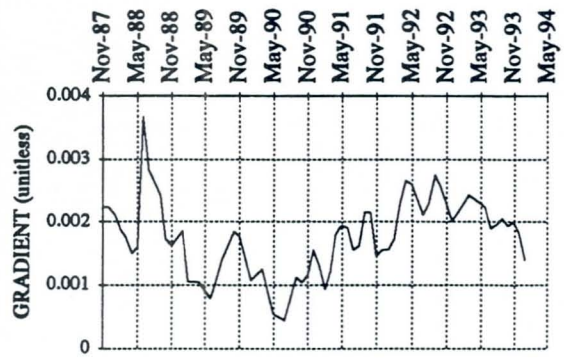
	Cubic meters/sec
Mean	33.2
Median	0.0566
Standard Deviation	133
Maximum	950
Minimum	0

FIGURE 5. HORIZONTAL HYDRAULIC GRADIENT FOR 3 WELLS SCREENED NEAR AN ELEVATION HEAD OF 285 METERS ABOVE MEAN SEA LEVEL (MAU), NORTH INDIAN BEND WASH STUDY AREA, APPROXIMATELY 3 KILOMETERS NORTH OF SALT RIVER



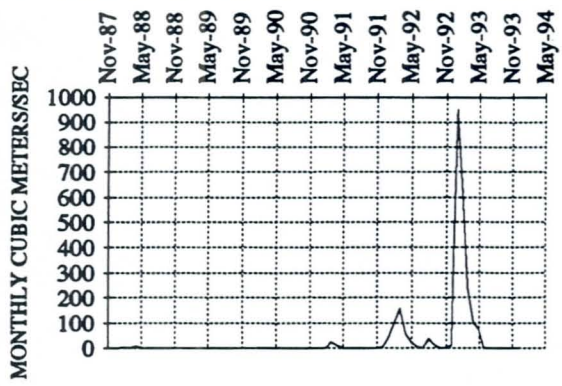
PRINCIPAL DIRECTION OF HORIZONTAL HYDRAULIC GRADIENT

	Degrees counter-clockwise from east
Mean	106
Geometric Mean	105
Median	104
Standard Deviation	15
Maximum	164
Minimum	80



MAGNITUDE OF HORIZONTAL HYDRAULIC GRADIENT (ALIGNED WITH PRINCIPAL DIRECTION OF HORIZONTAL GRADIENT)

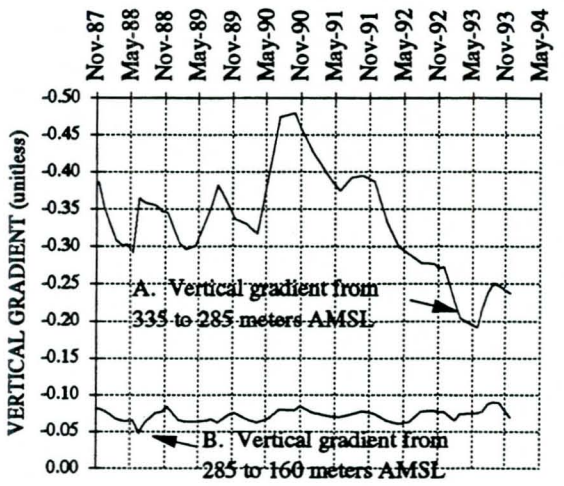
	Unitless
Mean	0.00179
Geometric Mean	0.00168
Median	0.00182
Standard Deviation	0.00059
Maximum	0.00367
Minimum	0.00045



SALT RIVER FLOW PAST GRANITE REEF DAM AND DRAINS (AVERAGE CUBIC METERS PER SECOND FOR EACH MONTH)

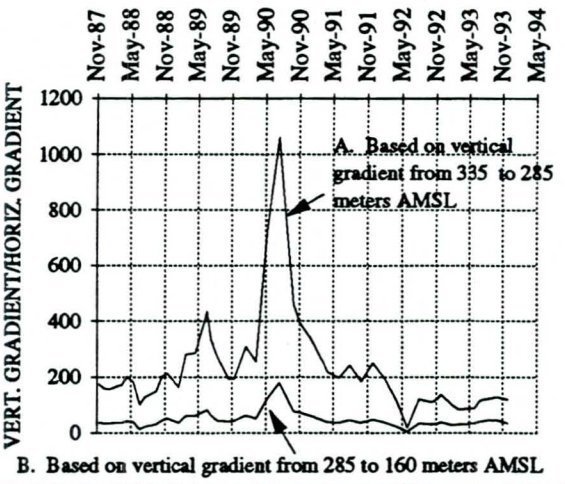
	Cubic meters/sec
Mean	33.2
Median	0.0566
Standard Deviation	133
Maximum	950
Minimum	0

FIGURE 6. VERTICAL HYDRAULIC GRADIENT, NORTH INDIAN BEND WASH STUDY AREA, APPROXIMATELY 3 KILOMETERS NORTH OF SALT RIVER



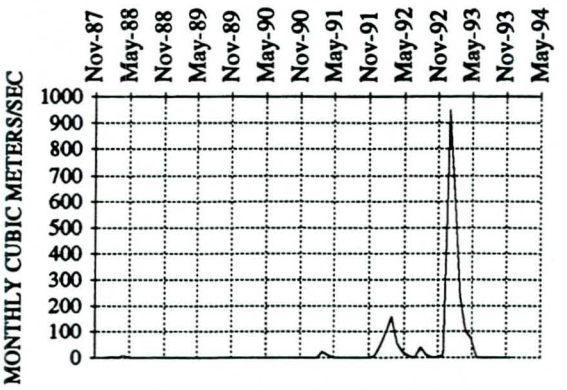
VERTICAL HYDRAULIC GRADIENT ACROSS TWO DEPTH PROFILES

	Unitless	
	A	B
Mean	-0.327	-0.0721
Geometric Mean	-0.320	-0.0715
Median	-0.330	-0.0735
Standard Deviation	0.068	0.0086
Maximum	-0.480	-0.0903
Minimum	-0.191	-0.0476



HYDRAULIC GRADIENT RATIO (VERTICAL GRADIENT DIVIDED BY HORIZONTAL GRADIENT)

	Unitless	
	A	B
Mean	223	46.6
Geometric Mean	182	40.8
Median	181	39.7
Standard Deviation	174	27.5
Maximum	1063	180
Minimum	19	4.1



SALT RIVER FLOW PAST GRANITE REEF DAM AND DRAINS (AVERAGE CUBIC METERS PER SECOND FOR EACH MONTH)

	Cubic meters/sec
Mean	33.2
Median	0.0566
Standard Deviation	133
Maximum	950
Minimum	0.0

LONG-TERM EFFECTS OF URANIUM-MINING RELEASES ON THE PUERCO RIVER AND UNDERLYING AQUIFER[1]

Laurie Wirt, Julia B. Graf, Sheryl A. Ferguson,and Gregory G. Fisk[2]

ABSTRACT: After more than two decades of radioactive releases to the headwaters of the Puerco River—including a one-time spill in 1979 of uranium processing liquid and tailings that is considered the largest spill of its kind in United States history—streamwater chemistry downstream from the uranium mines cannot be distinguished from that of tributaries where no mining occurred. Moreover, concentrations of dissolved uranium in shallow ground water beneath the Puerco River streambed appear to be declining rapidly. Mining ended in 1986 and during 1988-91 the U.S. Geological Survey studied the occurrence and distribution of radionuclides in (1) surface water and suspended sediment in the Puerco and Little Colorado Rivers and (2) the shallow alluvial aquifer underlying the Puerco River. Study findings indicate that rapid restoration to pre-mining conditions can be attributed to (1) sorption of contaminants to sediment, (2) high suspended-sediment concentrations in streamflow that dilute sorbed contaminants, (3) suspended transport of sediments downstream outside the study area, and (4) evaporative losses in the alluvial aquifer beneath the stream channel that limit downward movement of contaminated surface water and sediment.

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[1] Poster presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] The authors are employed by the Arizona District of the U.S. Geological Survey, Water Resources Division. Laurie Wirt, Julia B. Graf, and Sheryl A. Ferguson are hydrologists in the Tucson Projects Office, and Gregory G. Fisk is Field Chief of the Flagstaff Office.

NAWQA—THE U.S. GEOLOGICAL SURVEY'S WATER-QUALITY ASSESSMENT PROGRAM IN ARIZONA[1]

Gail E. Cordy[2]

In 1991, the U.S. Geological Survey (USGS) began to implement a full-scale National Water-Quality Assessment (NAWQA) program. The long-term goals of the NAWQA program are to describe the status and trends in the quality of a large, representative part of the Nation's surface-water and ground-water resources and to provide a sound, scientific understanding of the primary natural and human factors affecting the quality of these resources. In meeting these goals, the program will produce a wealth of water-quality information that will be useful to policymakers and managers at the National, State, and local levels.

Studies of 60 hydrologic systems that include parts of most major river basins and aquifer systems (study-unit investigations) are the building blocks of the national assessment. The 60 study units range in size from 1,000 to about 60,000 mi^2 and represent 60 to 70 percent of the Nation's water use and population served by public water supplies. Twenty study-unit investigations were started in 1991, 20 additional studies started in 1994, and 20 more are planned to start in 1997. The Central Arizona Basins study unit began assessment activities in 1994.

DESCRIPTION OF THE CENTRAL ARIZONA BASINS STUDY UNIT

The Central Arizona Basins study unit encompasses about 34,700 mi^2 in central and southern Arizona and northern Mexico (fig. 1). The boundary of the study unit is the Mogollon Rim in the north and other surface-water drainage divides along the west, east, and south. Five major river systems—the Gila, Salt, Verde, Santa Cruz, and San Pedro drain the area. The Salt, Verde, Santa Cruz, and San Pedro Rivers are tributary to the Gila River, which is tributary to the Colorado River near Yuma. The population of the study unit exceeds 3.1 million people. Phoenix and Tucson—the two major population centers—are in the central part of the area and provide water to more than 2.5 million people.

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[1]Poster presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]Gail E. Cordy is Project Chief for the Central Arizona Basins National Water-Quality Assessment Program, U.S. Geological Survey, Tucson, AZ.

Most of the Central Arizona Basins study unit is in the Basin and Range physiographic province, which is characterized by generally north- to northwest-trending mountain ranges separated by wide, flat alluvial basins. Altitudes in the study unit range from about 800 ft above sea level near Gillespie Dam at the western edge of the study unit to about 11,400 ft at Mt. Baldy, southeast of McNary.

Large-scale normal faulting during the Basin and Range disturbance, 14 to 6 million years ago, created a series of upthrown and downthrown blocks. Sediments that eroded from the surrounding mountain blocks, evaporites, and volcanics filled the subsiding basins. The basin-fill deposits range in thickness from a few thousand feet to more than 10,000 ft. The mountains consist mainly of extensively folded and faulted intrusive and metamorphic rocks that form impermeable boundaries between alluvial basins.

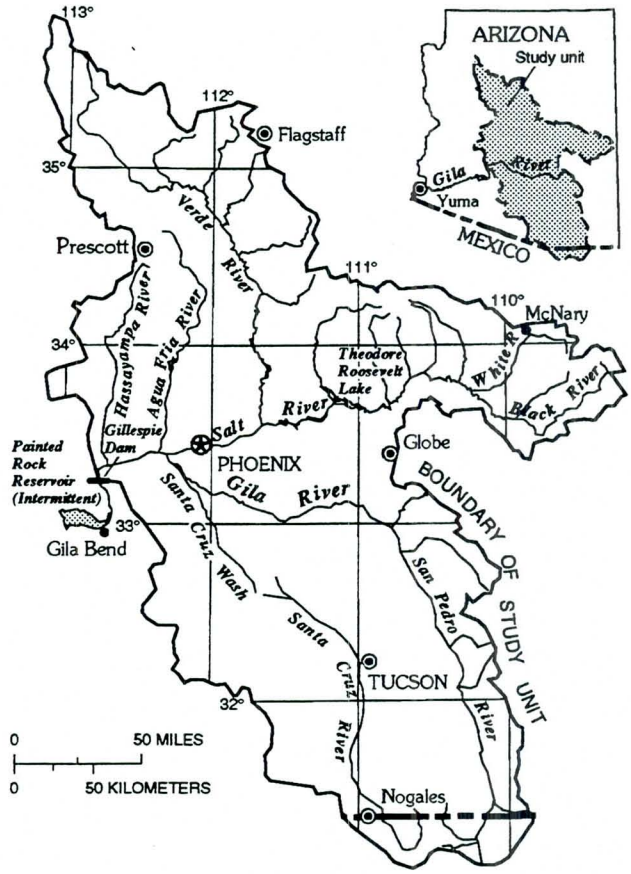

Figure 1. Location of the study unit.

The climate of the study unit is arid to semiarid. Average annual precipitation ranges from 25 to 40 in. at the higher altitudes in the northern part of the area to 6 to 10 in. at the lower altitudes south of Phoenix. Precipitation is extremely variable within any given year and from year to year. About 90 to 99 percent of precipitation is lost to evapotranspiration.

Precipitation, runoff, ground-water discharge, irrigation return flow, and treated sewage effluent are the main sources of surface-water flow in the study unit. The Verde and Salt Rivers are perennial in their upper reaches in the north and northeast, but most of the flow in these streams is diverted or dammed for irrigation or public supply. Streams in the southern part of the study unit are intermittent or ephemeral except for short perennial reaches such as the upper San Pedro and Santa Cruz Rivers. Some reaches of the upper Santa Cruz, lower Salt, and middle Gila Rivers have perennial flow that is sustained by treated sewage effluent.

The regional ground-water flow system closely parallels the direction of surface-water drainage. North and south of the Gila River, ground water flows toward and along the river. Within individual basins, water in the basin-fill deposits moves from the mountain front toward the basin axis where it discharges at land surface or mixes with existing underflow. Where the upper part of the basin-fill deposits is saturated, it is a productive, unconfined aquifer. At depth, water occurs in permeable sand and gravel lenses and may be unconfined or locally confined. In general, the alluvial deposits in the basins are hydraulically connected to form a single aquifer system. Ground water is near land surface along perennial streams but may be more than 300 to 800 ft deep near the mountain fronts.

Most of the land in the study unit is desert shrubland, open woodland, and grassland that is used for grazing. The main irrigated areas, which cover a small area of the unit, are adjacent to Phoenix and along the corridor between Phoenix and Tucson. Cotton, hay, and grains are the main crops. Urban land use continues to grow as the population increases. From 1980 to 1990, the population of Arizona increased by 35 percent, resulting in some changes from irrigated to urban land use. Copper and precious metals are extracted from several commercial mines in the study unit.

Water use in the study unit is dominated by agriculture, which requires large volumes of water to grow crops. As much as 40 percent of water used for agriculture is lost by seepage from unlined canals and reservoirs, infiltration below the root zone, or evaporation from the soil and open-water surfaces. With rapid population growth in the Phoenix (Maricopa County) and Tucson (Pima County) areas, water use is changing from agricultural to domestic, commercial, and industrial uses. Surface water and ground water each supply about 50 percent of the water used in the study unit. Ground water is the main water-use component in the southern part of the area and surface water is the main component in the northern part of the area.

In 1990, the surface-water diversions and ground-water withdrawals in the Central Arizona Basins NAWQA study unit, by use category, in acre-feet, were:

Water-use	Surface-water[1]	Ground-water
Agricultural	1,680,550	1,676,022
Municipal	325,280	319,451
Industrial	92,270	206,045
Total	2,098,100	2,201,518

[1]The values for surface-water include 593,860 acre-ft (agriculture) and 150,646 acre-ft (municipal and industrial) of Central Arizona Project water diverted from the Colorado River

The major water issue in Arizona is the imbalance between the quantity of water consumed and the quantity that is recharged back to the aquifers. For many years, ground-water withdrawals have exceeded recharge, causing depletion of the ground water in storage. Water-level declines of as much as 500 ft and associated land subsidence and earth fissures have resulted. The Central Arizona Project (CAP), a large canal that carries water from the Colorado River to the major water-use areas in central Arizona, was built to help alleviate overdraft pumping.

MAJOR WATER-QUALITY ISSUES

The major water-quality issues in the Central Arizona Basins study unit include:

- Effects of the discharge of treated sewage effluent on surface-water and ground-water quality, aquatic life, and instream flows near Phoenix, Tucson, and Nogales, Arizona;
- Effects of artificial recharge of Central Arizona Project water on ground-water quality;
- Effects of contamination from acid mine drainage on surface water, ground water, and human health;

- Movement and fate of organic contaminants in ground water from industrial discharges, spills, landfills, and other point sources in urban areas;
- Nitrate in ground water from natural and anthropogenic sources at concentrations that exceed National Drinking-Water Standards;
- Large concentrations of naturally occurring trace elements (fluoride, barium, arsenic, boron, and chromium) and activities of radon in ground water;
- Movement and fate of fertilizers, pesticides, and other contaminants from nonpoint sources such as irrigation return flow and stormwater runoff; and
- Effects of ground-water and surface-water quality on riparian areas and associated wildlife.

COMMUNICATION AND COORDINATION

Communication and coordination between USGS personnel and other interested scientists and water-management organizations are critical components of the NAWQA program. The liaison committee for the Central Arizona Basins study unit has proved very effective in this process and consists of representatives from Federal, State, and local agencies; universities; and the private sector who have water-resources responsibilities and interests. Specific activities of the liaison committee include exchange of information and identification of water-quality data sources; prioritization of water-quality issues; assistance in the design and scope of project elements; and review of project activities, findings, and interpretations, including reports.

SESSION 4A:

RIPARIAN STUDIES AND ISSUES

Moderator: Peter Livingston
SWCA

Hydrogeology of the Quitobaquito Springs Area, Arizona and Sonora, Mexico[1]

Robert L. Carruth[2]

ABSTRACT

Quitobaquito Springs is in Organ Pipe Cactus National Monument near the south end of the northwest-trending Quitobaquito Hills and is less than 0.25 mile north of the international boundary between the United States and Mexico. The National Park Service is concerned that the natural flow from Quitobaquito Springs might be adversely affected by ground-water withdrawals in the adjacent State of Sonora, Mexico.

Previous studies show that Quitobaquito and other nearby springs flow from a highly fractured granite gneiss that forms the Quitobaquito Hills. The chemical composition of water from all the springs is similar. The water is a sodium bicarbonate chloride type, and the dissolved-solids concentration ranges from 662 to 783 milligrams per liter. Water from Bonita Well, which is upgradient from the springs, is a calcium bicarbonate type and the dissolved-solids concentration is 338 milligrams per liter. The chemical composition and dissolved-solids concentration of water from Bonita Well are similar to those of ground water sampled from recharge areas in alluvial basins in Arizona. In contrast, the chemical composition and dissolved-solids concentration of water from the springs are similar to those of ground water sampled from downgradient areas in alluvial basins in Arizona. The carbon-14 analysis of a water sample from Quitobaquito Springs indicates that the water is less than 2,000 years old.

Discharge at Quitobaquito Springs averaged 28 gallons per minute and ranged from 15 to 40 gallons per minute for 1981-92. The variation in discharge with time may be partly explained by seepage losses between the spring-discharge points and the flume where discharge is measured, and by the buildup and subsequent removal of phreatophytes by the National Park Service. During a 10-year monitoring program ending in September 1992, rainfall at two gages in the probable area of recharge to the northeast of Quitobaquito Hills averaged 5.9 and 7.3 inches per year; however, daily accumulations of

[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22–23, 1994.

[2]Robert L. Carruth is a hydrologist with the U.S. Geological Survey, Tucson, AZ 85719-6644.

rainfall exceeded 4 inches on two occasions. The lack of a strong correlation between spring discharge and local precipitation indicates that local annual recharge may be small relative to the total quantity of ground water in storage.

Northeast of Quitobaquito Hills, a mantle of alluvial-fan deposits covers the pediment and interfingers with the stream-channel deposits of Aquajita Wash. Ground-water recharge through and storage within these deposits make up a local flow system that provides a source of water to the springs (fig. 1). Seismic refraction and direct-current resistivity data indicate that a head of 15 to 50 feet exists upgradient from the spring-discharge points. Seismic-refraction data also indicate that the saturated thickness ranges from about 57 to 85 feet along Aguajita Wash for at least a 1-mile section adjacent to Quitobaquito Hills upgradient from an area of shallow bedrock near Aquajita Spring. Bedrock outcrops and shallow depth to bedrock interpreted from seismic-refraction and gravity data indicate that the local flow system providing water to the springs may be separated from other ground-water systems in the study area by impermeable material. The altitude and relatively low permeability of the granite gneiss bedrock near the outflow point of the local flow system would probably provide a barrier to a northwest propagation of water-level declines caused by pumping near the Rio Sonoyta. Geophysical, water-level, and water-quality data support the conclusion that the source of water to the springs probably is local and is hydraulically separated from the ground-water system that is pumped for agriculture along the Rio Sonoyta.

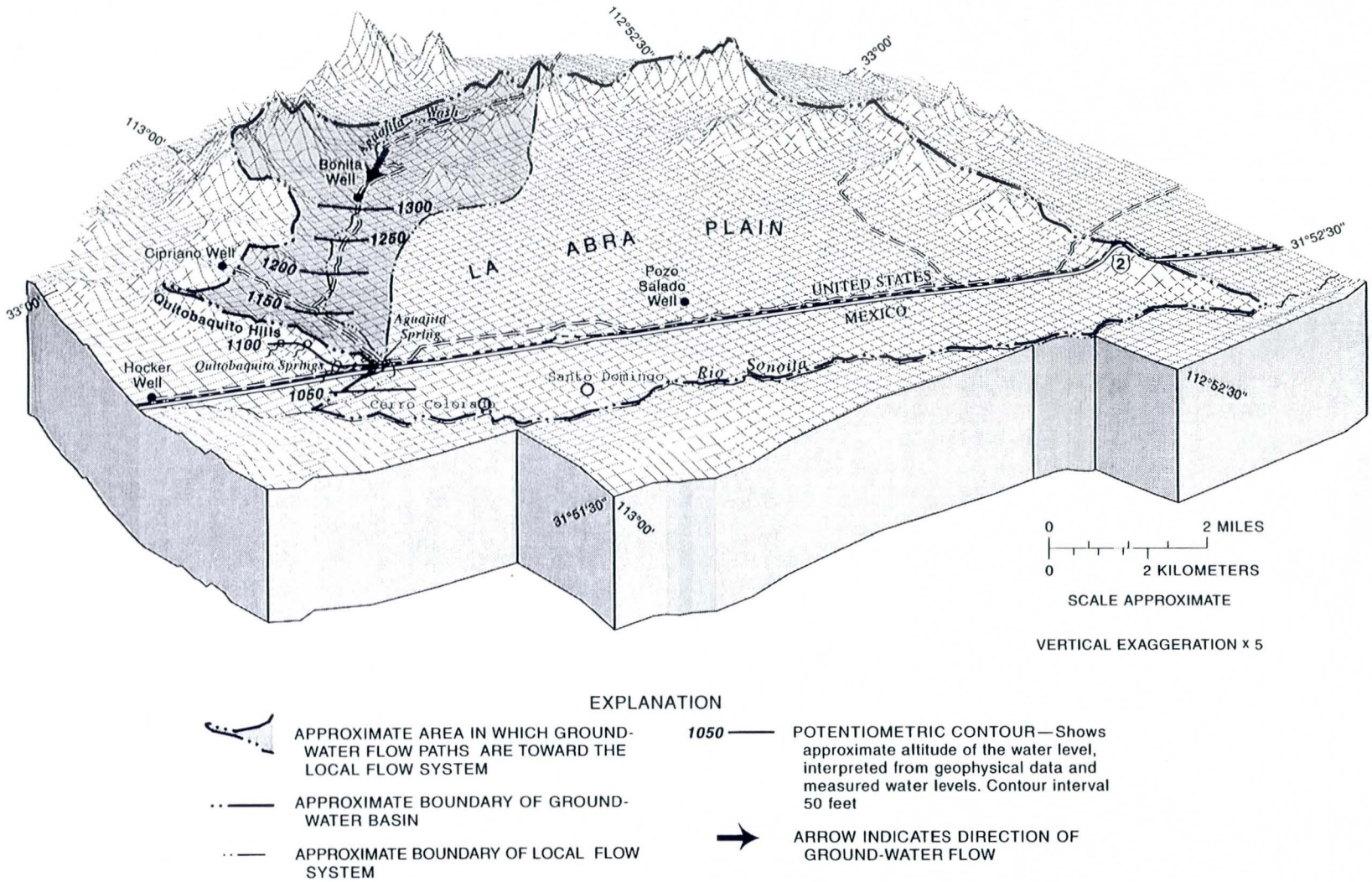

Figure 1. Topography and generalized hydrogeology of the Quitobaquito Springs and La Abra Plain area, Arizona and Sonora, Mexico.

INHERENT CONFLICTS IN ENVIRONMENTAL LEGISLATION [1]

Edwin H. McGavock [2]

ABSTRACT: Environmental legislation must recognize the natural conflict between maintaining stream flows and protecting riparian vegetation, because the vegetation "competes" with stream base flows. Along perennial streams alone, riparian vegetation "pumps" about 1.2 million acre-feet of water per year. That is comparable to Arizona's projected CAP use in 2040, or to the combined pumpage in the Phoenix and Tucson AMA's.

A common misconception is that stream base flow supports riparian habitat. In fact, riparian areas may increase as perennial flow ceases. The only common requirement of perennial streams and riparian vegetation is a shallow water table near the stream. Concurrent protection of streams and habitat must rely primarily on hydrologic expertise.

Stream flow diversions are another area of conflict. Out-of-stream diversions support significant riparian habitat, as in the Verde Valley, but often harm in-stream fauna. However, setting in-stream flow requirements can deplete riparian habitat. Likewise, moving pumping centers away from streams may preserve shallow, streamside water levels, but fail to protect stream base flows.

Legislation based on inadequate hydrologic understanding will be unfortunate for both the streams and the streamside habitat. ADWR's Hydrology Section should play a larger role in drafting and reviewing environmental legislation.

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[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] Edwin H. McGavock is a Hydrologist with the Verde Watershed Association, Sedona, AZ.

Legislation designed to "protect our rivers, streams, and associated riparian habitat" suffers from conflicting objectives and unresolved priorities. Consequently, the legislative results can be inefficient, at best, and possibly counterproductive.

First, we must recognize the natural conflict between protecting (maintaining) the base flow of our streams and protecting the riparian habitat. While not mutually exclusive, the one objective, riparian habitat, operates very much at the expense of stream base flow.

Riparian vegetation, along perennial streams alone, transpires (pumps) about 1,200,000 AFY on the 289,000 acres of riparian area identified by Arizona Game and Fish Dept. (ADWR, 1990; AGFD, 1993). That is comparable to the current total pumpage in the Phoenix and Tucson Active Management Areas, or to the projected CAP demand in the year 2040 (ADWR, 1993). And, because the riparian withdrawals are so close to the streams, they represent an almost direct depletion of stream base flow. This is not to say that riparian water use should not have priority over stream flow. It simply illustrates the hydrologic conflict built into legislative objectives.

Second, there is a misperception that maintenance of stream base flow directly supports riparian habitat. This is not a cause and effect relationship and, in fact, the reverse can be true. Arizona Dept. of Water Resources maps of the perennial-intermittent reaches of the San Pedro river show mapped riparian areas to be greatest in the intermittent reaches (ADWR, 1994). This may be because riparian plants are <u>not</u> aquatic plants, and cannot occupy the entire broad channel until perennial flow is eliminated.

Both entities that legislative desires to protect - both the base flow and riparian habitat - are dependent primarily on one condition. That is, the existence of a very shallow (less that 15') water table along the streams. Hydrologic aspects of legislative protection should thus focus on maintaining that condition. Riparian vegetation must have shallow ground water, and perennial streams must have shallow ground water in most of their reach. It is the only common requirement.

The hydrologic aspect of legislation protection is, then, primarily a ground-water problem, to be addressed by ground-water hydrology and hydrologists, and not primarily by riparian biologists. Despite claims by riparian advocates, riparian areas do not increase stream flow or increase

ground-water recharge. And, base flows can be reduced without affecting water tables in riparian areas. Legislation based on poor hydrologic understanding will be unfortunate for both the plants and the streams. ADWR's Hydrology Section should have the lead role in any legislation involving hydrology.

Third, proposed legislation frequently deals with stream flow diversions. This concern again highlights the tension between maintaining plants and maintaining stream flow; or between riparian habitat and fish.

Diversion of stream flow results in an immediate decrease of in-stream flow. This is usually a negative for aquatic organisms, including fish, but is rarely harmful to riparian habitat and often supports such habitat. In Verde Valley, 100 year old diversions for irrigation may support the majority of the cottonwood-willow riparian gallery there. Much of southern Arizona's riparian habitat is also supported by diversions into areas where water tables are too deep for riparian vegetation.

The concept of "determining the amount of stream flow required to support riparian habitat" is moot, at least with respect to base flow. Riparian plants use water in the aquifer and have no "in-stream flow" requirement.

Fish, of course, do have extensive in-stream flow requirements, such as depth, velocity, temperature, D.O., etc. Most of these requirements are related to stream discharge and, for base flows, we are right back to the ground-water hydrologists to advise on how to maintain that base flow. Such hydrologists might advise that "developing water resources away from riparian areas" offers no protection - it simply delays the impacts for some time.

Fourth, though riparian vegetation has no in-stream flow requirement, it does have an "out-of-stream requirement." Flood flows of some magnitude are required for seed dispersal and plant establishment. Some excellent field work by Stromberg and others (1993), on a 1991 Hassayampa River flood, documented both the requirements and desirable limits for flood flows. In brief, Stromberg found that banks needed to be flooded up to a point where land surface was about 10-12 feet above the water table - the limit of riparian root zones. Flood levels less than that were inadequate to re-vegetate the entire riparian zone. Higher flood levels were both wasteful of seed and more destructive of existing vegetation. Thus there appears to be a riparian requirement for out-of-channel flooding,

and an optimum range of flood levels. In the Hassayampa study, Stromberg worked with a 10 year R.I. flood and found that a lesser, 7 year R.I. flood would be optimum.

The Hassayampa study has prompted calls for removal of dams so that more large floods can occur, or for operation of dams to "reproduce natural hydrographs." In both cases, Stromberg's points are missed. We really don't want "large" floods to sustain riparian habitat. The desired range is narrow. It generally requires a 5 year R.I. flood to get water out of the channel, but a 10 year R.I. flood may be too high. Floods greater than a 30 year R.I. can be very damaging to riparian areas According to AGFD (1993), the 1993 floods destroyed 7% of all riparian habitat along perennial streams in the state. Like salt, a little bit is necessary, but a lot can kill you.

Stromberg's work might be considered in the operation of some dams, but it is premature to attempt legislative requirements. One reason is that we don't know what "optimum flood flows" are except for a few short reaches on a few streams. A 7 year R.I. was good for Stromberg's study reach. But that would be excess in a narrower reach and inadequate in a wider, flatter one. Also, few of our dams affect significant riparian reaches. Water tables downstream of the Salt, Gila, and Agua Fria dams have been pumped too deep for managed flood flows to help restore riparian areas.

In summary, drafters of "pro environment" legislation need to recognize that protection of stream flow and protection of riparian habitat are <u>not</u> synonymous and often are conflicting. Understanding of this conflict, and the knowledge to deal with it, seems to reside almost solely in the hydrologic community.

It is the legislature's responsibility to set priorities for what is to be protected, at what level, etc. Input from a broad spectrum of interests is appropriate. But hydrologists - primarily ground-water hydrologists - must provide the primary input to the making of hydrologic policy and regulations intended to preserve either in-stream or out-of-stream habitat.

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THE CENTRAL ARIZONA PROJECT AND THE ENDANGERED SPECIES ACT[1]

Douglas K. Miller[2]

I. INTRODUCTION

The Central Arizona Project (CAP) and the Endangered Species Act (ESA)[3] intersect in several areas. These include: (a) the recent critical habitat designation for certain Colorado River fishes; (b) the Section 7 consultation between the Bureau of Reclamation and the Fish and Wildlife Service regarding deliveries of water through the CAP aqueduct system; and (c) the Glen Canyon environmental impact statement (EIS) process.

This paper will not address the Glen Canyon EIS process at length. However, it should be noted that the Fish and Wildlife Service threatens to undo much of the work done during the development of the draft EIS, because it has apparently rejected, on the basis of Endangered Species Act concerns, the preferred alternative identified in the draft EIS for the operation of Glen Canyon Dam. This could have profound impacts on the users of power generated by the dam, but should not affect Lower Colorado River Basin water use.

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]General Counsel, Central Arizona Water Conservation District, Phoenix, Arizona. The views expressed herein are those of the author and do not necessarily represent the views of the Central Arizona Water Conservation District.

[3]16 U.S.C. §§ 1531, et seq.

II. OVERVIEW OF THE ESA

A. Purposes Of The ESA

The purposes of the ESA are to conserve endangered and threatened species and their critical habitat.[4] An endangered species is one which is in danger of extinction.[5] A threatened species is one which is likely to become endangered in the foreseeable future.[6] (For purposes of this discussion, there is no practical distinction between endangered and threatened species.)

B. Policies Of The ESA

The ESA states as national policy that (1) all federal agencies shall seek to conserve endangered and threatened species[7] and (2) that, in carrying out this policy, federal agencies shall cooperate with state and local agencies to resolve water resource issues.[8] This latter policy seems to have been honored more in the breach than in the observance, as the ESA has increasingly collided with the operation of Western water projects.

C. Enforcement Of The ESA

There are several statutory mechanisms by which the purposes of the ESA are to be achieved and enforced. The most important are the following.

First, the Secretary must identify and list endangered and threatened species.[9] For our purposes, "Secretary" means the Secretary of the Interior.

Second, the Secretary must identify their critical

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[4]Section 2(b), 16 U.S.C. § 1531(b).

[5]Section 3(6), 16 U.S.C. § 1532(6).

[6]Section 3(20), 16 U.S.C. § 1532(20).

[7]Section 2(c)(1), 16 U.S.C. § 1531(c)(1).

[8]Section 2(c)(2), 16 U.S.C. § 1531(c)(2).

[9]Sections 4(a)(1), 4(c)(1), 16 U.S.C. §§ 1533(a)(1), 1533(c)(1).

habitat.[10] This designation is normally to occur contemporaneously with listing, but may occur later.[11] The delay in identifying critical habitat for listed species has been the occasion for much recent litigation.

Third, under Section 7 of the ESA, each federal agency must consult with the Secretary in order to insure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of such species' critical habitat (Section 7 consultations).[12] Such consultations may occur at the request of and in cooperation with an applicant for a federal permit or license if the applicant has reason to believe that an endangered or threatened species may be present in the area affected by his project.[13] This is really an opportunity for the applicant to participate in what would otherwise be a consultation between the federal agencies alone. A Section 7 consultation will occur in any event if an endangered species is present and is likely to be affected by the project. There are highly restrictive procedures for exemption.[14]

Fourth, Section 9 of the ESA prohibits the taking of any endangered species by any person.[15] Strictly speaking, this statutory prohibition applies only to the taking of listed species of endangered fish and wildlife, but it has been extended by regulation to cover listed species of threatened fish and wildlife as well.[16] Endangered plants are less restrictively protected.[17] "Taking" means killing or injuring an endangered species,[18] which may not include

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[10]Section 4(a)(3), 16 U.S.C. § 1533(a)(3).

[11]Section 4(b)(6)(C), 16 U.S.C. § 1533(b)(6)(C).

[12]Section 7(a)(2), 16 U.S.C. § 1536(a)(2).

[13]Section 7(a)(3), 16 U.S.C. § 1536(a)(3).

[14]Sections 7(e), 7(g), 7(h), 16 U.S.C. §§ 1536(e), 1536(g), 1536(h).

[15]Section 9(a)(1)(B), 16 U.S.C. § 1538(a)(1)(B).

[16]40 C.F.R. § 17.31 (1993).

[17]ESA Section 9(a)(3), 16 U.S.C. § 1538(a)(3).

[18]Section 3(19), 16 U.S.C. § 1532(19).

adversely modifying its habitat. A recent United States Court of Appeals decision in the Sweet Home case held invalid a Fish and Wildlife Service regulation which defines "harm" in the definition of "take" to include the adverse modification of habitat.[19] The dissent in the case argues that a conflict now exists between this decision and another court of appeals decision.[20] The prohibition against taking an endangered species applies to any person. "Person" means individuals, businesses, state and local governments, and federal agencies.[21]

D. Section 7 Consultations

The United States Fish and Wildlife Service (FWS) performs the consultation function for the Secretary. The FWS provides a written opinion indicating how the agency action affects an endangered or threatened species or its critical habitat. If jeopardy or adverse modification is found, the FWS suggests those reasonable and prudent alternatives that would avoid the problem and allow the action to proceed without jeopardizing the species or adversely modifying its critical habitat. The reasonable and prudent alternatives may also include conditions which permit incidental takings of endangered species to occur, thereby avoiding violation of Section 9.[22] If no reasonable and prudent alternatives are identified, an exemption must be obtained -- a practical impossibility.

E. The Section 9 Prohibition On Takings

There are civil and criminal penalties for violating the ESA.[23] Citizens may bring suit to enjoin violations.[24]

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[19] Sweet Home Chapter of Communities, et al. v. Babbitt, et al., 17 F.3d 1463 (D.C. Cir. 1994).

[20] Palila v. Hawaii Dep't of Land and Natural Resources, 852 F.2d 1106 (9th Cir. 1988).

[21] Section 3(13), 16 U.S.C. § 1532(13).

[22] Sections 7(a)(2), 7(b)(1)(A), 7(b)(3)(A), 7(b)(4), and 7(o)(2), 16 U.S.C. §§ 1536(a)(2), 1536(b)(1)(A), 1536(b)(3)(A), 1536(b)(4), and 1536(o)(2).

[23] Sections 11(a), 11(b), 16 U.S.C. §§ 1540(a), (b).

[24] Section 11(g)(1)(A), 16 U.S.C. § 1540(g)(1)(A).

However, the prohibition on takings may be avoided by obtaining a permit from the Secretary under Section 10 of the ESA.[25] The permit applicant must prepare a conservation plan.[26]

III. ESA ACTIVITIES OF INTEREST TO THE CENTRAL ARIZONA WATER CONSERVATION DISTRICT (CAWCD)

A. The Critical Habitat Designation For Four Colorado River Endangered Fishes; The Razorback Sucker, The Colorado Squawfish, The Humpback Chub, And The Bonytail Chub, 59 Fed. Reg. 13,374, et seq. (March 21, 1994)

This designation encompasses most of the mainstem of the Colorado River and its tributaries, including significant portions of the Salt, Verde, and Gila Rivers in Arizona. The designated critical habitat for the bonytail includes Lake Havasu above Parker Dam, where the CAP intake, the Havasu pumping plant, is located. The Fish and Wildlife Service has separately designated additional portions of the Verde and Gila Rivers and their tributaries as critical habitat for the threatened spikedace and loach minnow.[27]

1. Potential Impacts

The most serious potential impacts would involve changes in the water operations of the Colorado River dams and reservoirs. However, the FWS has said, "[a]t present, the Service does not foresee changes in current hydrological operations of these rivers occurring as a result of recovery efforts for these fishes."[28] Other potentially serious impacts would involve changes in power operations. These could result in power losses and increased power costs and, possibly, losses of power revenues.

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[25]Section 10(a)(1)(B) of the Act, 16 U.S.C. § 1539(a)(1)(B). Takings may not include the adverse modification of habitat. See the Sweet Home case, supra, at note 19.

[26]Section 10(a)(2), 16 U.S.C. § 1539(a)(2).

[27]59 Fed. Reg. 10,897, et seq. (March 8, 1994).

[28]59 Fed. Reg. at 13,395.

2. Responses

The first thing one must do is evaluate the potential impacts of the critical habitat designation. One may consider cooperative approaches in response (e.g., Section 10). The states of Arizona, California, and Nevada are studying the feasibility of preparing a multi-species habitat conservation plan for the endangered and threatened species of the Lower Colorado River Basin as part of a process intended to lead to the issuance of a Section 10 permit. Other responses should also be considered, as necessary or appropriate. These could include legislation or litigation.

B. The Section 7 Consultation On CAP Operations

In a final biological opinion dated April 15, 1994, the FWS concluded that the proposed delivery of CAP water to water users in central Arizona is likely to jeopardize the continued existence of the threatened spikedace and loach minnow and the endangered Gila topminnow and razorback sucker and is likely to adversely modify the critical habitat of the spikedace, loach minnow, and razorback sucker. The issue addressed in the FWS's biological opinion is the potential transfer of non-native fish species from the Colorado River through the CAP aqueduct system into the waters of the Gila River basin and the possible impact of these non-native fish species on the endangered and threatened native fish of the Gila River basin. For purposes of the biological opinion, the Gila River basin does not include the Santa Cruz River or its tributaries. A separate Section 7 consultation is to occur with respect to the impact of CAP water deliveries on the Santa Cruz River basin.

The CAP pumps Colorado River water from Lake Havasu for delivery to central Arizona through a 335 mile long aqueduct system. The aqueduct system crosses, but does not interconnect with, Arizona's rivers and streams, except at designated points. These include New Waddell Reservoir on the Agua Fria River, where CAP water is stored in the winter for delivery during the summer. They also include an interconnection with the Salt River Project system at the Arizona and Southern canals below Granite Reef Diversion Dam, which is located below the confluence of the Salt and Verde Rivers. The movement of non-native fish above Granite Reef Diversion Dam is controlled by two electrical fish barriers constructed at the heads of these canals. Further upstream movement is restricted by Stewart Mountain Dam on the Salt River and Bartlett Dam on the Verde River. Another interconnection with the CAP system occurs where CAP water deliveries are made to the San Carlos Irrigation Project and

the Gila River Indian Community via the Florence-Casa Grande Canal, which also delivers water from Ashhurst-Hayden Diversion Dam on the Gila River. There is an electrical fish barrier at the head of the Florence-Casa Grande Canal. The next upstream barrier to fish movement is Coolidge Dam on the Gila River.

This is the principal area of concern. The fear is that non-native fish will find their way from the CAP aqueduct into the Gila River between Ashhurst-Hayden Diversion Dam and Coolidge Dam, and then into the San Pedro River and Aravaipa Creek, home to several species of endangered and threatened native fish.

The FWS has identified the reasonable and prudent alternatives which will be sufficient in its judgment to protect native fish from what it perceives to be the potential adverse impact of CAP water deliveries. They require the Bureau of Reclamation to: (1) construct and maintain four physical fish barriers (drop structures), two on Aravaipa Creek, and two on the San Pedro River; (2) operate three existing electrical barriers on the Salt River Project canals and the Florence-Casa Grande Canal; (3) perform a baseline study and long-term monitoring of the presence and distribution of non-native fish in the following areas -- the CAP aqueduct, the Salt River Project canals, the Florence-Casa Grande Canal, other water delivery canals as appropriate, the Salt River between Stewart Mountain Dam and Granite Reef Dam, the Gila River below Coolidge Dam, and the San Pedro River downstream of the Mexican border; (4) pay FWS $250,000 annually for 25 years for fish recovery efforts; (5) pay FWS $250,000 annually for 25 years for research on, and control of, non-native species; and (6) develop and implement a public education program (5 years).

The reasonable and prudent alternatives identified will likely increase CAP construction and operation and maintenance costs significantly. The estimated costs include $6 million for the construction of the additional fish barriers and $12.5 million in payments to the FWS for additional studies. These do not include the costs of the long term (life of the project) monitoring program for non-native fish.

The real problem, though, is the assumption that any of this money will be well spent. The likelihood that harm will occur from fish from the CAP aqueduct system being introduced into the surface streams of central Arizona is quite remote when compared to the fact that these streams already contain significant populations of non-native fish and the fact that new introductions of non-native fish occur frequently as a result of deliberate stocking of sport fish and bait bucket

dumping by fisherman. The facts suggest that a complete cessation of CAP water deliveries would not improve the status of the native fish in the areas in question. The reason is that the native fish are under significant pressure from sources over which the CAP has no control.

While CAWCD is still considering how it might respond to the biological opinion, the likelihood is that it will put aside its disappointment and direct its energies toward seeing that some agreeable alternative is implemented as efficiently as possible.

RIPARIAN PROTECTION THROUGH A BLM ADMINISTRATIVE APPEAL: THE COMB WASH CASE[1]

Joseph M. Feller[2]

Livestock grazing is a leading cause of riparian degradation in the western United States. Experience has shown that many damaged riparian areas will repair themselves without human intervention if they are relieved of livestock grazing.

On public lands managed by the U.S. Bureau of Land Management (BLM), livestock grazing may take place only where authorized by a permit issued by the BLM. In issuing a grazing permit, the BLM must comply with the National Environmental Policy Act (NEPA) and the Federal Land Policy and Management Act (FLPMA). NEPA requires the BLM to evaluate and consider the environmental impacts, including effects on riparian areas, of the grazing authorized by the permit. FLPMA, through the principle of "multiple use," requires the BLM to evaluate the harms and benefits of the grazing and to determine whether, on balance, the issuance of the permit is in the public interest.

The Comb Wash grazing allotment in southeastern Utah contains over 50 miles of stream riparian areas in five canyons. These five canyons are rich in natural scenery, recreational opportunities, and archaeological sites as well as potential riparian habitat. All of these resources have been degraded by cattle grazing in the canyons.

In 1991, the National Wildlife Federation, the Southern Utah Wilderness Alliance, and Joseph Feller filed an administrative appeal in the Department of the Interior challenging the BLM's decision to continue to authorize cattle grazing in the five canyons on the Comb Wash Allotment. On

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[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] Professor of Law, Arizona State University.

December 20, 1993, District Chief Administrative Law Judge John R. Rampton, Jr., issued a decision on the appeal.

Judge Rampton ruled that the BLM had violated NEPA by authorizing grazing in the canyons on the Comb Wash Allotment without preparing an environmental impact statement (EIS) that evaluates the environmental consequences of the grazing. He also ruled that the BLM had violated FLPMA by failing to determine whether grazing in the five canyons is in the public interest. Judge Rampton prohibited the BLM from authorizing further grazing in the canyons unless and until the BLM complies with NEPA and FLPMA.

Judge Rampton's decision is currently under appeal to the Interior Board of Land Appeals (IBLA). The IBLA has ordered that Judge Rampton's order barring cattle from the canyons will remain in effect while the IBLA considers the case.

Excerpts from Judge Rampton's decision are attached.

United States Department of the Interior

OFFICE OF HEARINGS AND APPEALS

Hearings Division
6432 Federal Building
Salt Lake City, Utah 84138
(Phone: 801-524-5344)

December 20, 1993

NATIONAL WILDLIFE FEDERATION, SOUTHERN UTAH WILDERNESS ALLIANCE, and JOSEPH FELLER, Appellants v. BUREAU OF LAND MANAGEMENT, Respondent - - - - AMERICAN FARM BUREAU FEDERATION, UTAH FARM BUREAU FEDERATION, PUBLIC LANDS COUNCIL, NATIONAL CATTLEMEN'S ASSOCIATION, AMERICAN SHEEP INDUSTRY ASSOCIATION, and UTE MOUNTAIN UTE INDIAN TRIBE, Intervenors	UT-06-91-1 Appeal from the District Manager's final decision dated March 6, 1991, Moab District, Utah
NATIONAL WILDLIFE FEDERATION, SOUTHERN UTAH WILDERNESS ALLIANCE, and JOSEPH M. FELLER, Appellants v. BUREAU OF LAND MANAGEMENT, Respondent	UT-06-93-01 Appeal of the San Juan Resource Area Manager's issuance of a grazing permit and schedule for the 1992-93 season on the Comb Wash Allotment

* * * *

BLM Failed to Comply with NEPA

"The NEPA process is intended to help public officials make decisions that are based on understanding of environmental consequences, and take actions that protect, restore, and enhance the environment." 40 CFR 1500.1(c). Consequently, "NEPA procedures must insure that environmental information is available to public officials and citizens before decisions are made and before actions are taken." 40 CFR 1500.1(b) (emphasis added). Thus, when an environmental impact statement (EIS) is required for a proposed action, the EIS should be prepared at the earliest time prior to implementation of the proposed action, so that alternative courses of action with less severe environmental consequences can be considered. Friends of the Earth, Inc. v. Coleman, 518 F.2d 323, 327 (9th Cir. 1975).

An EIS is required for all "major Federal actions significantly affecting the quality of the human environment." 42 U.S.C. § 4332(2)(C). Each party has assumed and not questioned the fact that BLM's authorizations of grazing on the Comb Wash allotment are major Federal actions. Therefore, BLM was required to prepare an EIS prior to issuing the grazing authorizations if they significantly affect the quality of the human environment.

> The standard to determine if an action will significantly affect the quality of the human environment is whether the plaintiff has alleged facts which, if true, show that the proposed project may significantly degrade some human environmental factor. A determination that significant effects on the human environment will in fact occur is not essential. If substantial questions are raised whether a project may have a significant effect upon the human environment, an EIS must be prepared.

Sierra Club v. U.S. Forest Service, 843 F.2d 1190, 1193 (9th Cir. 1988) (internal quotations and citations omitted, emphasis in original).

The record leaves no doubt of the following conclusions: (1) that grazing throughout the Comb Wash allotment has had a significant detrimental effect on many human environmental factors, (2) that substantial questions exist as to whether the grazing permitted by the grazing authorizations at issue may have significant effects upon the quality of the human environment, and (3) that substantial questions exist as to whether future grazing in the canyons, at any use level, may have significant effects upon the quality of the human environment. Conclusion (1) is essentially undisputed and supported by the overwhelming weight of the evidence. Conclusion (2) is based, in part, upon the fact that in areas outside the canyons, BLM is permitting the alternating seasonal grazing pattern, with a recent unexplainable increase in one of the utilization objectives, despite the failure of this grazing pattern to meet objectives or improve the poor condition of the range for the past 25 years. Both conclusions (2) and (3) are supported by the testimony of Dr. Platts and Professor Ohmart. Both men agreed that any amount of grazing in the canyons would cause some harm in that recovery of the riparian areas would not proceed or not proceed as quickly as under total rest. Professor Ohmart's testimony alone provides sufficient justification for conclusions (2) and (3). Therefore, BLM was required to prepare a proper EIS prior to issuance of the March 6, 1991 final decision and the subsequent grazing authorizations, and is required to prepare a proper EIS before any further grazing is permitted in the canyons.

* * * *

III.

BLM Failed to Comply with FLPMA

43 U.S.C. § 1732(a) provides that "[t]he Secretary shall manage the public lands under principles of multiple use and sustained yield * * *." "Multiple use" is defined to mean:

> the management of the public lands and their various resource values so that they are utilized in the combination that will best meet the present and future needs of the American people; * * * a combination of balanced and diverse resource uses that takes into account the long-term needs of future generations for renewable and nonrenewable resources, including, but not limited to, recreation, range, timber, minerals, watershed, wildlife and fish, and natural scenic, scientific and historical values[,] * * * with consideration being given to the relative values of the resources * * * .

43 U.S.C. § 1702(c). The principle of multiple use "requires that the values in question be informedly and rationally taken into balance," Sierra Club v. Butz, 3 Envt'l L. Rep. 20,292, 20,293 (9th Cir. 1973), to determine whether the proposed activity is in the public interest. See King's Meadow Ranches, 126 IBLA 339, 341-342 (1993) (upholding denial of request to amend right-of-way filed pursuant to regulations promulgated under the authority of FLPMA, because BLM properly found that the amendment of the right-of-way was not in the public interest).

A.

BLM Has Not Made a Reasoned and Informed Decision that the Benefits of Grazing the Canyons Outweigh the Costs

The record in this case clearly reveals that BLM violated FLPMA by failing to make a reasoned and informed decision that the benefits of grazing the canyons outweigh the costs. The Area Manager, Mr. Scherick, correctly believed that he had discretion under the RMP to allow or disallow grazing on the Comb Wash allotment. He testified that, in exercising this discretion, he had not considered the relative values of the resources in the canyons because consideration of those values would take place during the activity planning stage (formation of the new AMP). But a new AMP has not yet been developed because the CRMP process failed to produce consensus and BLM has yet to prepare an AMP on its own.

Mr. Scherick also admitted that neither he nor any document, including the Proposed RMP/FEIS, weighs the benefits and harms of grazing the canyons. In authorizing grazing in the canyons, Mr. Scherick simply relied upon the information and recommendations provided to him by Mr. Curtis, the range conservationist responsible for the allotment.

Contrary to the evidence and Mr. Scherick's belief, Mr. Curtis thought that the RMP had already considered the impacts of grazing on the allotment's resources and determined that the allotment should be grazed, regardless of the recognized conflict with recreational uses and the need for adjustment confirmed by monitoring. He therefore felt it was not his responsibility to consider those impacts. Mr. Scherick's reliance upon Mr. Curtis, who believed that the decision to graze had already been made and was still binding, does not constitute a rational basis for determining whether the canyons should be grazed.

Furthermore, Mr. Curtis, an expert in range management only, does not have the expertise necessary to understand all the impacts of grazing in the canyons. Yet, he testified that he relied solely upon the utilization data, the Proposed RMP/FEIS, and ocular observations to determine the specific terms under which grazing would be allowed. There is some question whether he also sought and relied upon advice from experts in archaeology and other fields, but he provided no documentation and little evidence of the context or content of any discussions with those experts.

Mr. Curtis' reliance upon the Proposed RMP/FEIS is unavailing, as he, Mr. Scherick, and Mr. Trotter, BLM's NEPA expert, each admitted that the Proposed RMP/FEIS does not contain the detailed information necessary for determining whether or not to graze the canyons. Neither the Proposed RMP/FEIS nor Mr. Curtis' ocular observations nor the utilization data provides an answer to, or permits an informed opinion on, many important factual issues bearing upon the question of whether grazing the canyons is in the public interest. Those issues include:

(1) How important are the canyons to the livestock operation of the Tribe?

(2) Is the poor condition of the vegetation on the alluvial terraces in the canyons a result of grazing or some other factor?

(3) Is grazing preventing the aggradation of the stream channels and the refilling of the arroyos in the canyons?

(4) Are cattle knocking over the walls of ancient Anasazi ruins and trampling archaeological artifacts in the canyons?

(5) Is grazing in the canyons degrading their scenic and recreational values and causing a consequent loss of income and jobs to the local community?

(6) Is the value of the scenic, recreational, ecological, and archaeological resources in the canyons far greater than the value of the livestock forage there?

In sum, BLM's decision to graze the canyons was not reasoned or informed, but rather, based upon Mr. Curtis' misinterpretation of the RMP and a totally inadequate investigation and analysis of the condition of the canyons' varied resources and the impacts of grazing upon those resources.

* * * *

Conclusion

With further belaboring this decision with additional references to contentions regarding errors of fact and law, except to the extent they have been expressly or impliedly addressed in this decision, they are rejected on the ground they are, in whole or in part, contrary to the facts and law or are immaterial. Based upon the foregoing, the following orders are entered:

(1) The March 6, 1991, final decision is hereby set aside;

(2) BLM is hereby prohibited from allowing any grazing in the canyons until an adequate EIS is prepared and considered;

(3) BLM is hereby prohibited from allowing grazing in the canyons until BLM makes a reasoned and informed decision that grazing the canyons is in the public interest; and

(4) The March 6, 1991, final decision is hereby remanded to BLM for further action consistent with this decision.

John R. Rampton, Jr.
District Chief
Administrative Law Judge

SESSION 4B:

RETHINKING REMEDIATION

Moderator: Keith Ross, R.G.
Arizona Department of Environmental Quality

GROUND WATER CONTAMINATION AND CLEANUP: WHERE DO WE GO FROM HERE[1]

R.N. Farvolden[2]

Last February in Denver the NGWA convened a Forum on Ground Water Remediation. The Forum was an opportunity for all parties involved in ground water remediation to define the current situation and to discuss improvement that should be made in both process and operations.

For over a decade we have been hearing horror stories of waste and lack of progress in the remediation program, in spite of the enormous effort that has been made to clean up contaminated ground water and soils. One barrier to progress that is commonly heard is the difficulty in reaching agreement among all parties- owners, consultants, regulators, public interest groups and lawyers. The latter group is thought by most to have had an unduly powerful role in the program. Further, important decisions are made, mostly by regulators, often without being approved by the parties most affected.

More than one- half of the 25,000 members of NGWA are involved in one way or another in the ground water remediation industry, so it seemed appropriate that the Association provide a suitable opportunity for discussion of the remediation program in the hope that some consensus might be reached on important issues such as an evaluation or critique of the program and the current situation, and proposals for improvements. Also, we felt it important that the views of this group of highly trained and experienced professionals be made known to legislators and other interested groups, including the public.

The meeting was set up as a forum to convey the intention that ample time would be provided for questions to each of the four panels of speakers and for open discussion among members of the audience. The schedule was divided almost equally between formal presentations and discussion. An evening "Town Hall" type meeting offered even

[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]R.N. Farvolden, Sr. Scientist with the National Ground Water Association, Dublin, Ohio.

more time for open discussion, and a secondary purpose was to identify the barriers to progress in achieving the goals of the remediation program. The Town Hall meeting was followed by a final half-day session, at which the attendees were divided into five working groups, each charged with the task of discussing one of the main "barriers" and making recommendations for changes to improve the program.

Formal presentations were heard in four sessions, each focusing on a specific theme. John Cherry was moderator for the first session which presented the views of consultants, that is, scientists and engineers, on the current situation. We heard of the need for integration of all technical work at a given site, and that mistakes in characterization of both the hydrogeologic setting and the contaminant in the subsurface could be the cause of poor results in remediation. Cherry had strong praise for the United States for the strong and sincere effort in ground water remediation and protection, noting that nothing like Superfund legislation exists in other countries. On the other hand, the lessons that have been learned have not been used to improve the efficiency of the program, interms of both achieving cleanup and reducing excessive costs. To illustrate his point, he quoted from work he recently published with Doug MacKay, describing major contaminant plumes in the United States according to areal extent and to mass (barrels) of contaminant in the dissolved phase. The message was very clear. It is possible to cleanup plumes of dissolved contaminants in aquifers but only if the source can be removed or isolated. In the case of DNAPLs, it is generally impossible to ensure future protection of the aquifer by removing the source. Another intriguing point he raised was on the results of their examination of the records to find that the cost of a single monitoring well at a Superfund site, properly designed approved and installed, and sampled for one year is between ten thousand - and one hundred thousand dollars.

The second session was on the experiences and views of PRPs. Michael Kavanaugh was moderator, and he spoke on the results of the NRC committee report (now available) on alternative methods for remediation. The committee found little evidence of true success in ground water remediation at any of the examples they chose for close scrutiny, in spite of the fact that an average of 27 million dollars has been spent on each Superfund site and 40 million on each DOE site where remediation has been attempted. Kavanaugh estimates that as many as 400,000 sites will be discovered that need remediation of some kind. Industrial representatives made a strong case for more realistic measures of success in remediation and supported the suggestion mentioned many times during the Forum that isolation of the source in conjunction with pump and treat should be accepted practice for DNAPLs at least. "Protection of human health and the environment, predicated on sound risk assessment and risk management practices..." was proposed as a reasonable goal of remediation. The ground water remediation program at the Rocky Mountain Arsenal was used as an example of the advantages of starting with remediation before all uncertainties in characterization have been resolved, following "design and build" procedures. The new DOE "Expedited Site Characterization Initiative" was

explained by Caroline Purdy and provoked considerable discussion. Considerable discussion ensued on whether or not characterization can be effectively done through "indirect or non- intrusive" methods and whether it is good practice to begin remediation before characterization is completed. PRPs insisted that public involvement was essential to decision making in remediation and that lack of this input was a major deficiency in the current program.

The third session had the theme "Partnerships With the Regulatory Community" and was moderated by William Colglazier, co-author of the University of Tennessee report on the costs of remediation. The facts and the predictions made in this report had been mentioned many times throughout the forum. Colglazier emphasized the need for all parties to work together to find ways to reduce the costs. Papers in the session provided examples of the high cost of recovering contaminants from ground water and showed examples of success in reducing costs through collaboration between regulators, PRPs, the consultants and the public. Invoking the use of the "technical impracticability" policy guidance after forming a partnership with regulators, led to significant improvement in progress at a difficult site in fractured rock in California. Peter Fritz of the Institute for Environmental Research at Leipzig- Halle (in former East Germany) emphasized the need for good applied research before proceeding with any attempts at remediation where extensive contamination by a variety of chemicals in complex hydrogeologic conditions, made the outcome of any procedure highly questionable.

A session on "The Role of Legislation and Regulation in the Remediation Process" was organized and moderated by Robert Dahlquist of the American Bar Association Business Law Section. The speakers in this session emphasized the difficulties in the current CERCLA legislation for all parties, and described the changes being formally recommended to Congress. Bills currently before Congress were discussed and compared. The pro's and con's of "voluntary cleanup" were presented along with examples of advantages and disadvantages of the various options offered in different states. Most of the audience were heartened, if not surprised, to learn that the representatives of the ABA agreed with almost all of the grievances of the other professionals and offered strong support for the changes that had been suggested.

The Town Hall meeting was well attended, with a vocal and lively audience. During the course of the evening five major barriers to effective remediation were identified. The next day, at the last session, the audience was divided, by choice, into five working groups to discuss and report on recommendations to removing the barriers. "Information transfer" had been identified as one of the barriers but no working group was formed because interest was higher in "Risk Assessment", so two working groups were formed to deal with that topic. Below are listed the recommendations made by the working groups. Recommendations of the Working Groups on Risk Assessment to Establish Site-Specific Cleanup Levels:

1) national generic cleanup levels for selected contaminants based on generic exposure conditions and land use;
2) flexible adjustment of generic cleanup levels according to site- specific risk-based factors including prevention of exposure by land use controls and water restriction;
3) more reliance/allowance of natural attenuation and /or enhanced attenuation processes to mitigate migration.

Recommendations of the Working Group on Barriers to Use of Innovative Technologies

1) the Government(s) should promote consortiums between companies, and tax incentives, to encourage more open communication on technology advances;
2) a national center should be set up to disseminate performance data;
3) a reimbursement program like that for the UST program should be set up;
4) trust funds could be established to assist and encourage research;
5) more government- based research and government sponsored grants to academics and industrial institutions would lead to increased research activity in innovative technologies.

Recommendations of the Working Group on Site Characterization

1) characterization should be done in sufficient detail to determine if significant/unacceptable risks or potential risks exist as a consequence of contaminant release and migration;
2) characterization should establish the hydrogeologic framework of the site and the properties of the contaminants for a conceptual model which should guide the design of the sampling and monitoring systems;
3) research on the use of statistics is needed to determine uncertainties in site characterization;
4) the characterization process should strike a balance between the need for detail and limited resources.

Recommendations of the Working Group on the DNAPL Issue

1) removal of the source should not be required if it can be shown that it will not lead to effective remediation;
2) the decision to remove a source should be based on site- specific conditions and should incorporate technical practicability, cost/benefit analysis tied with risk reduction, legal issues and community involvement;
3) DNAPL sources should be managed by horizontal containment through hydraulic or physical means;
4) where possible, DNAPLs should be addressed by treatment of the dissolved contaminants at the point of use;
5) improvement in DNAPL remediation should be addressed through research on characterization, treatment of sources, and containment;

6) flexible regulations are needed which establish performance standards to improve DNAPL plume characterization, source containment and removal;
7) improved training at all levels within the regulatory community is needed, as is state statutory reform, and federal regulatory reform to allow for flexibility in coping with the complex DNAPL problem;
8) the scientific community should educate the public on realistic expectations with regard to remediation of DNAPLs.

David Miller closed the Forum on an optimistic note. He pointed out that we had learned a lot on remediation in a very short time; we had developed a very strong cadre of highly skilled professionals and support staff; and we had begun to recognize the great possibilities of applying well- known technologies from other fields to our remediation problems.

A revelation of the Forum was the consensus of opinions among all parties that the Superfund legislation and current regulations had to be changed to avoid further unnecessary waste and encourage more effective cleanup of contaminated sites. At NGWA we first heard this view strongly expressed by members, many of whom felt a strong, professional responsibility to the public, who might well feel we had neglected their interests. In fact the Forum was organized to provide an outlet for this sense of dissatisfaction and frustration. Other groups were brought in to provide a balance of views, but early in the Forum it became obvious that the wish for change was almost unanimous among the 232 attendees. The goal then became preparation of credible information to support our protest of the status quo and to offer clear suggestions for changes.

I still have a sense of satisfaction that our members, many of whom have enjoyed considerable benefit from the remediation industry, were the first to speak up for change. Members of the ABA Business Law Section also deserve credit for sharing this position.

It is also clear that PRPs from all sectors are long past the denial stage. Almost all of them recognize the problem and accept their responsibility. They are prepared to spend very large sums of money in remediation of their contaminated sites. They object to spending large sums of money on projects that have little likelihood of achieving success or even of reducing their liability.

PRPs were among the most vocal at the Forum in expressing the need and benefit to all of having public participation in the decision-making process in remediation projects.

NGWA has an official position on Superfund Reauthorization that is completely compatible with the opinions and suggestions expressed by the majority of attendees of our Forum.

INNOVATIVE IDEAS IN REMEDIATING CALIFORNIA'S SAN GABRIEL VALLEY[1]

Wayne Praskins[2]

The four San Gabriel Valley Superfund Sites are typical of many hazardous waste sites throughout the country. The industrial use (and misuse) of perchloroethene (PCE), trichloroethene (TCE), and other chlorinated solvents has contaminated soil and groundwater; the only proven method of clean up is to extract and treat contaminated vapor and groundwater; and the most contentious issue is who pays.

In other ways the Sites are less typical. The TCE and PCE have spread into plumes of groundwater contamination up to several hundred feet thick and several miles long; more than 40 independent water companies pump water from the San Gabriel Basin ("the Basin") in or near contaminated areas; thousands of solvent-using businesses have been investigated as potential sources of the groundwater contamination; and the clean up of the most highly contaminated central portion of the Basin will require the extraction, treatment, and delivery of more than 19,000 gallons per minute of contaminated groundwater (19,000 gallons per minute equals approximately 31,000 acre-feet per year, or 27 million gallons per day [MGD]). At 100 gallons/day/person, the project will provide enough water to serve 300,000 people.

The remainder of this paper describes the remedy for the most highly contaminated central portion of the Basin, known as the Baldwin Park Operable Unit.

The remedy, selected earlier this year in a *Record of Decision*, calls for the extraction of enough contaminated groundwater to limit further plume movement in two key

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994

[2]Wayne Praskins is a Superfund Program Project Manager with the U.S. Environmental Protection Agency Region 9 in San Francisco, CA

areas. The remedy is classified as an *interim* rather than final clean up action, because the U.S. Environmental Protection Agency (EPA) has deferred setting final clean up goals until after the currently planned project has operated long enough to allow for an evaluation of the Basin's response to large-scale pumping in contaminated areas. As yet, EPA has neither adopted nor rejected the goal of completely cleaning up (i.e., restoring) all or portions of the Basin to allow use of the groundwater without treatment.

An important decision made during the remedy selection process was to limit contaminant movement, by large-scale pumping, in the two key areas. The two areas are: (i) the *source area* where most of the contaminants are believed to have entered the subsurface, and where significant contaminant mass remains in the unsaturated and saturated zones (most likely with significant mass in the non-aqueous phase); and (ii) at the apparent *leading edge* of the groundwater plumes approximately four miles downgradient of the source area. The *leading edge* threatens several active water supply wells. Further downgradient, contaminant concentrations decrease significantly although measurable levels of contamination remain. Computer simulations of groundwater flow indicate that approximately 9,000 to 10,000 gallons per minute must be extracted from each area to *capture* the known area and depth of contamination.

The *source area* is believed to include ten or more distinct sources of groundwater contamination scattered throughout a several square mile commercial and industrial area. Extraction will occur at the downgradient margin of the *source area*, from hundreds to thousands of feet downgradient of the locations where the releases most likely occurred. EPA concluded that a single groundwater extraction system in the *source area* would be nearly as effective as individual extraction systems at each facility, but much lower in cost.

EPA also considered but rejected less aggressive clean up strategies, including a proposal to rely solely on *wellhead treatment*. In a *wellhead treatment* strategy, in its extreme form, groundwater treatment systems would be installed only as needed at existing drinking water wells to ensure that the extracted groundwater meets drinking water standards. Because existing wells are not optimally located for contaminant removal or migration control, this strategy would allow, and in some cases accelerate, the continued expansion of the plumes of groundwater contamination. This strategy would also leave the burden of installing and operating treatment on the water purveyors and their

ratepayers, rather than on those responsible for the contamination.

EPA's strategy partially relies on *wellhead treatment*. Portions of the Basin beyond the *leading edge* are contaminated at or near drinking water standards, but EPA plans no action in this portion of the Basin. Individual water purveyors must install treatment as needed, whether or not State, local, or Potentially Responsible Party funding is available. To date, three water purveyors have independently paid for and installed granular activated carbon or air stripping treatment systems in this downgradient area.

Another key issue, as yet unresolved, is the user and use of the treated groundwater. EPA's options are to supply treated water to water purveyors in the San Gabriel Valley for distribution to their residential and business customers, or to recharge the treated water in man-made spreading basins where water percolates back into the Basin. In the first option, the treated groundwater would be used directly for drinking; in the latter option the water would still be used as a drinking water source, but indirectly.

Surprisingly, there is competition among local water agencies for use of the treated groundwater, at least for the moment. The competition arises largely from differences in the price of water among neighboring water companies. In the San Gabriel Valley, customers pay as little as $50 per acre-foot for water if they (or their water company) are lucky enough to own enough water rights to meet all of their demand with clean groundwater, but over $400/acre-foot if they must purchase imported water. This difference in price has attracted interest in acquiring the treated groundwater, moving the water to high-price areas, and securing revenue from sales of the treated groundwater.

Some water companies or agencies are also interested in participating in the clean up in order to overcome restrictions in the existing water rights judgment on the storage and export of water outside of the San Gabriel Valley. One agency, the Metropolitan Water District of Southern California, has had a long-standing interest in acquiring and exporting treated groundwater produced as part of a clean up project, and in increasing its rights to use the San Gabriel Basin's storage capacity in a *conjunctive use* operation.

Many San Gabriel Valley residents have for years been drinking water with TCE, PCE, carbon tetrachloride, and other groundwater contaminants at detectable levels, but

below drinking water standards. Surprisingly, the public has expressed little concern about drinking water with low-level contamination or drinking treated groundwater. It may be that public concern will rise after EPA's planned project moves closer to operation, or maybe its just that Californians are more tolerant and trusting than most. Most likely, at some time in the not too distant future someone will publicize the fact that residents are drinking water from a Superfund Site and ignite public concern. A similar sequence of events has occurred at a locally-sponsored San Gabriel Valley project to recharge the Basin with treated wastewater. The project to receive widespread support until one local groundwater user, Miller Brewing Company, apparently realized that the treated wastewater would be recharged near their groundwater supply wells. In an ongoing "educational campaign," Miller Brewing Company and others have used organized postcard mailings, threats of legal action, and full-page newspaper advertisements to publicize fears about the risks, from AIDs to dementia, that might result from drinking "sewage water."

One other important component of EPA's clean up effort has been to ensure that the benefits of new pump and treat systems are not offset by the operation of existing water supply wells. The pumping of a well at the periphery of a groundwater plume can accelerate contaminant movement or spread contaminated groundwater into adjacent clean areas. To minimize this problem, coordinated operation of existing and new extraction wells is necessary. EPA and the State have worked to establish regulatory authority (currently delegated to a court-appointed Watermaster) to control pumping by local purveyors that may adversely impact contaminant migration in groundwater. The Watermaster has adopted a rule that requires that "any new or increased extraction ... shall not contribute to contaminant migration." Two years after enactment, the impact of the rule is unclear, but it represents a positive step toward what has often been a fractious Federal, State, and local clean up effort.

STEPPING OUT OF THE PUMP AND TREAT RUT: CENTRAL PHOENIX PLUME MANAGEMENT STRATEGY[1]

Jeffrey P. Kulon, Keith A. Ross, Richard C. Olm[2]

ABSTRACT: Traditional aquifer restoration by pumping and treating groundwater may not be technically or economically feasible in cases where tremendous volumes of water and high extraction rates would be involved. A 15-mile long groundwater contaminant plume meeting these characteristics exists in the central Phoenix area. A public drinking water system is threatened by the contamination. The Arizona Department of Environmental Quality (ADEQ) is currently working with the U.S Environmental Protection Agency, a number of state and local agencies, and community members to assess the potential of performing contaminant plume management, in place of traditional restoration, on this plume. This management approach would require: 1) treatment systems where groundwater must be used by public or private parties; 2) control of sources of groundwater contamination; 3) monitoring of plume movement; and 4) in-plume treatments to provide control of plume movement or to accelerate natural processes. The approach would be funded by companies responsible for the contamination with ADEQ providing oversight. Under this management approach ADEQ can ensure the immediate protection of the public health and welfare while providing a considerably less-expensive alternative to traditional methods. While a significant amount of development work remains, response to the basic concept has been favorable.

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]Jeffrey P. Kulon is a Remedial Projects Manager, Arizona Department of Environmental Quality (ADEQ); Keith A. Ross is a Hydrologist, ADEQ; Richard C. Olm is a Remedial Projects Manager, ADEQ.

BACKGROUND

The Remedial Projects Unit of the Arizona Department of Environmental Quality (ADEQ) conducts and oversees Arizona Water Quality Assurance Revolving Fund (WQARF) and federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) projects within Arizona. Figure 1 shows some of these projects in the central Phoenix area. As a result of migrating volatile organic compounds in groundwater from three adjacent WQARF/CERCLA sites, a groundwater contaminant plume occurs from 52nd Street near McDowell Road to 83rd Avenue near Van Buren Street. ADEQ assessed the potential of standard remedial approaches to remediate this immense plume, and concluded that current methods may be extremely limited. A plume management approach was one of several alternatives to traditional pump and treat methods that ADEQ evaluated to address this situation.

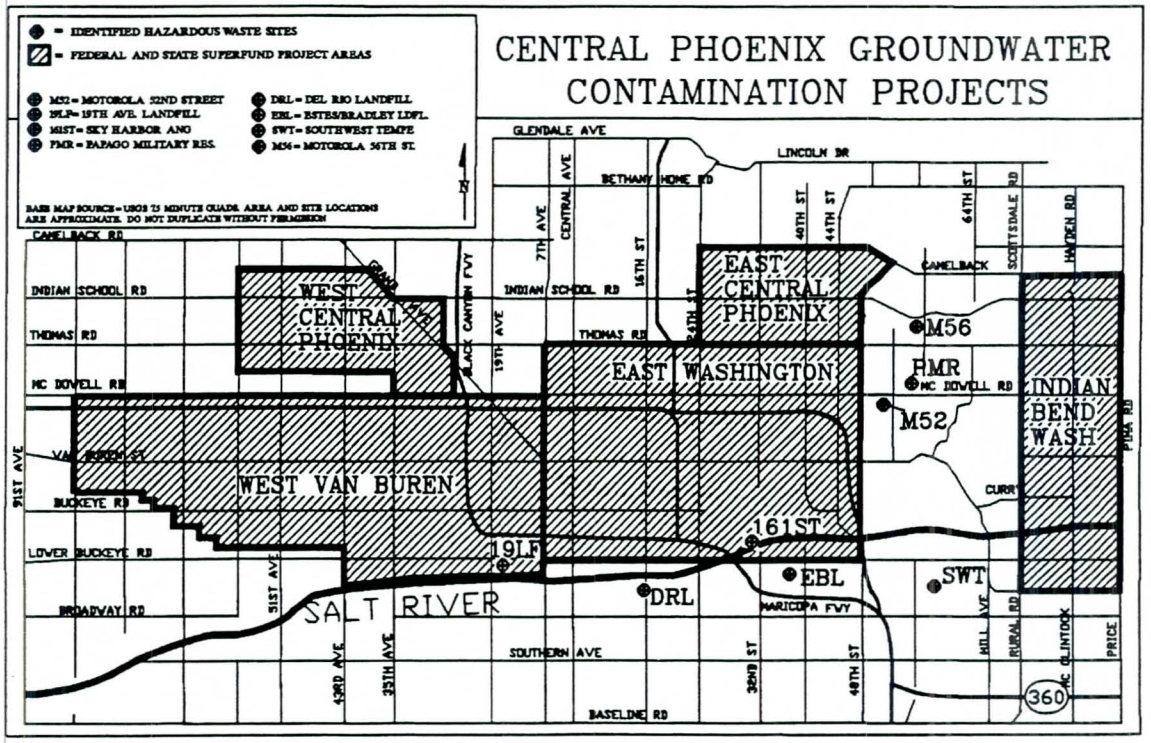


Figure 1.

The Motorola 52nd Street Superfund Site

The Motorola 52nd Street Superfund Site (M52) is a CERCLA, or federal Superfund, site. This project began with investigation of reported releases of solvents at the Motorola plant at 52nd Street and McDowell. With oversight from ADEQ and the U.S Environmental Protection Agency (EPA), Motorola has established one interim remedy to control the further movement of the contaminants from the area of the plant. A second interim remedy alternative was selected in July 1994 to provide additional control of the contaminant plume downgradient of the Motorola Plant. Contaminants from the Motorola plant have moved into the East Washington WQARF (EWA) area, where they combine with contaminants from sources in the EWA. Several of the identified sources in the EWA have received general notice from EPA notifying them of potential liability in the M52 site.

The East Washington Area

The East Washington WQARF area is a twenty-four square mile investigation area in which ADEQ is attempting to identify the sources of VOC groundwater contamination detected in the area. The boundaries of the area include Thomas Road to the north, Lower Buckeye Road to the south, 48th Street to the east, and 7th Avenue to the west. Contamination was first detected in 1984 in an irrigation well at Eastlake Park, near 16th Street and Jefferson Street. Subsequent sampling revealed widespread contamination throughout that portion of Phoenix and the EWA was placed on the WQARF priority list in 1987. After initiating its own investigations, as well as working with facilities in the area, several suspected sources of VOCs have been identified by ADEQ.

The West Van Buren Area

The West Van Buren WQARF area (WVB) is an investigation area similar to EWA. The boundaries of this area are generally McDowell road to the north, Lower Buckeye to the south, 7th Avenue to the east, and 75th Avenue to the west. The exact shape of the area can be seen in Figure 1. 7th Avenue is the boundary between the EWA and WVB areas. The boundary is only an administrative boundary, and VOC contaminants in groundwater are known to be migrating from the EWA into WVB where they again combine with contaminants from other sources. Groundwater contamination in WVB has been identified as far west as 83rd Avenue. The City of Tolleson is west of WVB and uses groundwater for public supply. ADEQ's current understanding of the plume suggests that public supply wells used by the City of Tolleson will be impacted in approximately 5 years.

Regional Geology and Hydrogeology

The EWA and WVB areas are located within the Salt River Valley sedimentary basin. Typical basin-fill deposits consisting of conglomerate, gravel, sand, silt, clay and evaporites underlie the study areas. Depth of these deposits ranges from less than 25 feet on the eastern edge of the study area (56th Street) to over 1000 feet on the western edge (83rd Avenue). The alluvial sediments are divided into three units. However, for the study area, only the Middle Alluvial Unit (MAU) and Upper Alluvial Unit (UAU) are of interest. The depth to the MAU ranges from 0 to 450 feet in the project area. The thickness of the UAU ranges from 25 to 450 feet, becoming greater east to west. Underlying the eastern portion of the study area is bedrock consisting of Precambrian granites, meta-volcanics and Tertiary volcanic and sedimentary rocks. Depth to bedrock ranges from 25 feet near the eastern edge to greater than 1000 feet on the western edge.

Aquifer tests within the study area have produced different hydraulic conductivities (K) and transmissivities (T). A test near 20th Street indicated a K of 207 feet per day and a T of 20,000 square feet per day (Dames and Moore, 1993). ADEQ conducted a test at 67th Avenue indicating a K of 270 feet per day and a T of 57,000 square feet per day.

Depth to groundwater ranges from 15 feet below land surface in the east to 90 feet below land surface in the west. The groundwater flow patterns within the study area vary. Near the eastern boundary, flow is generally southwest at a gradient of approximately 0.005 feet per foot (ft/ft). The direction becomes westerly near 24th Street partially due to the presence of a bedrock ridge trending northwest near 32nd Street. Groundwater flow continues at a gradient of 0.002 to 0.003 ft/ft into WVB. Direction within WVB is influenced by the presence of irrigation wells that pump during parts of the year. During non-pumping conditions, flow direction is generally west to west-northwest with a gradient of 0.0014 to 0.002 ft/ft (Brown and Caldwell, 1994). During pumping conditions, local gradients and flow direction vary depending on proximity to a pumping well. The generalized groundwater flow for the western edge of the study area is west to northwest.

Contaminant Distribution

Figures 2, 3, and 4 show the portion of the aquifer in this area contaminated above EPA Maximum Contaminant Levels with trichloroethene (TCE), tetrachloroethene (PCE), and 1,1-dichloroethene (DCE), respectively. The figures were generated using data from over 200 wells across the project area. The contaminant plume is approximately 15.5 miles long and 1.5 to 2 miles

Figure 2.

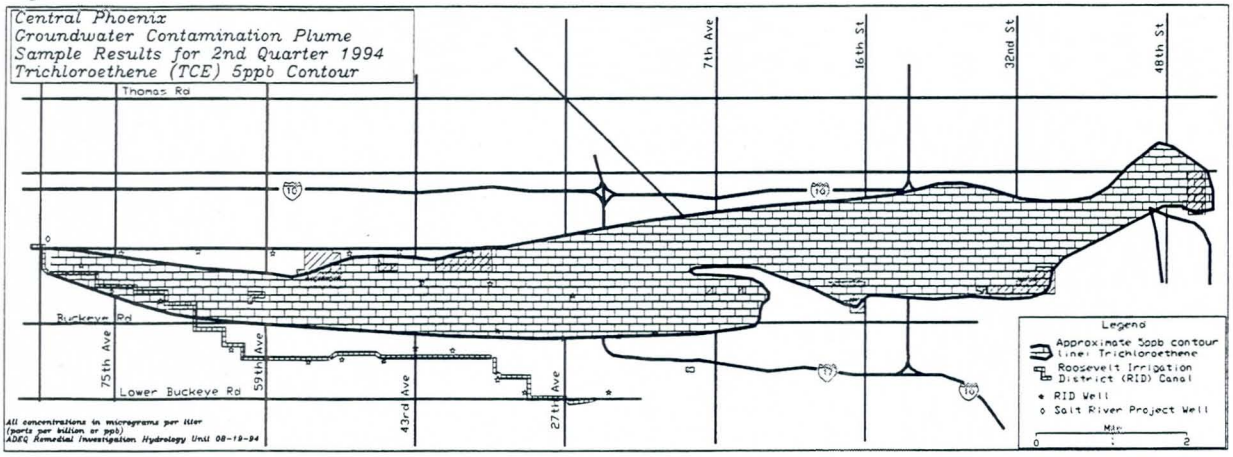


Figure 3.

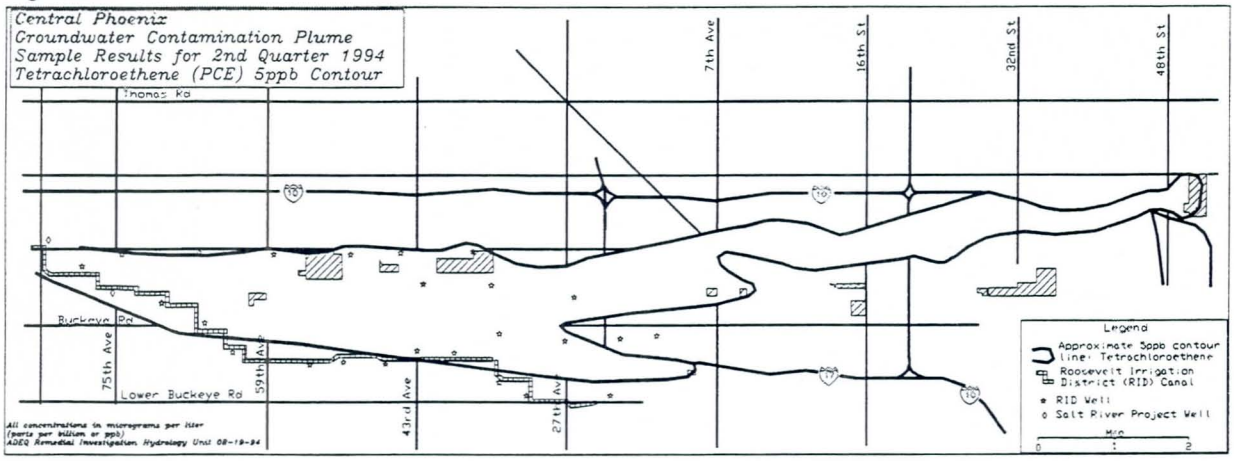
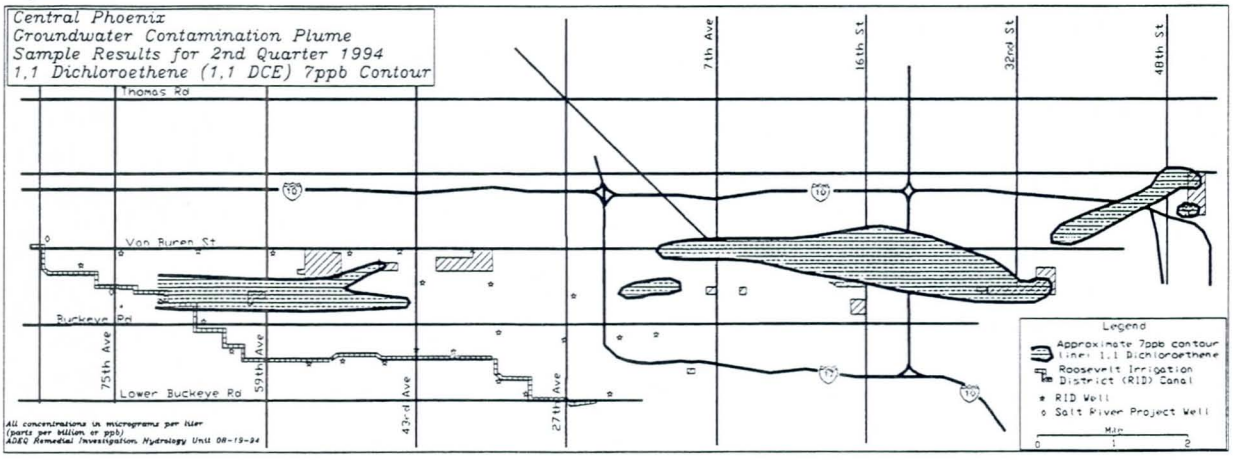


Figure 4.



wide. The vertical extent of contamination is less well defined due to the limited number of multiport and deep wells within the area. These wells have shown that the contamination is at least 450 feet deep beneath 52nd Street and shallows to 300 feet near 16th Street. The vertical extent deepens to at least 500 feet in a deep well drilled in August 1994 at 79th Avenue.

ANALYSIS OF OPTIONS

ADEQ evaluated a range of options for addressing this situation. Factors used in the evaluation included protection of the public health, community acceptance, and resources required.

The Current Standard Approach

One option is to maintain the current standard approach of requiring the responsible parties to treat the entire aquifer to meet EPA Maximum Contaminant Levels (MCLs) or Arizona Aquifer Water Quality Standards. This approach is consistent with current laws and approaches at other sites and should be agreeable to the EPA and the public.

A key disadvantage of this approach is the excessive financial resources required. With the limited capabilities of current technology, a tremendous capital and operation and maintenance budget would likely be required. Making conservative assumptions, ADEQ estimated that a capital investment of approximately $250,000,000 would be required to construct facilities capable of restoring the aquifer within thirty years. Operation and maintenance of those facilities would require approximately $41,000,000 annually.

Because of these high costs and multiple responsible or potentially responsible parties, it is highly likely that lengthy and costly litigation would result. These legal battles could delay action needed to protect Tolleson's water supply.

One assumption used in developing this option is that the required groundwater extraction rate, 300,000 to 400,000 gallons per minute, could be sustained. Given the existing aquifer characteristics, this assumption is likely not true.

Aquifer Reclassification

One of the requirements driving ADEQ's environmental restoration efforts is Arizona Revised Statute §49-224, which states that all aquifers of the state are subject to drinking water protected use, unless specifically reclassified by law.

Following the statutes, the entire Salt River Valley aquifer could be reclassified for other than drinking water use. The primary advantage of this would be that it eliminates the need for extensive future action in this area and frees ADEQ resources for other problems.

A number of disadvantages to this option exist. This option would reduce the drinking water resource for Phoenix. Another source of public water would be required for the city of Tolleson. The current law would need to be revised to allow reclassification of a portion of the aquifer rather than the entire aquifer. These legislative changes may take considerable time. This option would likely be unacceptable to citizens and some environmental groups.

An Innovative Alternative

ADEQ staff developed this third option with the primary intent of protecting the public health, welfare and the environment, considering the limitations of current technology and the financial ability to implement it. The concept begins with working with each facility to require source control measures at their respective properties. The combined effort by the parties would include the development of a trust fund for the construction and monitoring of sentinel wells, possible in-plume treatment (i.e., enhanced biological processes), and any necessary well-head treatment and other institutional controls. Limited plume containment may also be possible through groundwater extraction and irrigation use of the extracted water, which might be accomplished by relocating existing irrigation supply wells. The trust would also fund extensive community involvement in and near Tolleson. Maximum contaminant levels would be identified as clean-up goals rather than requirements. The time frame for meeting them would be extensive.

Advantages of this approach start with quicker protection of drinking water supplied to Tolleson residents. Arguments among parties involved in this approach would be limited to how much each will donate to the trust fund. This would allow the resources to be focused more on protecting the public health than on fueling lawsuits.

This option faces some of the same disadvantages as the aquifer reclassification option. Although there will be hot spot containment and source control, some dissolved VOCs will remain present over a large area. This will require treatment of groundwater before consumption. Citizens would be likely to accept this approach if there is no added household cost. Other cities, including Scottsdale, Arizona and some in California, are blending treated water into the public supply system.

Although this option will face difficult obstacles from both regulatory and community views, ADEQ feels that this approach provides the best protection of public health, welfare, and the environment within a reasonable time frame.

DETAILED DESCRIPTION OF THE CONCEPT

Activities Under The Concept

As briefly mentioned above, the basic concept is to require each responsible party to control their respective sources and to contribute to a trust fund for the management of the remainder of the contaminant plume. Different levels of work will be necessary by each of the responsible parties, as some may involve soil contamination only while others may have dense non-aqueous phase liquids (DNAPLs) contaminating groundwater.

Conceptually, after 10 years of operation of this approach, it is expected that the TCE and PCE sources would be isolated from the remaining portion of the plume. In the eastern portion of area, contamination from the Motorola plant will become a separate area of contamination, accomplished by a currently operating line of extraction wells along 46th Street. This isolation is similar to what would be expected at each source facility as they each perform their source control activities. Although the sources would be isolated or remediated, a large area of contamination above MCLs would remain. This contamination would be managed by the trust fund under this approach, and be allowed to naturally attenuate.

ADEQ has developed some preliminary cost estimates for steps to ensure that the public is not exposed to contaminated water. Wellhead treatment for the 5 City of Tolleson public supply wells will require capital investment of approximately $1.3 million, and require $400,000 for annual operation and maintenance. The cities of Avondale, Laveen, and Phoenix also have 5 wells in the same area which may require similar wellhead treatment. The City of Tolleson has been working on alternatives for providing safe water. The cost estimates provided here are for comparison purposes only. More appropriate alternatives may exist.

Beyond wellhead treatment for the city of Tolleson, there will be areas within the plume where private wells may also require protection. Assuming that 250 of such private wells may exist, ADEQ estimates that approximately $2,000,000 in capital will be required to treat the water from these wells, and

approximately $270,000 annually would be required for operation and maintenance. These figures would likely be spread across a number of years, since not all of the 250 assumed private wells would require action in the first year.

In addition to the minimum needs of protecting the public and private water wells, there are several other actions that could be taken using the trust fund money. Some hydraulic control of the contaminant plume may be gained by relocating existing irrigation wells to more beneficial locations. In this case ADEQ would use the trust fund to provide replacement wells for irrigation water purveyors, such as the Roosevelt Irrigation District. Operation and maintenance of those wells would be conducted by the irrigation water purveyor. As these types of wells are deep, high-volume wells, installation costs may average $300,000 per well.

The potential for bioremediation techniques to accelerate groundwater restoration is currently being researched at other sites being overseen by ADEQ. Laboratory tests of this method have been promising, and field tests are underway. If bioremediation proves to be beneficial, trust fund money may also be used to strategically locate a number of bioremediation facilities within the plume. The costs for this are still under development, however they are not expected to be prohibitive.

Funding The Activities

A main component of this concept for managing this contamination is the development of a trust fund. The basic activities to be funded were described above. To address only the basic needs of protecting the private and public water supplies within the plume, ADEQ's preliminary calculations indicate that an initial fund of approximately $25,000,000 to $30,000,000 would be required. This does not take into account potential in-plume treatments, such as bioremediation or relocation of irrigation wells. The potential for orphan sites, whose sources ADEQ would necessarily need to control, is also not accounted for. These factors, as well as regulatory oversight costs, would require a certain percentage increase in the calculated initial fund amount. Once these factors are included, the required initial trust fund amount could easily double.

It is expected that the known responsible parties would be required to develop this initial fund under a formal agreement. ADEQ feels that this is considerably more attractive than participation in what could be an $800,000,000 project. This, and providing source control, would likely be the extent of each party's liability.

THE NEXT STEP

ADEQ has been coordinating with the U.S. EPA and the Arizona Department of Water Resources during development of the initial concept. A number of industry members who may be invited to participate have been briefed. Others who have been briefed include the City of Tolleson and City of Phoenix governments, and the Gateway Neighborhood Coalition representing the community impacted by the Motorola 52nd Street Site. These introductory meetings have generated much discussion and identified a number of issues requiring resolution. Some of the issues identified to date include:

- The characteristics of the plume are not fully understood
- It is unclear what impact this concept will have on remedial actions at other sites across the state
- The exact requirements of source control and hot spot pumping have not been defined
- The area to managed by this concept is not fully defined

Generally positive responses have been received from the groups contacted so far. Once the initial contacts with potentially impacted groups are complete, ADEQ can be confident in committing resources toward full development of the concept. Efforts to complete the development may include detailed study of the feasibility of traditional approaches, computer modelling of the groundwater contamination, and continued community involvement.

REFERENCES CITED

Dames & Moore, 1993. Draft Aquifer Test Report, Well DM-518, Motorola 52nd Street. October 1993.

Brown & Caldwell, 1994. First Quarter 1994 Groundwater Monitoring Report, Phoenix Terminal Group, Phoenix Arizona. June 3, 1994.

SESSION 4C:

COMPUTER APPLICATIONS IN WATER RESOURCE STUDIES (PART 2)

Moderator: Bradley M. Hill
Arizona Department of Water Resources

PROJECTIONS FOR LONG-TERM GROUNDWATER YIELD FROM THE COCONINO-SUPAI AQUIFER, LAKE MARY AREA, NORTHERN ARIZONA[1]

Daniel S. Weber and Errol L. Montgomery[2]

ABSTRACT: Long-term groundwater yield from the Coconino-Supai aquifer was estimated for the area comprising Kaibab National Forest lands south and east from the City of Flagstaff, including the Lake Mary municipal wellfield. Long-term sustainable yield of groundwater from the Coconino-Supai aquifer and Lake Mary wellfield was defined as the condition where the maximum quantity of groundwater can be withdrawn annually without serious long-term depletion of storage in the aquifer. Based on flow net analysis and groundwater flow modeling for the recharge areas south from the Lake Mary wellfield area, an upper limit for annual long-term sustainable yield of groundwater from the Coconino-Supai aquifer in the Lake Mary area is judged to be about 4.5 million gallons per day. Because the Lake Mary wellfield is not capable of capturing all of the regularly replenished groundwater in the Coconino-Supai aquifer without causing substantial decline in groundwater level near pumping wells and depletion of groundwater in storage, the long-term sustainable yield for the Lake Mary wellfield is less than the long-term sustainable yield for the Coconino-Supai aquifer. Based on analysis of modeling projections for pumping regimens, the upper limit for annual long-term sustainable yield for the Lake Mary wellfield, as presently configured, is judged to be about 2.1 million gallons per day.

INTRODUCTION

Groundwater flow modeling investigations for the Lake Mary area were conducted for City of Flagstaff as part of a comprehensive program for evaluation of potential long-term yield from the Lake Mary wellfield and regional Coconino-Supai aquifer, and for selection of sites for future production water wells. Hydrogeologic investigations included:

- formulation of a conceptual model for occurrence and movement of groundwater in the Lake Mary area based on review of historic reports and records of hydrogeologic conditions;

[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.
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- compilation and analysis of long-term pumping data and groundwater level data to estimate aquifer parameters;
- design, construction, and operation of a computer-based groundwater flow model to assist in projecting long-term groundwater yield for the Coconino-Supai aquifer and the Lake Mary wellfield; and
- preparation of recommendations for wellfield operation and selection of sites for future production water wells.

HYDROGEOLOGIC CONDITIONS

The San Francisco Plateau in northern Arizona, which includes the Lake Mary area, is characterized as having relatively large amounts of precipitation and small amounts of perennial streamflow. Fractured and porous rocks at land surface in the plateau area enhance rapid infiltration of precipitation and percolation to underlying aquifers. Surface water runoff generally occurs only during extreme precipitation events or from rapid snowmelt. The Lake Mary wellfield is located about 8 miles southeast from Flagstaff. The Lake Mary area includes Upper and Lower Lake Mary and encompasses a drainage area of about 95 square miles. A location map for the Lake Mary area is shown on Figure 1. The wellfield is adjacent to the downthrown side of the Anderson Mesa fault and is in the vicinity of Lower Lake Mary.

Stratigraphy and Hydrogeologic Characteristics

Hydrogeologic features of the Lake Mary area were described by Cooley (1962), Harshbarger and Carollo (1972), Harshbarger and Associates (1976 and 1977), and Montgomery & Associates (1992a, 1992b, and 1993). The rock units in the Lake Mary area, in descending order are: alluvial and colluvial deposits, volcanic rocks, Moenkopi Formation, Kaibab Formation, Coconino Sandstone, Supai Group, Redwall Limestone, Martin Formation, and Precambrian crystalline rocks. The Coconino Sandstone and upper part of the Supai Group comprise the principal aquifer for City of Flagstaff Lake Mary wellfield. The Coconino-Supai aquifer is also the regional aquifer for large areas of northern Arizona.

Structural Features

The occurrence of faults and fractures in the Lake Mary area controls the occurrence and movement of groundwater and potential yield from wells. The principal structural feature in the Lake Mary area is the Anderson Mesa fault extending north from Mormon Lake to Upper and Lower Lake Mary, and then northwest toward Flagstaff (Figure 1). In the vicinity of the Lake Mary wellfield this principal fault trends northwest; near the dam at Lower Lake Mary the trend of the fault changes to northward. Maximum

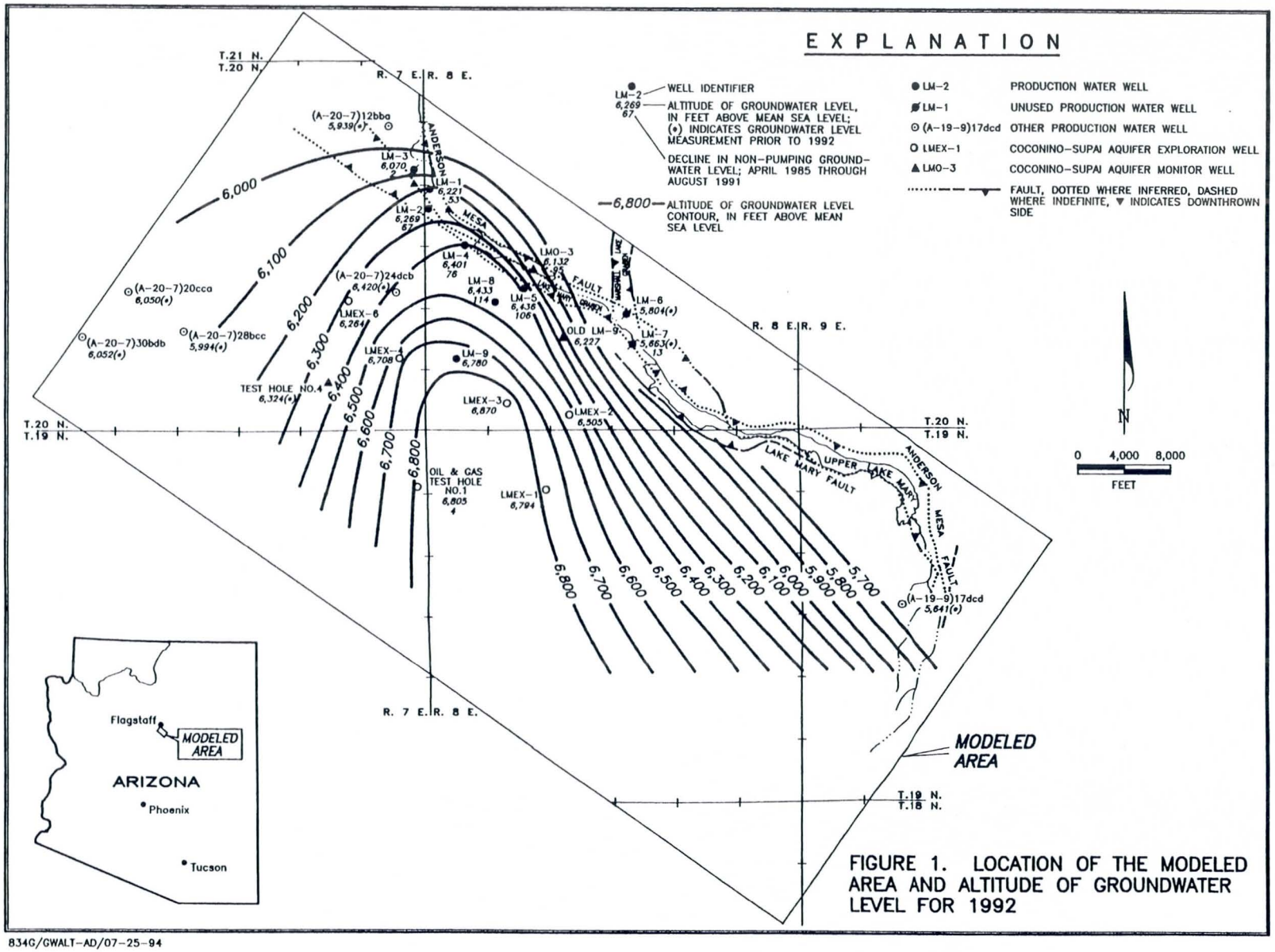

FIGURE 1. LOCATION OF THE MODELED AREA AND ALTITUDE OF GROUNDWATER LEVEL FOR 1992

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topographic displacement on the fault is about 400 feet; maximum stratigraphic displacement is projected to be about 700 feet (Harshbarger and Associates, 1977).

Faulting in the Lake Mary area is characterized by reverse drag movement and by the occurrence of downthrown or graben fault blocks adjacent to the downthrown side of the Anderson Mesa fault. Hydraulic conductivity of rock units is believed to be largest in the deepest parts of graben fault blocks. Numerous secondary faults, which range from subparallel to oblique to Anderson Mesa fault, have been observed and have been postulated to exist in the Lake Mary area. The Lake Mary fault is a prominent secondary fault and together with the Anderson Mesa fault, delineates the Lake Mary graben (Figure 1).

Groundwater Features

Groundwater in the Coconino-Supai aquifer moves from areas of recharge to areas of discharge. In the study area, groundwater recharge occurs chiefly from infiltration of rainfall and snowmelt in the south-central and southeast parts of the Lake Mary area. Recharge percolates downward through the fractured and permeable surficial rocks to the Coconino-Supai aquifer. Groundwater movement in the Coconino-Supai aquifer is believed to occur chiefly in fractures that are concentrated along principal and secondary faults. These faults function as drains through which groundwater discharges from the Coconino-Supai aquifer to the Redwall-Martin aquifer. Most of the natural groundwater discharge from the Coconino-Supai aquifer to the Redwall-Martin aquifer is believed to occur near these principal and secondary faults.

Average annual precipitation for the years 1962 through 1991 at the Flagstaff airport, about 6 miles northwest from the Lake Mary wellfield, was approximately 21 inches. Average annual precipitation in the south-central and southeast parts of the Lake Mary area is believed to be larger. Using analytical flow net analysis and numerical groundwater flow modeling analysis for the Coconino-Supai aquifer, estimates for annual recharge via infiltration in the Lake Mary area range from 4 to 17 percent of average annual precipitation recorded at Flagstaff airport; average was calculated to be about 9 percent of average annual precipitation recorded at Flagstaff airport. Annual recharge via infiltration to the Coconino-Supai aquifer for the Lake Mary drainage area was evaluated from flow net and modeling analysis to range from about 0.8 inches per year to about 3.6 inches per year; average was evaluated to be about 1.9 inches per year. Simmers (1988) compiled regional studies estimating natural groundwater recharge from precipitation for various hydrogeologic and climatologic regions of the world. Average annual recharge via infiltration for regions similar to the Lake Mary area range from 3 to 25 percent of average annual precipitation. Previous investigations conducted by Duren Engineering (1983) and HDR Infrastructure (1986) for the Lake Mary area estimated recharge via infiltration to be about 1 inch per year, or about 5 percent of average annual rainfall measured at Flagstaff airport.

Groundwater Occurrence and Movement in the Coconino-Supai Aquifer

In much of the Lake Mary wellfield area, the upper part of the Coconino-Supai aquifer is not fully saturated and in these areas the aquifer is unconfined. In the Lake Mary graben and the Marshall Lake graben, saturated thickness of the Coconino-Supai aquifer is small. The full thickness of the Coconino-Supai aquifer is saturated and the aquifer is confined in the south-central and southeast parts of the Lake Mary area, including the area near Lake Mary production water well LM-9.

Contours of altitude of groundwater levels for 1992 for the Coconino-Supai aquifer in the Lake Mary area are shown on Figure 1. Groundwater level altitude in the Coconino-Supai aquifer ranges from more than 6,800 feet in the south-central and southeast parts of the Lake Mary area, to less than 5,700 feet near the intersection of Lake Mary graben and Marshall Lake graben and in the extreme east part of the Lake Mary area. Depth to non-pumping groundwater level in Lake Mary production water wells ranges from 94 feet at well LM-9 to 568 feet at well LM-2.

Groundwater level data for City of Flagstaff production water wells completed in the Coconino-Supai aquifer in the Lake Mary area are summarized in Table 1. Groundwater level data were reported by Harshbarger and Associates (1976 and 1977), HDR Infrastructure (1986), Montgomery & Associates (1992a, 1992b, and 1993), and were obtained from the files of the Arizona Department of Water Resources, Water Resources Division of United States Geological Survey, and City of Flagstaff. Complete historic water level data including monitor wells, exploration wells, and other production water wells in the Lake Mary area was reported in Montgomery & Associates (1993). Except for the Lake Mary wellfield area and surrounding Lake Mary exploration wells, water level data are sparse and directions of groundwater movement are poorly known. At the north, east, and west boundaries of the study area, ground-water level contours are based on water level measurements obtained prior to 1992. Therefore, water level conditions shown on Figure 1 are approximate, and only tentative conclusions can be made for areas in which no wells or recent data exist.

The direction of lateral groundwater movement in the Coconino-Supai aquifer is indicated from inspection of Figure 1. Groundwater moves parallel to the direction of the maximum water level gradient, which is perpendicular to water level contours. The general pattern of groundwater movement is from areas of recharge, located in the south-central and southeast parts of the Lake Mary area, to principal areas of groundwater discharge from the area, located in the north and west parts of the Lake Mary Area.

Groundwater discharge from the Coconino-Supai aquifer in the Lake Mary area occurs chiefly via deep percolation, enhanced in areas of extensive fracturing, to the Redwall-Martin aquifer, and by pumping municipal production water wells. In many parts of the Lake Mary area, vertical groundwater movement downward to the Redwall-Martin aquifer is larger than lateral groundwater movement through the Coconino-Supai aquifer.

TABLE 1. SUMMARY OF HYDROGEOLOGIC DATA FOR LAKE MARY WELLFIELD PRODUCTION WATER WELLS, COCONINO-SUPAI AQUIFER, COCONINO COUNTY, ARIZONA

WELL IDENTIFIER	DATE COMPLETED	ALTITUDE OF LAND SURFACE (feet,msl)[a]	DEPTH DRILLED (feet)	PERFORATED INTERVAL (feet,bls)[b]	...NON-PUMPING WATER LEVEL.... DEPTH (feet)	DATE MEASURED	ALTITUDE (feet,msl)
LM-1	10/1962	6,839.75	1,287	790-826	587.00	10/1962	6,252.75
					576.09	03/1975	6,263.66
					562.8	04/1985	6,277.0
					616.20	09/1991	6,223.55
					619.01	10/1992	6,220.74
					621.12	03/1993	6,218.63
					619	10/1993	6,221
LM-2	11/1964	6,837	1,091	569-1,081	432.42	04/1965	6,405
					474.00	03/1975	6,363
					498.00	02/1985	6,339
					475.00	01/1987	6,362
					483.20	03/1988	6,354
					550.5	09/1991	6,287
					568	09/1992	6,269
					573.3	02/1993	6,264
LM-3	06/1965	6,830	1,050	715-1,032	760.37	11/1965	6,070
					760.00	03/1975	6,070
					761.3	04/1985	6,069
					759.4	04/1991	6,071
					759.5	09/1992	6,070
LM-4	09/1972	6,809	1,345	800-1,280	334.90	02/1973	6,474
					329.00	03/1975	6,480
					326.30	04/1985	6,483
					401.70	09/1991	6,407
					407.80	09/1992	6,401
LM-5	12/1975	6,817.9	1,336	650-1,325	275.0	12/1975	6,542.9
					281.2	04/1985	6,536.7
					387.1	09/1991	6,430.8
					382.4	09/1992	6,435.5
					396.6	03/1993	6,421.3
LM-6	---	6,800	1,298	421-OH[c]	1,045	08/1978	5,755
					996	11/1980	5,804
LM-7	10/1978	6,792	1,630	1,107-1,607	1,091	10/1978	5,701
					1,116.0	09/1988	5,676
					1,128.7	09/1991	5,663
LM-8	03/1982	6,822.7	3,393	600-1,300	257.4	03/1982	6,565.3
					272.4	04/1985	6,550.3
					386.4	09/1991	6,436.4
					389.4	09/1992	6,433.3
					385.9	03/1993	6,436.8
LM-9	08/1991	6,874.6	1,414	357-1,318	108.89	09/1991	6,765.7
					94.31	05/1992	6,780.3
OIL & GAS[d] TEST HOLE NO.1	08/1976	7,177.5	3,512	404-OH	365.0	08/1988	6,812.5
					368.5	09/1991	6,809.0
					372.25	09/1992	6,805.3
					372.34	03/1993	6,805.2

[a] feet,msl = feet above mean sea level

[b] feet,bls = feet below land surface

[c] OH = open hole

[d] potential site for production water well

Yield from the Coconino-Supai Aquifer

The five active municipal wells that comprise the Lake Mary wellfield, are production water wells LM-2, LM-4, LM-5, LM-8, and LM-9. These production water wells were constructed between 1964 and 1991 (Table 1). The Lake Mary wellfield has a combined potential pumping rate judged to be about 5.3 million gallons per day (MGD). Maximum reported pumping rates for the Lake Mary production water wells are:

Well	Pumping Rate (MGD)
LM-2	0.60
LM-4	1.01
LM-5	0.69
LM-8	2.45
LM-9	0.58

Prior to 1975, the Coconino-Supai aquifer was in an approximate state of hydraulic equilibrium; groundwater inflow to the aquifer was approximately equal to groundwater outflow from the aquifer and storage did not change substantially. Combined annual groundwater pumping rate from Lake Mary production water wells is shown on Figure 2.

Beginning in 1975, larger quantities of groundwater were withdrawn from the Lake Mary wellfield for municipal use by the City of Flagstaff. Groundwater withdrawals from April 1975 through April 1985 ranged from about 0.1 to 1.0 MGD; average for this period was about 0.6 MGD. These groundwater withdrawals resulted in minor changes in hydraulic equilibrium measured by minor changes in groundwater levels at wells in the Lake Mary wellfield. Change in groundwater levels in the Lake Mary wellfield from April 1975 through April 1985 ranged from a rise in water level of 9 feet at well LM-5 to a decline in water level of 24 feet at well LM-2; average non-pumping groundwater level for the wellfield declined about 7 feet.

Groundwater withdrawals increased substantially during the period April 1985 through August 1991, ranging from 0.9 to 4.2 MGD (Figure 2). Average groundwater withdrawal for the period April 1985 through August 1988 was about 0.8 MGD; average for the period September 1988 through August 1991 was about 3.0 MGD. Groundwater withdrawal for 1992 was 2.5 MGD. Large groundwater withdrawals during recent years have resulted in substantial water level decline centered on the Lake Mary wellfield. Non-pumping groundwater levels in the Lake Mary wellfield from April 1985 through August 1991 are included in Table 1. Maximum groundwater level declines for this period ranged from 68 feet at well LM-2 (1988 through 1991) to 114 feet at well LM-8 (1985 through 1991); average non-pumping groundwater level declined about 91 feet in the Lake Mary production water wells during the period April 1985 through August 1991 (Figure 1).

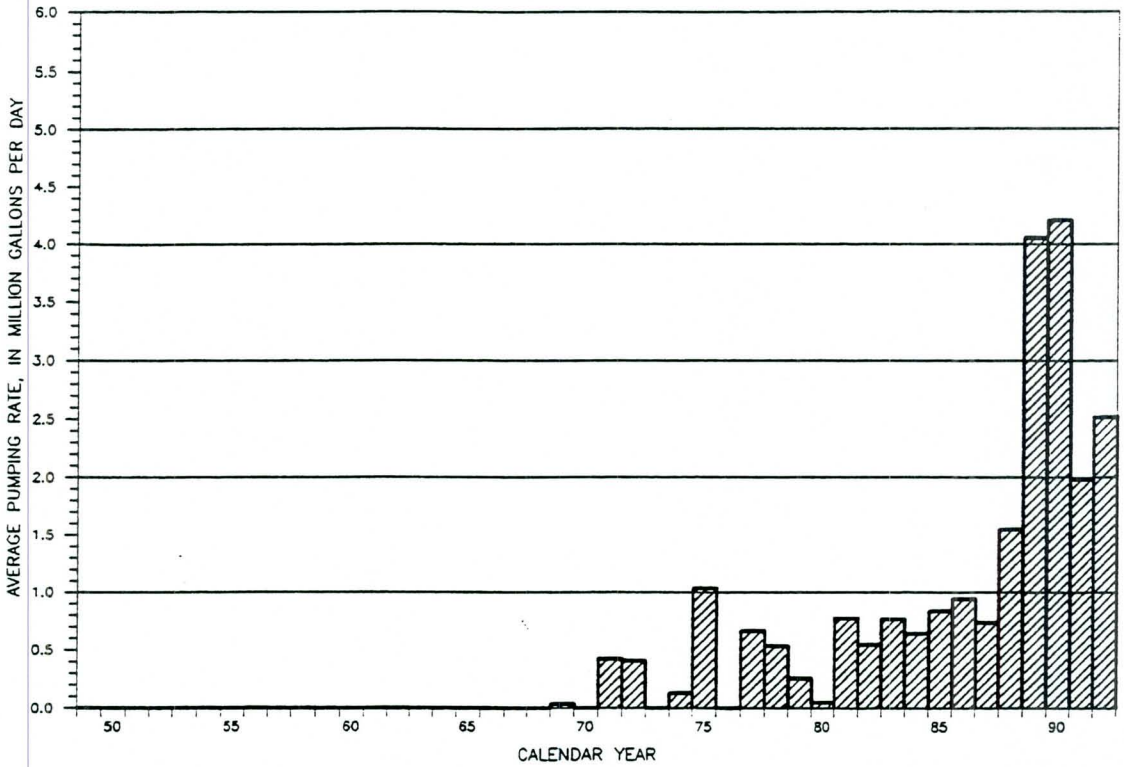

FIGURE 2. GROUNDWATER PUMPED FROM LAKE MARY PRODUCTION WATER WELLS

GROUNDWATER FLOW MODEL

To project the long-term sustainable yield from the Coconino-Supai aquifer and the Lake Mary wellfield, a steady-state and transient computer-based groundwater flow model for the Lake Mary area was constructed using MODFLOW, a finite-difference groundwater flow model developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). MODFLOW is frequently used in groundwater resource investigations, more commonly for simulation and analysis of porous media aquifers, but is also used for modeling fractured rock aquifers (Bubey and Prudic, 1991).

The Lake Mary area groundwater flow model was constructed to encompass the Coconino-Supai aquifer in the Lake Mary wellfield area, and in important recharge areas lying south and southeast from the wellfield (Figure 1). The area investigated using the groundwater flow model is about 78 square miles (Figure 1). Dimensions for the model grid cells range from 1,000 to 2,000 feet on a side; each cell represents an area ranging from about 1,000,000 to 2,000,000 square feet or about 0.04 to 0.07 square miles. Small grid cells are located to encompass the Lake Mary wellfield where hydrogeologic parameters for the Coconino-Supai aquifer are best defined and where the most critical changes in hydrogeologic parameters occur. Large grid cells are located in the peripheral areas where hydrogeologic data are sparse and where details for

changes in hydrogeologic parameters are less critical for projection of regional water level drawdown. A detailed description of the flow model is given in Montgomery & Associates (1993).

Boundary Conditions

For groundwater flow modeling projections of long-term groundwater yield, groundwater underflow into and out of the Coconino-Supai aquifer in the model area is represented by specified flux boundaries in the area of the Lake Mary graben; head dependent flux boundaries are specified along the south, east, and west perimeter of the model (Figure 1). Analysis of a groundwater flow net and results of the groundwater flow model based on groundwater level contours for 1975 groundwater level measurements indicate groundwater underflow into the model area may be approximately 1.4 MGD and groundwater underflow out of the model area may be approximately 8.9 MGD. Groundwater underflow into the model area is chiefly from the Mormon Mountain area and adjacent areas, in the south-central and southeast parts of the Lake Mary area. Groundwater underflow out of the model area is chiefly along Upper and Lower Lake Mary, into the Lake Mary graben and then downward to the Redwall-Martin aquifer (Figure 1).

Hydraulic Conductivity

Hydraulic conductivity for the Coconino-Supai aquifer in the model area was interpolated for each grid cell from analysis of results of aquifer tests and pumping tests for wells in the vicinity of the Lake Mary wellfield and from analysis of a groundwater flow net. Hydraulic conductivity assigned to individual cells for the model area ranged from 0.5 to 18 gallons per day per square foot of aquifer at 1:1 hydraulic gradient (gpd/ft^2).

Recharge

Recharge via infiltration was assigned to selected model grid cells in the south-central and southeast parts of the model area to simulate groundwater movement from the axial part of the groundwater mound (Figure 1). The total rate of recharge via infiltration in this area was calculated to be 4.5 MGD from analysis of the groundwater flow net, or about 3.6 inches per year for the area. Recharge via infiltration was also assigned to model grid cells which do not occur on the groundwater mound. The rate of recharge via infiltration to model grid cells which do not occur on the groundwater mound was calculated to be 3.0 MGD from analysis of the groundwater flow net, or about 0.8 inches per year for the area. Total rate of recharge via infiltration for the entire model area was calculated to be about 7.5 MGD, or an average of about 1.9 inches per year for the entire model area.

Groundwater Pumping

Pumping data for production water wells in the Lake Mary wellfield were provided by City of Flagstaff. The quantity of groundwater pumped from the wellfield for the years 1969 through 1992 is shown on Figure 2. Records for groundwater pumped from wells for the period April 1985 through September 1991 were used in the MODFLOW model to project groundwater level drawdown conditions for September 1991 and to calibrate assigned aquifer parameters used in the model. Groundwater pumped from wells from a 90-day aquifer test was also used to calibrate assigned aquifer parameters for the model.

Initial Groundwater Level Altitude

Prior to large increases in groundwater withdrawals from the Lake Mary wellfield, the most comprehensive non-pumping groundwater level measurements for the wells in the model area were compiled by Harshbarger and Associates (1976) **(Table 1)**. Average initial groundwater level altitude in the Coconino-Supai aquifer was determined using the groundwater level measurements for 1975, and using groundwater level measurements for wells outside the wellfield obtained in other years.

Calibration

The model was calibrated against a steady-state condition and two different transient-state conditions to enhance uniqueness of the solution. Groundwater level conditions for 1975 are believed to give the best representation for hydraulic head for the Coconino-Supai aquifer during a period of hydraulic equilibrium. The 1975 groundwater level conditions were used as a basis for calibrating the MODFLOW groundwater flow model for steady-state aquifer conditions. The calibration procedure for the steady-state model included varying aquifer parameters within limits indicated by hydrogeologic conditions and by the groundwater flow net analysis until the groundwater level altitude contours projected by the model closely matched observed groundwater level altitude contours.

In addition to a comparison of projected and observed groundwater level altitude contours, agreement between projected and observed groundwater level altitudes was statistically determined by means of root-mean square (RMS) deviation (Anderson and Woessner, 1991). The RMS deviation is analogous to the standard deviation and measures the mean departure of projected groundwater level altitude distribution to the observed groundwater level altitude distribution.

For reasonable calibration, the RMS deviation was not allowed to vary by more than 10 percent of the total change in groundwater level altitude in the Lake Mary model area. Using the groundwater level altitudes for the 18 wells shown on Figure 1 as calibration targets, the RMS deviation for the steady-state flow model was less than 5 percent of the total change in groundwater level altitude.

Based on historic groundwater level measurements (Table 1), near steady-state groundwater level conditions in the Lake Mary wellfield existed until about 1985. After groundwater withdrawals increased, most notably in 1988 and subsequent years, the Coconino-Supai aquifer in the Lake Mary wellfield area is believed to have been in a transient state of groundwater depletion. For transient-state conditions, groundwater outflow is more than or less than inflow and the amount of groundwater in storage in the aquifer changes with time. Transient-state calibration and verification of the steady-state model was accomplished by matching projected groundwater level decline computed by the model to observed groundwater level decline resulting from Lake Mary wellfield pumping for the period April 1985 through August 1991, and to observed groundwater level decline during a 90-day aquifer test conducted during the period September 1992 through March 1993.

Contours of groundwater level decline projected by the model for April 1985 through August 1991 are shown on Figure 3. Input parameters for the transient model included: initial altitude of groundwater level for 1975 from the steady-state model, aquifer parameters from the steady-state model, and reported pumping for April 1985 through August 1991. Values for observed groundwater level decline and projected groundwater level decline computed by the model for wells in the Lake Mary wellfield and surrounding area for the period 1985 through 1991 are shown on Figure 3. The model-projected August 1991 groundwater level conditions were used to define initial groundwater level altitude for projections of groundwater yield for the Coconino-Supai aquifer and the Lake Mary wellfield.

Sensitivity Analysis

The sensitivity of the calibrated groundwater flow model to uncertainties in definition of aquifer parameters was analyzed by varying changes in hydraulic conductivity, storage coefficient, and recharge within reasonable ranges of values. The sensitivity analysis for the model was conducted for the transient pumping period April 1985 through August 1991 by systematically varying individual aquifer parameters. Projected groundwater level decline for each sensitivity model run was compared to projected groundwater level decline from the calibrated model and observed groundwater level decline in the Lake Mary wellfield for August 1991.

Results of the sensitivity analysis for the groundwater flow model in the area of the Lake Mary wellfield for the transient period of pumping indicate that model sensitivity to increases in hydraulic conductivity and storage coefficient is moderate, and sensitivity to decreases in hydraulic conductivity and storage coefficient is large.

Sensitivity to decreases in recharge in the Lake Mary wellfield area for the transient period of pumping is small; sensitivity to increases in recharge is moderate. Results of the sensitivity analysis for short-term changes in recharge via infiltration, simulating years of below average or above average precipitation, indicate groundwater level response in the Lake Mary wellfield to drought conditions is small and sensitivity to flood conditions is moderate.

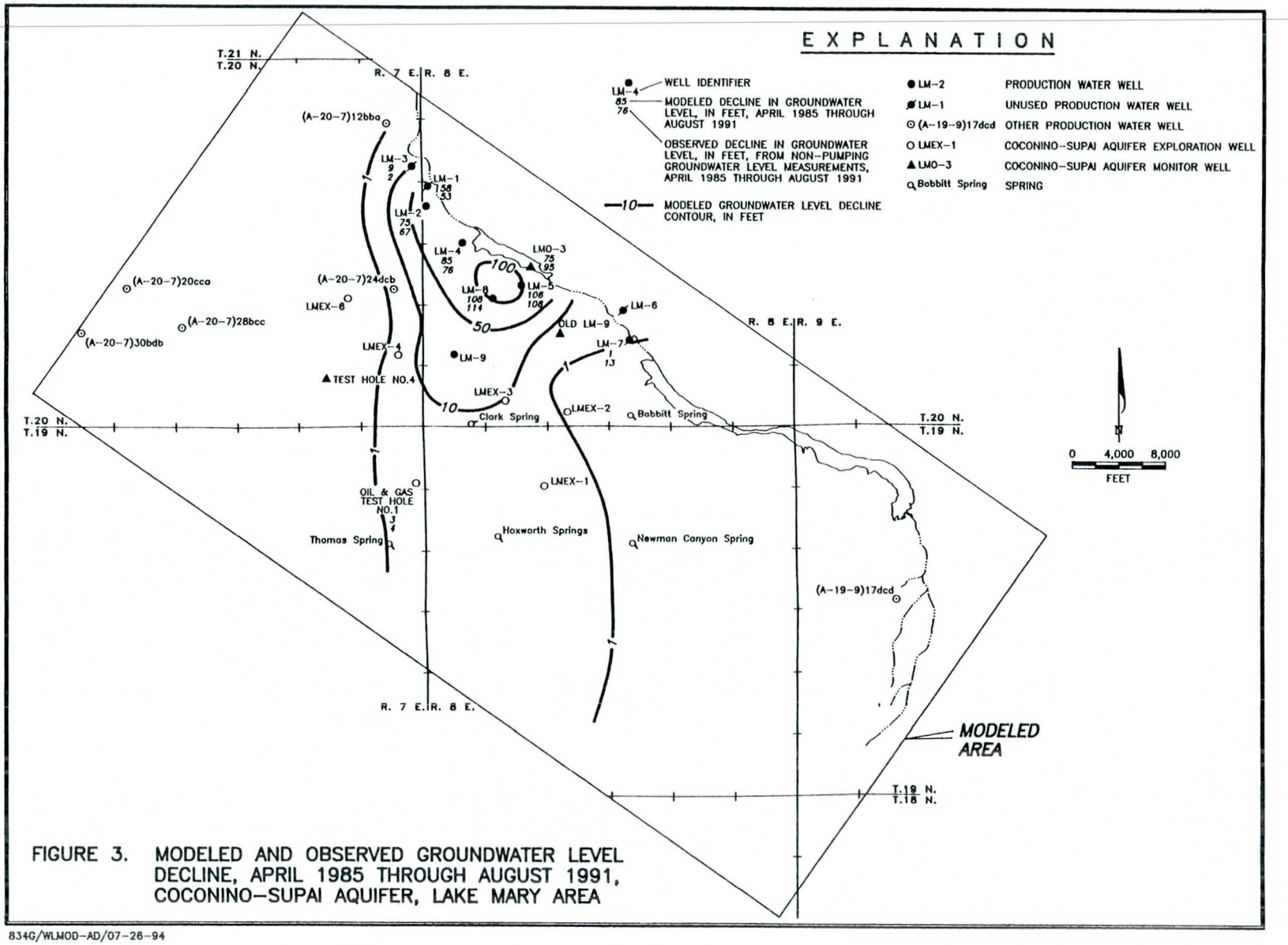

FIGURE 3. MODELED AND OBSERVED GROUNDWATER LEVEL DECLINE, APRIL 1985 THROUGH AUGUST 1991, COCONINO-SUPAI AQUIFER, LAKE MARY AREA

834G/WLMOD-AD/07-26-94

Projections for Long-Term Groundwater Yield

The groundwater flow model was used to project long-term sustainable yield of groundwater for the Coconino-Supai aquifer and the Lake Mary wellfield. Long-term sustainable yield of groundwater for the Coconino-Supai aquifer and the Lake Mary wellfield is judged to be the maximum quantity of groundwater that can be withdrawn annually without substantial long-term depletion of storage in the aquifer. Based on groundwater flow net analysis and on groundwater flow modeling of the recharge areas south and southeast from the Lake Mary wellfield, an upper limit to annual long-term sustainable yield for the Coconino-Supai aquifer in the Lake Mary area is judged to be about 4.5 MGD.

Pumping Regimens

Because the Lake Mary wellfield is not capable of capturing all recharge to the Coconino-Supai aquifer without causing substantial drawdown near pumping wells and local depletion of groundwater in storage, the long-term sustainable yield for the wellfield is less than the long-term sustainable yield for the aquifer. The groundwater flow model was used to project long-term sustainable groundwater yield for the Lake Mary wellfield using five pumping regimens. Pumping regimens R1 through R5 are based on average annual groundwater withdrawal rates ranging from 2.1 to 4.5 MGD. The pumping regimens simulate an annual schedule of 6 months of non-peaking demand and 6 months of peaking demand. Duration of each pumping regimen was 15 years.

Pumping regimens R1 and R2 include the five active production water wells in the Lake Mary wellfield yielding groundwater at the maximum pumping rate for each well. Pumping regimens R3 and R4 include five active production wells and one or two hypothetical production water wells in the Lake Mary wellfield yielding groundwater at hypothetical maximum pumping rates for each well. Pumping regimens R3 and R4 include hypothetical production well LM-10 at the Oil and Gas Test Hole No. 1 site. Pumping Regimen R4 includes hypothetical well LM-10 and hypothetical production water well LM-11 at a site between well LM-10 and well LM-9. Pumping rates for the active and hypothetical wells for pumping regimens R1 through R4 are:

Well	Pumping Regimen	Pumping Rate (MGD)	Pumping Rate (gpm)
LM-2	R1, R2, R3, R4	0.60	420
LM-4	R1, R2, R3, R4	1.01	700
LM-5	R1, R2, R3, R4	0.69	480
LM-8	R1, R2, R3, R4	2.45	1,700
LM-9	R1, R2, R3, R4	0.58	400
LM-10	R3, R4	1.01	700
LM-11	R4	1.01	700

Pumping regimen R5 includes the five active production wells yielding groundwater at smaller pumping rates than reported maximum rates for individual wells. Pumping rates for pumping regimen R5 are:

Well	Pumping Regimen	Pumping Rate (MGD)	Pumping Rate (gpm)
LM-2	R5	0.58	400
LM-4	R5	0.86	600
LM-5	R5	0.58	400
LM-8	R5	1.73	1,200
LM-9	R5	0.43	300

Projected Groundwater Level Decline

The upper part of the Coconino-Supai aquifer is not saturated throughout much of the Lake Mary wellfield. Because in these areas the aquifer is unconfined, groundwater level declines would result in decreases in saturated thickness of the aquifer. Well hydraulic losses could increase substantially and well efficiency would be reduced as saturated thickness of the aquifer decreases. The groundwater flow model can not project increasing well losses and reduction of well efficiency due to declining saturated thickness of the aquifer. Groundwater level decline at production water wells is expected to increase at a rate larger than projected by the groundwater flow model if the altitude of pumping groundwater level declines below about two-thirds of the original saturated thickness of the aquifer.

Using pumping rates and schedules for pumping regimens R1 through R4, groundwater level altitude after 15 years of pumping in the five active production water wells is projected below the altitude of two-thirds saturated thickness of the aquifer. Using pumping rates and schedules for pumping regimen R5, groundwater level altitude after 15 years of pumping at the five active production wells approximates the altitude of two-thirds saturated thickness of the aquifer. Results of pumping regimen R5 indicate that, after 15 years of pumping, groundwater level altitude at the Oil and Gas Test Hole No. 1 site declined about 20 feet.

Based on results of groundwater flow modeling, long-term pumping rates simulated for pumping regimens R1 through R4 are not sustainable. Long-term groundwater withdrawals would result in decline of groundwater levels to below the two-thirds saturated thickness of the aquifer at production water wells. Using pumping rates and schedules for pumping regimen R5, the altitude of pumping groundwater level after long-term pumping does not decline below the altitude of two-thirds saturated thickness of the aquifer. Based on groundwater flow modeling projections for pumping regimen R5, an upper limit to annual long-term sustainable yield for the active Lake Mary wellfield as presently configured is judged to be about 2.1 MGD.

RECOMMENDATIONS

The following recommendations are based on analysis of hydrogeologic data obtained for the Lake Mary area, and on results of model projections for long-term groundwater yield.

1) An upper limit for average annual groundwater withdrawal from the active Lake Mary wellfield as presently configured should be about 2.1 million gallons per day. This limit is based on a 12-month pumping regimen whereby production wells LM-4 and LM-5 are pumped during a 6-month non-peaking period at a combined pumping rate of about 1.4 million gallons per day. During a 6-month peaking period, wells LM-4 and LM-5 are not pumped and production wells LM-2, LM-8, and LM-9 are pumped at a combined rate of about 2.7 million gallons per day.

2) Expansion of the Lake Mary wellfield should be considered to meet peaking demands by the City of Flagstaff and to distribute ground-water withdrawals over a larger area. This development would reduce potential for local depletion of groundwater in storage. New production water wells outside of the active wellfield area would increase existing pumping capacity of the wellfield and capture a larger part of the long-term inflow to the Coconino-Supai aquifer in the Lake Mary area.

Areas for further development of the Coconino-Supai aquifer are at Oil and Gas Test Hole No. 1 and at unused production water well LM-1; however, withdrawal of groundwater from confined parts of the Coconino-Supai aquifer, such as in the area of Oil and Gas Test Hole No. 1, may impact springs that issue from shallow aquifers in the Kaibab Formation. Expansion of the Lake Mary wellfield in these areas should include monitoring of shallow aquifers. Where impact on springs is of important concern, groundwater withdrawal from the Coconino-Supai aquifer from new wells may be limited to short-term demands.

3) A monitoring program for the Lake Mary wellfield and surrounding area should be implemented and should include: 1) measurement of groundwater levels at all production and observation wells completed in the Coconino-Supai aquifer at 1-month intervals; 2) measurement of groundwater levels at observation wells completed in shallow aquifers in the Kaibab Formation at 1-month intervals, including springs that issue from the Kaibab Formation; and 3) recording pumping rates, pumping schedules, and cumulative amount of groundwater pumped at each production water well at 1-month intervals. The monitoring program should include preparation of an annual summary report.

4) After data for groundwater level drawdown and groundwater withdrawals have been obtained for a period of 3 years or more, the groundwater flow model should be refined, new projections for groundwater level decline in the Coconino-Supai aquifer should be made, and, if warranted, the groundwater flow model should be modified to include other aquifers. If additional development of the Coconino-Supai aquifer occurs, the groundwater flow model should be used to optimize Lake Mary wellfield

pumping schedules and to project the long-term sustainable yield from the expanded wellfield.

5) Hydrogeologic investigations should be conducted for potential development of the Redwall-Martin aquifer as a means to increase the capacity of long-term sustainable groundwater withdrawal in the Lake Mary area. The groundwater exploration program for the Redwall-Martin aquifer may include development of this aquifer in the area of Lake Mary and Marshall Lake grabens, and in extensively faulted areas in the vicinity of Crater 379, Howard and Priest Draws, and Railroad Tank.

ACKNOWLEDGEMENTS

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USE OF A GEOGRAPHIC INFORMATION SYSTEM TO CONSTRUCT A GROUND-WATER-FLOW MODEL OF THE ALBUQUERQUE BASIN, CENTRAL NEW MEXICO[1]

John Michael Kernodle[2]

The current investigation of the geohydrology of the Albuquerque Basin in central New Mexico began in July 1992. The first phase of the investigation was a report that described the current understanding of the geohydrologic framework and hydrologic conditions in the basin (Thorn and others, 1993). The second phase of the investigation is focused on the completion and documentation of a three-dimensional finite-difference ground-water-flow model of the basin. As of this writing (August 1994) the model has been completed and the documentation is being prepared for review and publication. The U.S. Geological Survey's involvement with the model is not over after the documentation is published, however. Recently, a cooperative agreement has been reached with the City of Albuquerque to continue updating the model as new information becomes available about the geohydrologic framework of the basin and about historical activities that might have affected real, and therefore simulated, hydrologic trends. The model is designed to be flexible and adaptive to new information. The use of a Geographic Information System (GIS) as a data-base manager is essential to assimilate the massive quantities of information needed for the current model and to meet the requirement that the model evolve as more information becomes available.

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]John Michael Kernodle is a Hydrologist at the U.S. Geological Survey, Water Resources Division, Albuquerque, New Mexico.

The model simulates ground-water flow in the valley-fill alluvium (Holocene) and basin-fill deposits (Santa Fe Group of Tertiary age) in the Albuquerque Basin, and underflow to and from adjacent basins in the Rio Grande Rift and older basins of the Colorado Plateau. The period of simulation is from 1901 (simulated as being "pre-development," even though the basin has been populated for well over 1,000 years) to spring of 1994. Fifty-nine stress periods are used to simulate the 93-year interval. The GIS was used to prepare model input for model layer tops and bottoms, hydraulic conductivities and transmissivities, vertical harmonic leakance, and storage coefficients for each of the 11 model layers. Simulated underflow to and from the basin was distributed by the GIS along the basin margin, as was mountain-front and tributary recharge. Evapotranspiration estimates for riparian vegetation were constructed from 1:24,000-scale and 1:12,000-scale data provided by the U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation for 1935, 1975, and 1989. The same agencies provided GIS data that were used to estimate agricultural irrigation-return flow to ground water for 1935, 1975, and 1992, and to locate and classify the channels of the Rio Grande, irrigation canals, laterals, ditches, and drains for 1935, 1975, 1989, and 1992. Land-surface-altitude data that were needed in conjunction with the land-use/land-cover data were obtained from U.S. Geological Survey 30-meter and 3-arc-second Digital Elevation Models. Population data from the U.S. Department of Commerce and GIS data for utility service areas from the City of Albuquerque for 1970, 1980, and 1990 were used to compute volumes of privately supplied water, imported utility-service water, and septic returns. Finally, the GIS was used to unravel the historical ground-water-withdrawal data provided by the City of Albuquerque and the State Engineer Office and format those data for model input.

Currently, the model simulates ground-water flow over an area of about 2,400 square miles to a depth of about 1,800 feet below the water table with 244 rows, 178 columns, and 11 layers. Of the 477,752 cells in the model, 310,376 are active. Because one of the major objectives of the simulations is to define the effect of ground-water withdrawals on the surface-water system, a large amount of detail is focused on the shallow-aquifer system. The top four model layers approximate the 80-foot thickness of alluvium in the incised and refilled valley of the Rio Grande. Away from the valley these layers represent the interval within the Santa Fe Group aquifer between the water table and a level 80 feet below the grade of the Rio Grande; thus, they are each equal to or greater than 20 feet in thickness. Virtually all ground-water withdrawals from the system are from the upper Santa Fe Group axial-channel deposits (the top nine model layers) in the Albuquerque area east of the Rio Grande.

Interfaces between the GIS and the numerical model allow management-level resolution of space and time on a regional scale. Enhanced numerical detail and accuracy result from the ability of the GIS to describe relevant features on a very large scale and to discretize the features into small finite-difference cells. Many of the information layers used as model input have accurately mapped and classified features as small as 1 acre, and a few have mapped features as small as a few tens of square feet. Although these small features are well beyond the resolution of the current model, they are easily reclassified to larger mapping units by area-weighted averaging. The finite-difference model has a cell resolution of one-eighth mile (200 meters) throughout the metropolitan Albuquerque area (177 square miles), and nowhere does a cell dimension exceed two-thirds of a mile. Despite the detail and focus of the model on the urban Albuquerque area, other ground-water users in the basin have begun to recognize the advantage of cooperative assistance in the study because the level of detail given to the outlying areas of the Albuquerque Basin serves their interests in ground-water and water-rights management.

The City of Albuquerque plans several uses of the completed and ongoing model. The first use will be to evaluate the consequences of possible future water-management plans. Another use of the model, to be carried out by private-sector consultants, will be to devise a long-range management plan for the City. A third use of the model, being carried out by the U.S. Bureau of Reclamation, will be to evaluate the effectiveness of recharge-enhancement strategies.

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SESSION 5A:

RIPARIAN ISSUES, POSSIBLE SOLUTIONS

Moderator: Placido Dos Santos
Arizona Department of Water Resources

SESSION 5B:

NEW APPROACHES TO GROUNDWATER CLEANUP: IN-SITU BIOREMEDIATION

Moderator: Gordon Stephenson
ASL Hydrologic and Environmental Services, Phoenix, AZ

IN SITU BIOREMEDIATION: STRATEGIES, CAPABILITIES, AND LIMITS[1]

Edward J. Bouwer[2]

EXTENDED ABSTRACT: The most important principle of bioremediation is that microorganisms (mainly bacteria) can be used to destroy hazardous contaminants or transform them to less harmful forms. The microorganisms act against the contaminants only when they have access to a variety of materials--compounds to help them generate energy and nutrients to build more cells. In a few cases the natural conditions at the contaminated site provide all the essential materials in large enough quantities that bioremediation can occur without human intervention--a process called natural or intrinsic bioremediation. More often, bioremediation requires construction of engineered systems to supply microbe-stimulating materials--a process called engineered bioremediation. Engineered bioremediation relies on accelerating the desired biodegradation reactions by encouraging the growth of more organisms, as well as by optimizing the environment in which the organisms must carry out the detoxification reactions.

There are many engineering challenges associated with in situ bioremediation. The combination of the intricacies of microbial processes and the physical challenge of monitoring both microorganisms and contaminants in the subsurface makes bioremediation difficult to understand. It makes some regulators and clients hesitant to trust bioremediation as an appropriate cleanup strategy. The inherent complexity involved in performing bioremediation in situ means that special attention must be given to evaluating the success of a project. There are many site-specific factors that control the success of intrinsic or engineered bioremediation. Adapted microorganisms need to be present. These can be the indigenous bacteria or introduced bacteria. The microorganisms need the proper environment and suitable chemicals (nutrients, electron donor, and electron acceptor) to function. Finally, mass transfer plays an important role in delivery of chemicals for growth and the contact between bacteria and the contaminant.

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

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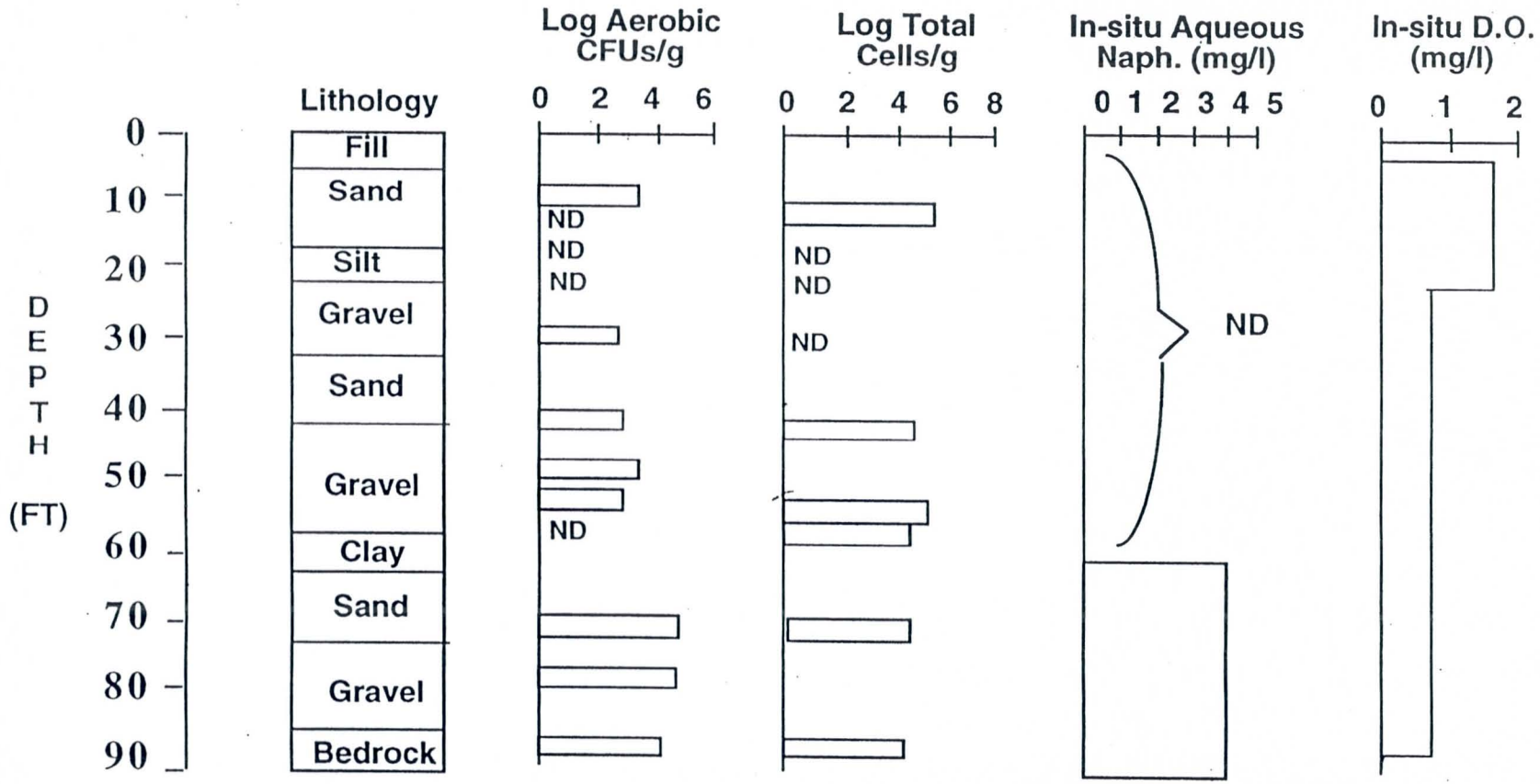
The importance of these factors will be discussed using results from field and laboratory studies which are being conducted at a former manufactured gas plant in Baltimore to examine ways to apply microbial processes for remediation. The site has extensive coal tar contamination. Microbial populations were enumerated in sediments obtained from the site. Total cell counts ranged from 8.6×10^3 to 5×10^6 cells/g dry sediment (Figure 1). Population densities did not appear to vary significantly as a function of depth. Fine-grained samples tended to contain low or undetectable populations. Aerobic plate counts were between 0 and 10^4 CFUs/g dry sediment (Figure 1) with about half the samples yielding culturable populations. For those samples with culturable populations, aerobic viable counts were generally 10- to 100-fold less than the total counts, which is typical for subsurface microflora. Aerobic CFUs were detected in samples from both relatively clean and contaminated (4 mg/L naphthalene) zones (Figure 1 gives the aqueous naphthalene concentration of the groundwater in sediment sampling locations). Dissolved oxygen in the site groundwater ranges from below detection to 2 mg/L, indicating microaerophilic or anoxic conditions throughout the site.

Sediment samples obtained aseptically from boreholes drilled on-site were incubated in the laboratory to determine if the indigenous bacteria are capable of mineralizing the principal aromatic compounds in the groundwater plume (benzene, naphthalene, and phenanthrene). Aerobic conditions were most favorable for the biotransformations. Of the 49 samples assayed under aerobic conditions, 13 samples exhibited capacity to mineralize significant ($p \leq 0.05$) quantities of naphthalene (8±3 to 43±7 %) and/or phenanthrene (3±1 to 31±3 %) during 4 weeks of incubation at 22°C. Aerobic naphthalene mineralization was more common and varied with depth as illustrated in Figure 2. Two of the 11 samples prepared and incubated under anaerobic conditions were able to mineralize naphthalene during the four week period (one positive sampling location is shown in Figure 2). Phenanthrene was not observed to degrade under anaerobic conditions. Significant benzene mineralization (6±2 to 24±1 %) was observed in 3 of 11 samples assayed for benzene, but no mineralization of this compound was observed in the 7 anaerobic samples tested. Aerobic mineralization (5±2 to 70±2 %) of acetic acid, an easily biodegraded compound which indicates biochemically active microorganisms, was detected in 20 of the 49 aerobic samples, and anaerobic mineralization (42±17 to 60± 3 %) in 4 of the 12 samples tested. Supplementing the natural sediment microcosms with nutrients (N & P) and dissolved oxygen enhanced the extent of mineralization for benzene, naphthalene, and phenanthrene. The amount of naphthalene mineralized increased at least 3-fold in the presence of stoichiometric quantities of nitrogen (as ammonia) and phosphorus (as phosphate) and dissolved oxygen in equilibrium with air (Figure 2).

Biodegradation rates in the field are significantly slower than in the laboratory because of reduced bioavailability. There must be a close association between a microorganism and contaminant for biodegradation to occur. The

Borehole B Profile



ND = Not Detected

Figure 1. Depth profile diagram of viable (CFU) and total cell counts, groundwater naphthalene concentration, and groundwater dissolved oxygen concentration.

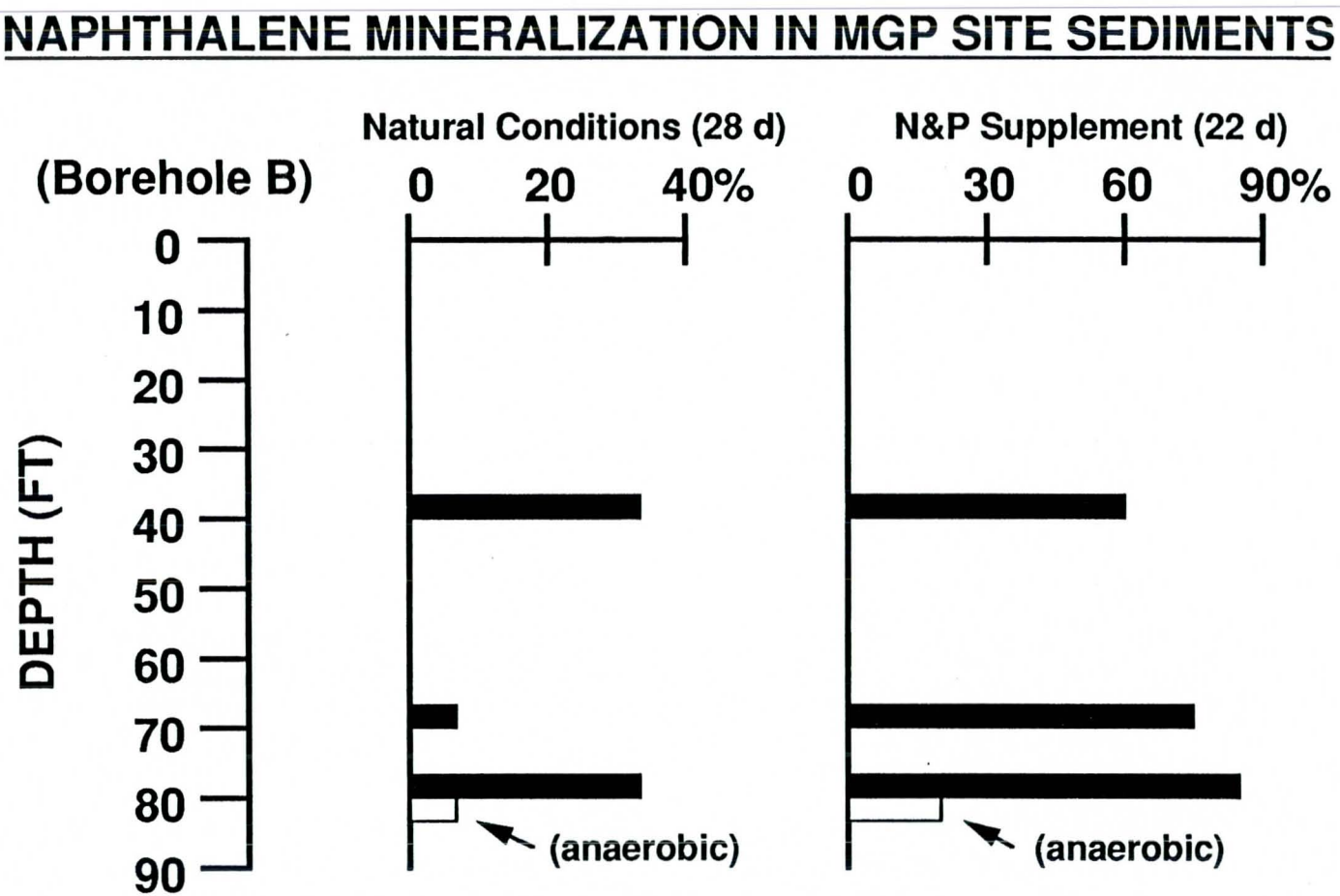


Figure 2. Depth profile diagram of naphthalene mineralization in sediment-water microcosms for Site B Borehole. Only statistically significant mineralization ($p \leq 0.05$) is shown.

contaminant must be available for uptake and utilization by the microorganism. Microorganisms and the hydrophobic pollutants are distributed among the solid, liquid, and gas phases within the subsurface as shown in Figure 3. The aromatic hydrocarbon contaminants at the site are hydrophobic, so they tend to sorb onto soil such that only a small fraction of the compound may actually be in the bulk water phase. Over long contact time, the sorbing pollutants slowly diffuse into the inorganic and organic matrix and may also form bound residues. Most evidence indicates the uptake of compounds by bacteria proceeds via the liquid phase. Consequently, a process such as sorption or volatilization that reduces the solution concentration tends to reduce the biotransformation rate. Furthermore, the accumulation of contaminants in fissures and cavities within subsurface solids renders them inaccessible to microorganisms and their enzymes. These processes decrease the bioavailability. The important conclusion from the influence of mass transfer in terms of reduced bioavailability is that the overall reaction rate is controlled by the desorption rate and not by the activity of the degrading microorganisms. The practical effect of such slow diffusion from within soil aggregates and other kinetic limitations to desorption is a decrease of the rate of removal of the contaminant, thereby increasing the time required to achieve clean-up and the amount of chemicals that must be added to sustain microbial activity. The influence of sorption on biodegradation is quantified by defining a Bioavailability Factor, B_f. A Thiele Modulus which indicates the ratio of characteristic times for sorption and biodegradation is helpful for determining the extent of mass transfer control during biodegradation of the aromatic compounds. The use of the B_f and Thiele Modulus will be developed and discussed during the conference presentation.

It is difficult to stimulate biodegradation everywhere on-site due to site heterogeneities and distributions in microbial populations. Such a bioremediation effort will require continuous site management and maintenance, which are generally expensive processes. Nonpumping approaches that do not require a continuous energy input are being developed. The approaches under investigation rely on the aquifer's intrinsically favorable conditions for biodegradation, contain the contamination, or use hydraulic barriers to direct groundwater flow through a reactive medium. The latter approach appears especially attractive for control of the dissolved hydrocarbon contamination that exists at the site. This concept is illustrated in Figure 4. The contaminant plume is treated biologically as it passes through a reactive zone within the aquifer. Impermeable walls can help direct the groundwater flow to create a more confined and controlled biological reactive zone. The merits of this approaches to bioremediation and some fruitful areas of further research will be discussed.

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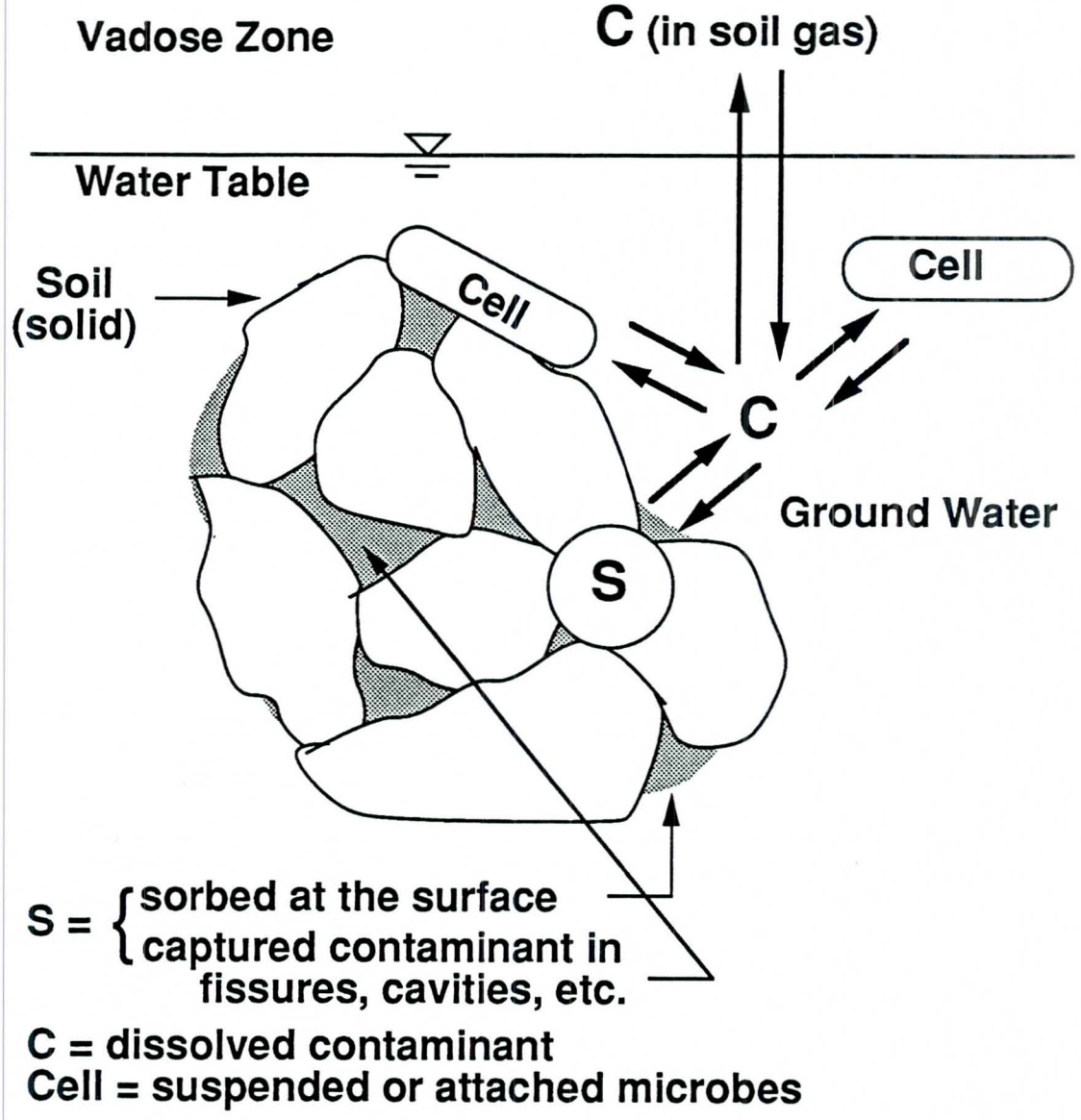

Figure 3. Distribution of microbial cells and contaminant (substrate) in the subsurface.

Plan View of Plume-Capture Bioremediation Wall

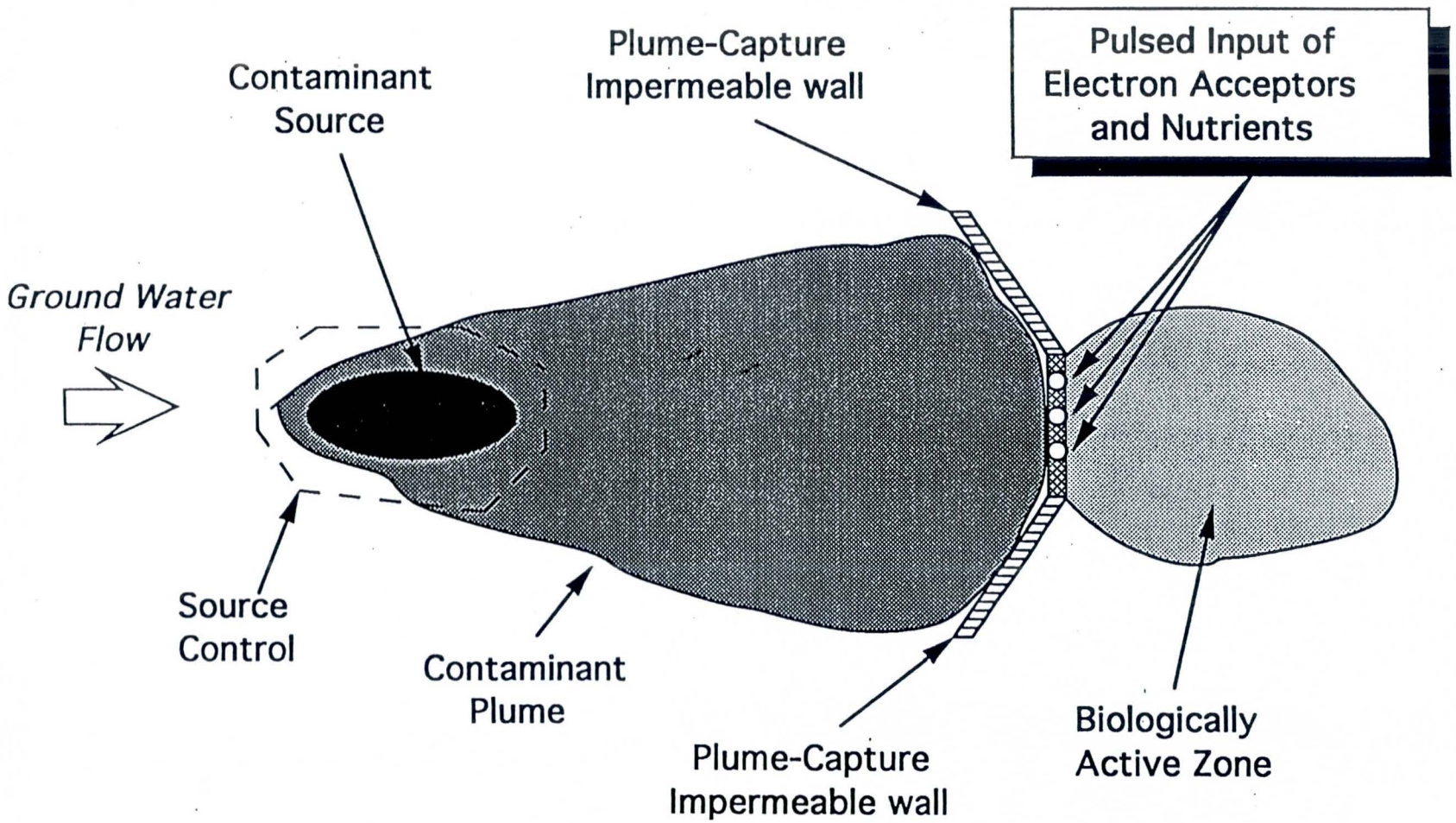

Figure 4. Process diagram for plume-capture bioremediation wall.

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AEROBIC BIODEGRADATION OVER A RANGE OF TRICHLOROETHYLENE CONCENTRATIONS WITH AND WITHOUT THE ADDITION OF A COMETABOLIC INDUCER

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The results from a bench-scale biodegradation study indicate that indigenous soil and/or groundwater microorganisms from a site in Phoenix, Arizona are capable of degrading trichloroethylene (TCE) under aerobic conditions in the absence of an amended cometabolic inducer. The potential aerobic biodegradation of TCE in groundwater was evaluated using indigenous microorganisms in bench-scale batch microcosms. The microbial populations originated from site groundwater and soil extracts. The amended microcosms received hydrogen peroxide (an oxygen source), nutrients and tyrosine (a potential cometabolic inducer) amendments. Non-amended microcosms were prepared to evaluate TCE biodegradation in the absence of hydrogen peroxide, nutrients and tyrosine amendments. Sterile microcosms were prepared to evaluate TCE removals due to abiotic losses. Although the non-amended microcosms were not amended with an oxygen source, the dissolved oxygen concentration of the groundwater pumped from the aquifer was approximately 8 to 9 mg/L, indicating highly aerobic conditions. The bench-scale results indicate that the indigenous groundwater and/or soil microorganisms are capable of degrading TCE at concentrations ranging from hundreds to tens of thousands of micrograms per liter without the addition of a cometabolic inducer.

Materials and Methods

Microcosms were prepared using site groundwater and a soil extract. The amended microcosms consisted of aerated groundwater stripped of its native TCE concentration, a soil extract (0.6% vol/vol, 4.0×10^2 colony forming units per milliliter [CFU/ml] final concentration), hydrogen peroxide (100 mg/L), ammonium phosphate (C:N:P = 100:10:1), tyrosine (9.06 mg/L) and TCE at various initial concentrations (7,200 µg/L, 11,000 µg/L, 23,000 µg/L, 45,000 µg/L, and 72,000 µg/L). The non-amended microcosms were prepared in the same manner but without the addition of hydrogen peroxide, ammonium phosphate, or tyrosine. Sterile microcosms were prepared by filter-sterilizing aerated groundwater. Sterile microcosms were amended with TCE (72,000 µg/L), hydrogen peroxide (100 mg/L), and ammonium phosphate dibasic (160 mg/L).

All microcosms were prepared in 250-ml amber volatile organic analysis VOA vials in sufficient quantity for sacrifice at each sampling date. The 250-ml VOA vials were filled

completely with no visible headspace so volatile organic compound (VOC) losses due to volatilization would be minimized. Each VOA bottle was prepared with a sterile stir bar to facilitate TCE dissolution in the groundwater. The microcosms were incubated in the dark (to prevent photosynthetic growth) at room temperature (approximately 22°C). The microcosms were rotated 180 degrees three times per week to prevent settling. The 250-ml VOA microcosms were used for volatile organic analyses, nutrient analyses and microbiological analyses. Chlorinated volatile organics were quantified using EPA Method 601. Heterotrophic microorganisms were enumuerated via plate counts on R2A Agar (Difco). Dissolved oxygen concentrations and pH were measured using appropriate electrode methodologies. Hydrogen peroxide concentrations were determined with test strips (Peroxide Test) from EM Quant. Analysis for nitrogen, nitrate nitrogen, and total phosphorus concentrations was performed using EPA Methods 350.3, 353.2, and 365.3, respectively. Laboratory activities were performed at BBC Laboratory (Phoenix, Arizona) by Ms. Vicki Bess.

Results

Figure 1 shows the percent TCE removed versus time for the amended and non-amended Microcosm A series (7,200 µg/L TCE) and filter-sterilized native groundwater amended with 72,000 µg/L TCE (Sterile Microcosm). The percent TCE removed in the sterile microcosms was less than approximately 15 percent during the 12-week study. This indicates that degradation of TCE significantly exceeding 15 percent may be attributed to a microbiological mechanism. Figure 1 indicates that the indigenous microbial population in the groundwater and/or soil is capable of degrading more than 80 percent of the TCE during the first two weeks when supplemented with hydrogen peroxide (100 mg/L), nutrients and the potential cometabolic inducer, tyrosine. When the groundwater was not amended with a cometabolic inducer and the dissolved oxygen concentration was approximately 8 mg/L, a 4-week lag period was observed before the indigenous microbial population began degrading the TCE. By time 12 weeks more than 65 percent of the TCE had been degraded in the non-amended Microcosm A series.

When the initial TCE concentration was increased to 11,000 µg/L (Microcosm B series), the indigenous microbial population in the amended series degraded more than 80 percent of the TCE during the first two weeks (Figure 2). Similar to the results in the non-amended Microcosm A series, the percent TCE removed in the non-amended Microcosm B series by time 12 weeks was also approximately 60 percent (Figure 2). When the initial TCE concentration was 23,000 µg/L (Microcosm C series), the amended and non-amended microcosms both showed significant percent TCE removals (approximately 65 percent) by time 12 weeks. However, the percent TCE removed was slightly higher in the amended microcosms than the non-amended microcosms after time 4 weeks. Figure 3 shows the percent TCE removed versus time for Microcosm D and E series amended with 45,000 µg/L and 72,000 µg/L TCE, respectively. The Microcosm D series showed similar percent TCE removed by time 12 weeks in amended and non-amended microcosms. However, for the Microcosm E series, the percent TCE removed in the non-

amended microcosms was less than approximately 20 percent, whereas the amended series showed approximately 60 percent TCE removed by time 4 weeks. This lack of microbial degradation in the non-amended microcosm may have been due to an oxygen and/or nutrient limitation which was not observed in the lower initial TCE concentration series microcosms.

Discussion

The microorganisms in the groundwater and/or soil at a site in Phoenix, Arizona are capable of degrading TCE at concentrations ranging from hundreds to tens of thousands of micrograms per liter under aerobic conditions without the addition of a cometabolic inducer. The groundwater and/or soil contains a natural cometabolic inducer for an oxygenase responsible for TCE degradation. Results from a separate study conducted by Oak Ridge National Laboratory utilizing the lux-gene bioassay confirm that the groundwater contains a natural cometabolic inducer. The batch bench-scale study results indicate that oxygen and nutrients may become limiting in the batch vessels over time and may result in limiting the biodegradation of TCE at higher concentrations.

Figure 1. Percent TCE Removed Versus Time for Amended and Non-Amended Microcosm Series A (7,200 ug/L TCE) and for the Sterile Microcosm Series (72,000 ug/L TCE)

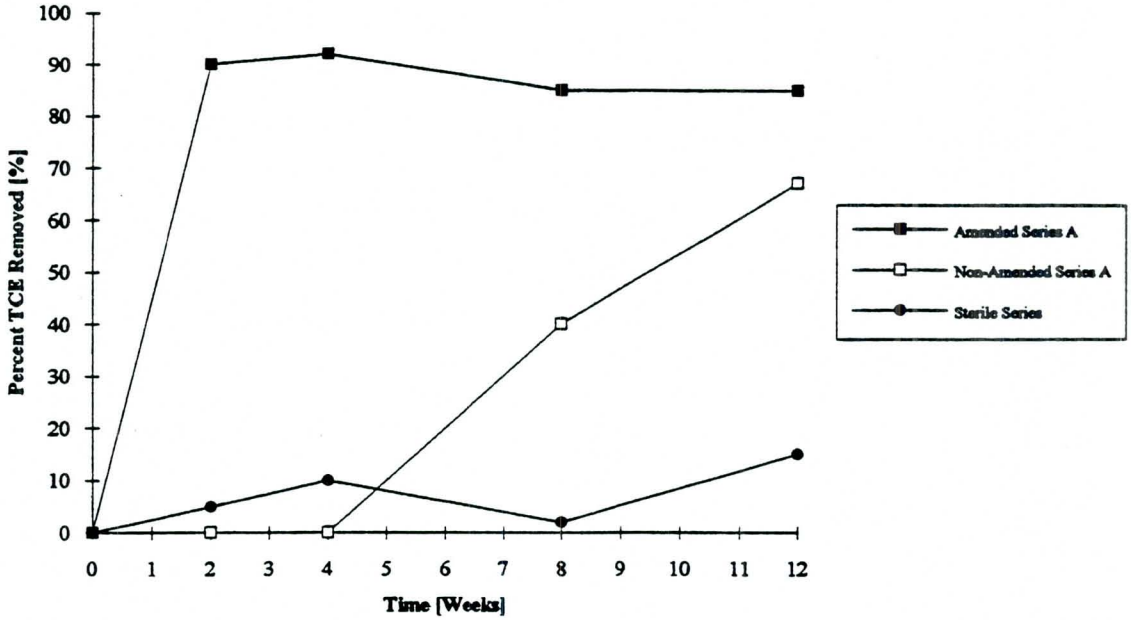


Figure 2. Percent TCE Removed Versus Time for Amended and Non-Amended Microcosm Series B (11,000 ug/L TCE) and Series C (23,000 ug/L TCE) and for the Sterile Microcosm Series (72,000 ug/L TCE)

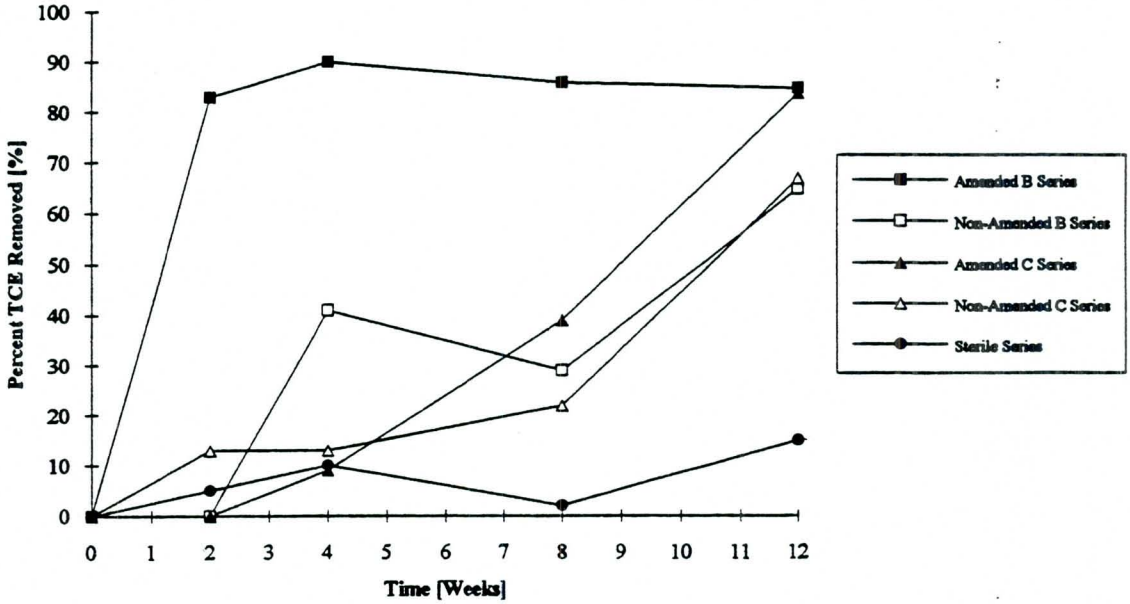
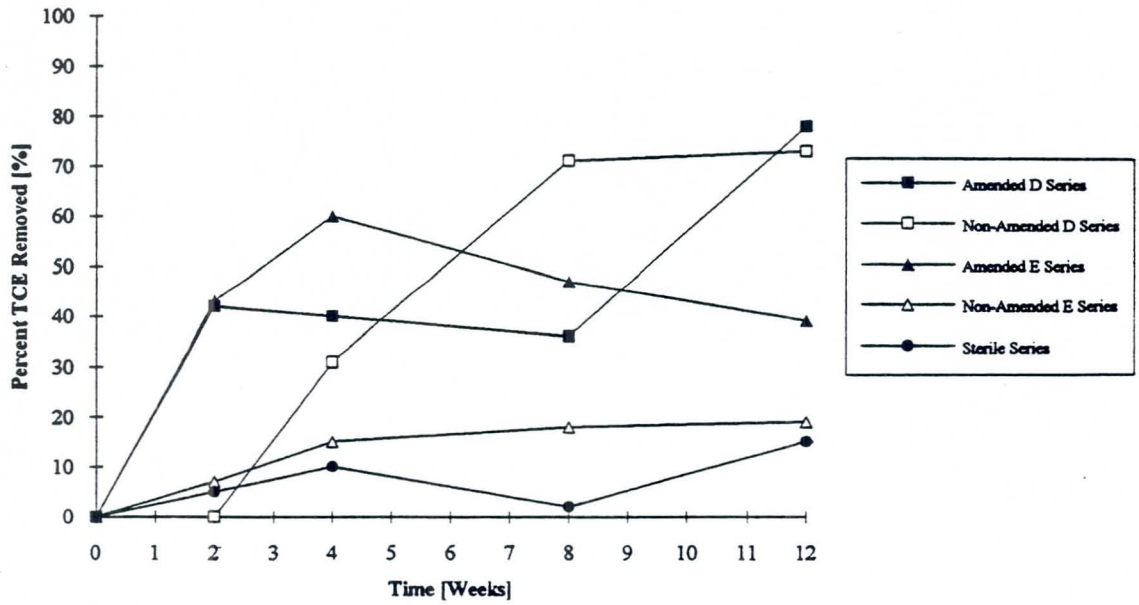


Figure 3. Percent TCE Removed Versus Time for Amended and Non-Amended Microcosm Series D (45,000 ug/L TCE) and Series E (72,000 ug/L TCE) and for the Sterile Microcosm Series (72,000 ug/L TCE)



SESSION 5C:

MEXICO BORDER ISSUES: BORDERLINE HYDROLOGY

Moderator: Jim DuBois
Arizona Department of Environmental Quality

U.S. DEPARTMENT OF INTERIOR ACTIVITIES ALONG THE MEXICO BORDER REGION[1]

Norman J. Page and John M. Klein[2]

ABSTRACT: A major issue in the implementation of the North American Free Trade Agreement (NAFTA) is the increased risk of environmental degradation brought about by increased economic development and population in the U.S./Mexico transboundary area - a region that contains environments and ecosystems of particular sensitivity. The NAFTA environmental side agreements have therefore set in motion the formation of a NAFTA environmental infrastructure that is designed to holistically treat U.S./Mexico border issues.

Through its land and resource management functions (Bureau of Indian Affairs, Bureau of Land Management, Bureau of Reclamation, Fish and Wildlife Service, Minerals Management Service, and National Park Service) and its research bureaus (Bureau of Mines, Geological Survey, and National Biological Survey), the Department of Interior has had an extensive and long history in issues along the U.S./Mexico border. In formalizing this interest on August 11, 1994, the Department of Interior chartered the U.S./Mexico Border Environmental Issues Fiel Coordination Committee composed of representatives from the nine bureaus and offices. The border region contains a wide variety of natural and cultural resource protection areas, a myriad of General Trust species, and extensive Native American reserved lands. Thus, the committee is charged with encouraging the appropriate and joint involvement between and among the Interior bureaus and officies and facilitating the priorities. It is also charged with coordinating and communicating with NAFTA related or created institutions such as the Border Environment Cooperation Commission.

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[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2] Norman J. Page is the Scientist-in Charge of the U.S. Geological Survey's Center for Inter-American Mineral Resource Investigations (CIMRI), Tucson, Arizona, and John M. Klein is Associate Regional Hydrologist, Pacific Southwest Division, Water Resources Division, U.S. Geological Survey, Sacramento, California.

From a multitude of area, subject specific, or policy issues, the committee by a ranking process selected ten issues that appear to require immediate focused attention. Among the selected issues are U.S./Mexico environmental education, research and management of shared water resources, aerial photography and resource mapping, San Pedro River drainage, Tohono O'Odham resource protection, and the lower Rio Grande. Issue teams composed of appropriate field personnel are being formed to address each topic. The teams are charged with mission statements such as the one for research and management of shared water resources: Identify hydrologic and geologic information, data deficiencies, and potential research directives to provide the necessary framework, in a variety of formats, upon which decisions can be made and evaluated. The approach will support themes of (1) inventory and monitoring, (2) data standardization, (3) transboundary pollution, and (4) data dissemination. The other issues have similar mission statements.

BINATIONAL GROUND WATER MONITORING ACTIVITIES IN AMBOS NOGALES[1]

Mario Castaneda[2]

ABSTRACT: Industrial development and population growth along the U.S./Mexico border have caused pollution that threatens human health and the environment. The region in and around the twin cities of Nogales, Sonora and Nogales, Arizona is no exception. Many environmental problems in this border region have concentrated on the Nogales Wash. The Arizona Department of Environmental Quality has been monitoring surface water flows in the Nogales Wash since 1986 and has documented high fecal coliform bacteria levels, ammonia, and heavy metals in the surface water.

A joint U.S./Mexico groundwater quality study is being implemented along the Nogales Wash to collect reliable soil and groundwater quality data from the vadose zone and the alluvial aquifer along the wash. Data collection will document whether or not surface activities and discharges to the Nogales Wash have significantly affected groundwater quality. Thirteen ground water monitoring points within approximately 5 miles north and south of the International Boundary will be sampled. Groundwater monitoring wells will be constructed for this purpose. This paper presents an update on the project activities.

INTRODUCTION

Nogales Wash originates 7 miles (mi) south of the International Boundary and flows north through Nogales, Sonora and Nogales, Arizona. Perennial flow in Nogales Wash is fed by springs near its head, however, grey-water and sewage contribute to the flow. ADEQ has been monitoring surface water flows in the Nogales Wash since 1986 and has documented high fecal coliform bacteria levels, ammonia, and heavy metals in the surface water. Parasite sampling of

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[1]Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.

[2]Mario Castaneda is the Border Water Technical Coordinator for the Arizona Department of Environmental Quality, Phoenix, AZ.

the wash has shown the presence of Giardia and Cryptosporidium (Earth Technology, 1993).

The water bearing units beneath the Nogales Wash include the Younger Alluvium and Nogales Formation. The lower member of the Nogales Formation borders the Nogales Wash adjacent to the proposed monitor well sites and consists of conglomerate, fanglomerate, tuffaceous sandstone, and tuff that may be as much as 1000 feet (ft) thick (Halpenny, 1964). The Younger Alluvium is the primary water bearing unit in the area. The Younger Alluvium occurs as flood plain and channel deposits along the Nogales Wash. This deposit is comprised of unconsolidated gravel, sand, and silt, and is generally less than (50 ft thick along the Nogales Wash (John Carollo Engineers, 1979).

Shallow groundwater exists within the alluvial aquifer along the wash. The estimated depth to water at the International Boundary, based on previous sampling events is 15 to 20 ft below land surface (bls). The direction of groundwater flow at the International Boundary is generally to the north (Earth Technology, 1993). Because of the shallow water table and high hydraulic conductivity, this aquifer is more vulnerable than deeper aquifers to be impacted by surface activities, such as spills and discharge of pollutants. This shallow aquifer may also have significant interaction with surface water in the Nogales Wash. In addition, this aquifer is tapped by some of the municipal supply wells in Nogales Sonora, and is a drinking water aquifer used by private wells in Nogales, Arizona.

Volatile Organic Compound (VOC) contamination was discovered by the Santa Cruz County Health Department (SCCHD) and the Arizona Department of Health Services (ADHS) in the Nogales Wash study area during groundwater sampling conducted in 1986 and 1987 (Earth Technology, 1990). Concentrations of tetrachloroethylene (PCE) detected in the samples collected in 1986 and 1987 exceeded the existing Arizona Action Level of 1.0 micrograms per liter (μg/L) for drinking water. Since this groundwater sampling was completed, the EPA established a Maximum Contaminant Level (MCL) of 5.0 μg/L for PCE in drinking water which superseded the previous Arizona Action Level. Other VOCs including, 1,1,1-trichloroethane (1,1,1-TCA), dibromochloromethane, bromoform, chloroform, 1,1-dichloroethane (DCA), trans-1,2-dichloroethylene (t-1,2-DCE), and trichloroethylene (TCE) were detected during ADHS's groundwater sampling and analysis in 1987 (ADEQ, 1990). Because of the detection of the VOCs, ADEQ recommended that further investigation be conducted for these contaminants under the Water Quality Assurance Revolving Fund (WQARF).

As part of the Nogales Wash WQARF Phase I investigation, Earth Technology Corporation implemented a groundwater sampling plan during August 22 through 25, 1988. Eighteen wells were sampled as part of the investigation. The only VOC detected during the WQARF Phase I and previous investigations that exceeded an existing drinking water EPA MCL or Arizona Action Level at the time of sampling was PCE. The 1988 Arizona Action Level for PCE of 1.0 μg/L was slightly exceeded in the three wells sampled during the WQARF Phase I investigation and in seven wells along Nogales Wash during investigations conducted by SCCHD and ADHS in 1986 and 1987 (Earth Technology, 1993).

A compilation of previous and recent water quality data available for the Nogales Study Area was completed during the WQARF Phase I investigation and indicated that wells containing PCE extended northward approximately 3 to 3.5 mi along the wash from the International Boundary. The observed extent of PCE in the groundwater appeared to be continuous, from the International Boundary to approximately 3 to 3.5 miles north. The concentrations of PCE detected in the wells ranged from 2.2 μg/L near the International Boundary to 0.9 μg/L, 3 to 3.5 mi north of the International Boundary. However, data gaps were present (Earth Technology, 1993).

OBJECTIVE AND SCOPE

A work plan consisting of a sampling plan, a quality assurance project plan, and a safety plan was prepared in order to implement a joint groundwater quality study in the United States and Mexico along the Nogales Wash in both Nogales. Participants in the sampling activities are representatives of the United States and Mexican Sections of the International Boundary and Water Commission (IBWC), U.S. Environmental Protection Agency (EPA), Mexican National Water Commission (CNA), Arizona Department of Environmental Quality (ADEQ), Santa Cruz County, The City of Nogales, and state and municipal agencies responsible for water management in the State of Sonora.

The objective of this jointly groundwater sampling project is to collect reliable soil and groundwater quality data from the vadose zone and the alluvial aquifer, respectively, along the Nogales Wash. Data collection will document whether or not surface activities and discharges to the Nogales Wash have significantly affected groundwater quality. It should be noted that the groundwater wells available for sampling near the International Boundary during the WQARF Phase I investigation were not installed for monitoring purposes and were never developed. The wells were either piezometers installed for water elevation

monitoring only or collection sumps for flood mitigation. Therefore, the samples obtained from the wells and subsequent analytical results may not be representative of aquifer conditions. This work plan is being implemented because of the need for good quality data collected under controlled conditions. ADEQ has previously installed a set of two monitor wells near the International Boundary in February, 1993, for the specific purpose of groundwater quality monitoring and these groundwater monitoring wells are being considered for sampling in this study.

Initially, the study will test thirteen wells at twelve different sites within approximately 5 mi north and south of the International Boundary. Representatives of the participating agencies from the U.S. and Mexico selected and agreed upon sites for monitoring well placement. All sites are located along the Nogales Wash or its tributaries in areas where the shallow alluvial aquifer is present. Except for two monitor wells installed immediately north of the International Boundary and two existing wells in Mexico, none of the wells targeted for sampling have been constructed yet. They will be drilled as part of this project. Most of the sites lie downgradient of or adjacent to areas where past or present land use includes industrial activity or development that may have had an impact on groundwater quality. In this manner, it is hoped that, if groundwater contamination is found, the location of potential or sources can be narrowed to a smaller region within the urban area for more focused study by other interested parties. Such detailed source investigations are beyond the scope of this joint groundwater monitoring program.

Samples will be tested for Volatile Organic Compounds (VOCs), Total Petroleum Hydrocarbon (TPH), major cations and anions (MCAs), trace metals, fecal coliform, and field parameters. VOC's and trace metals will be tested because historical industrial activity along the wash and the known VOCs occurrence in groundwater of the area. Major cations and anions are being tested to characterize general hydrochemical conditions and to provide data for hydrologic interpretations. Coliform bacteria is being tested because the Nogales Wash has shown elevated levels of bacteria for a long period of time. Wells will be sampled quarterly.

Sampling procedures and quality assurance methods for this study were developed specifically for this project and are being discussed with the Mexican group. These procedures are in accordance with the 1991 ADEQ Quality Assurance Project Plan, EPA protocols, and Mexican guidelines. Quarterly field sampling operations will be audited by personnel from EPA/ADEQ. The audit report will include an evaluation on field sampling techniques procedures, use of field equipment, and adherence to the sampling plan protocols. A training session on sampling procedures specifically for this project will be given by the

Arizona Department of Health Services with ADEQ and EPA participation to all project involved personnel.

The laboratory(s) responsible for the analyses conducted in the U.S. will be certified by the ADHS for the particular parameters and methods specified. These laboratories submit analytical results to both the State of Arizona and the EPA on a regular basis in order to maintain certification. Samples for which CNA has analytical capabilities will be submitted to a Mexican laboratory. Internal QA/QC samples will be collected to validate the collected data. In addition, Performance Sample Standards will be used and supplied "blind" to all laboratories involved in this project. A project officer will be appointed for field sampling operations to make sure that when problems identified during the field sampling operations audit be addressed and corrected.

A Health and Safety Plan that addresses the procedures that will be followed by all personnel at the work site in the U.S., either engaged in work or present on the site as a visitor was developed. OSHA training will be implemented for Mexican personnel that have not received the appropriated OSHA training because the Nogales Wash is considered to be an Arizona State superfund site. In Mexico, U.S. personnel will follow these guidelines or any more stringent health and safety requirements Mexican authorities deem to apply. This Plan will remain in effect for the duration of the sampling activities unless modified based on site conditions by field personnel.

ADDITIONAL WORK BEING PERFORMED AT THIS BORDER REGION

As part of the continuing activities in this region, nearly 22 monitoring wells that are part of public drinking water supply systems in Nogales, Arizona, including the City of Nogales municipal supply wells are being sampled by the Nogales Wash WQARF State Superfund project. The selection of wells under this plan will provide better definition of the nature and degree of groundwater contamination in this area. The wells included in this sampling activity are part of the City of Nogales' drinking water production well network. The production wells included in this plan are registered wells. The list of wells would also include wells currently of unknown use. This plan would monitor drinking water sources for a major portion of the Nogales population.

In addition, long-term efforts to protect groundwater are under way in Nogales, Arizona under the state's Wellhead Protection Program. EPA has awarded a wellhead protection grant to the SouthEastern Arizona Governments Organization (SEAGO), to study the municipal drinking water wells in Nogales,

Arizona, and the land use of the surrounding wells which could affect the quality of the drinking water. Another goal of this project is to develop a bilingual school curriculum about water conservation and pollution for use in the Nogales and Santa Cruz County Schools. A planning advisory committee has been formed with representatives of SEAGO, the City of Nogales, Santa Cruz County, local environmental and education representatives, and members of the public.

ADEQ, through the Water Resources Research Center (WRRC) of the University of Arizona is developing a bilingual (English/Spanish) field manual for water quality sampling as an official guidance document for the State of Arizona. The objective of this manual is to standardize surface water and groundwater sampling protocols for use along the Sonora-Arizona border. Several U.S. and Mexican institutions have already participated in the manual review process. The manual will be adopted as an official document by the US and Mexico in all groundwater/surface water quality sampling being performed in both US and Mexican border states. A consensus on adopting the field manual from the US side (including all US border states involved and corresponding EPA Region offices) is being obtained so IBWC can present the proposal to the Mexican Comision Nacional de Limites y Aguas (CILA) (IBWC Mexican counterpart).

An Arizona/Sonora Multimedia Border Intensive Study Initiative is being implemented by ADEQ and ADHS to address contamination and health issues along the Arizona/Sonora border. This initiative was designed to be a year-long multimedia effort by both agencies to collect environmental/health information in the Nogales, Arizona area. The information collected will be used to establish a baseline of environmental data to define what is being released, what is being generated and what contaminants are in the air and water. Although the Initiative is not a binational project, and activities will be therefore limited to the Nogales, Arizona area, efforts will be made to acquire corresponding environmental information from the Sonora side, if available. Additional projects are being implemented at the U.S./Mexico federal level.

FINAL REMARKS

The Binational Ground Water Monitoring Project in Ambos Nogales is being funded by EPA. It requires coordination among the different U.S. and Mexican (federal/state) agencies through both sections (U.S. and Mexico) of the International Boundary Water Commissions. The environmental problems associated with the rapid demographic/industrial explosion experienced at the border communities can still be investigated and solved under a binational setting, since contamination knows no border.

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WATER QUALITY ALONG THE ARIZONA - MEXICO BORDER[1]

Lin Lawson
Arizona Department of Environmental Quality

ABSTRACT: The Santa Cruz River begins as a small perennial stream flowing south out of the San Rafael Valley, Arizona, and into Sonora, Mexico. Data collected by the Arizona Department of Environmental Quality (ADEQ) over a period of three years indicates that this water is of good quality. After entering Mexico, the Santa Cruz makes a 35-mile westerly loop and reenters the United States, 5 1/2 miles east of Nogales, Arizona. Contrary to what some local residents believe, the quality of the water at this point is also good. Occasionally, acute violations of Arizona's water quality standards have occurred, but the violations have not been a chronic problem. Generally, this water flows not more than 2 miles north of the border before it infiltrates into the aquifer.

The Nogales Wash originates in Nogales, Sonora, flows north through Nogales, Arizona, and enters the Santa Cruz River about one mile upstream of the Nogales International Wastewater Treatment Plant discharge point. Some infiltration of this water into the aquifer probably occurs before it joins with the effluent that is discharged by the treatment plant. The flow in the wash is perennial, but the quality of the water is poor. Identified pollutants include raw sewage, petroleum, heavy metals and VOC's such as PCE, TCE and THM's. Biological agents that have been detected in the water are enteric viruses, parasites such as Giardia and Cryptosporidium, and fecal coliforms with counts in the millions. Recent findings by ADEQ indicate the presence of DDT in Nogales Wash sediments. Generally, these pollutants are not a persistent problem, but there is a potential threat to the underlying aquifer and to the health and lives of humans and livestock who may come into contact with the water.

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[1] Paper presented at the Seventh Annual Symposium of the Arizona Hydrological Society, Scottsdale, Arizona, September 22-23, 1994.