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Examination of the Phoenix Regional Water Supply for Sustainable Yield and Carrying Capacity

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ABSTRACT

Metropolitan Phoenix lacks a current, publicly accessible statement of its water supply from which to evaluate options for growth. This article presents research into the size and sustainability of the regional water supply. It introduces residential carrying capacity as an intuitive measure of the economic size of a water supply and examines entitlements, regulatory programs, and subsidies that constrain existing supplies from supporting new economic uses. The findings are (1) that the Phoenix renewable water supply is, in theory, sufficiently large to meet future regional economic goals and protect many environmental functions if the current context of entitlements and institutional arrangements is ignored; and (2) that Phoenix needs to engineer new water supply policies instead of new water resources, to avoid large economic and environmental costs in the future.

I. INTRODUCTION

Metropolitan Phoenix neither lacks water nor is soon likely to face shortages, having acquired a large (albeit finite) water supply associated with an integrated delivery system.[1] Instead, the problem is

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1. Adam Kress, *Water Research Center Begins Conservation Projects*, BUS. J. OF PHOENIX, Sept. 23, 2005, *available at* http://phoenix.bizjournals.com/phoenix/stories/2005/09/26/story8.html (quoting John Sullivan of Salt River Project's Water Group: "Our major metro areas are OK for the next 20 or 30 years. We're not running out of water, but we need to manage it better."); DOUGLAS E. KUPEL, FUEL FOR GROWTH: WATER & ARIZONA'S URBAN ENVIRONMENT 228 (2003); Phoenix AMA Safe-Yield Task Force supp. attachment, *Impact of*

that the region lacks a water supply budget: a current, integrated, quantified, and publicly accessible statement evaluating the regional water supply, particularly the sustainable component.[2,3] Planners and elected officials consider scenarios for economic growth or water management in the absence of a concise and comprehensive assessment. Without informed regional consensus on the size and condition of the currently available supply, it is difficult to evaluate the merits of development proposals or the underlying assumption that new water sources are needed for growth.

This lack of a comprehensive regional hydrological budget leads to disagreements between policy makers who subscribe to different water management philosophies. Disagreement over the degree to which available water supplies are limited and connected creates a fundamental division. On one side, commentators call for realistic strategies that accept the water supply "as is" and quantify what population it can be expected to support.[4] They view the communal water glass as half full. Prudence, they claim, requires protection of existing supplies by recognizing and promoting an optimum level of residential growth. Others view the glass as half empty and call for fresh efforts to find and finance new supplies.[5] These observers focus on

Out-of-AMA Pumping on Surface Water Supplies Used in Phoenix AMA 1 (draft Nov. 28, 2000) [hereinafter Phoenix AMA Task Force, *Impact of Pumping*], to Attachment 4, *Renewable Supplies* Issue Paper #1, *Availability, Reliability & Utilization of Renewable Supplies, in* GOVERNOR'S WATER MGMT. COMM'N, FINAL REPORT OF THE COMMISSION (2001) (estimating regional demand in 2025 between 2.4 and 2.9 million acre-feet, with the "vast majority" of that demand expected to be met by renewable supplies).

2. The terms "sustainable," "permanent," and "renewable" are used interchangeably in this article.

3. *Cf.* UNIV. OF ARIZ. WATER RESOURCES RESEARCH CTR., WATER IN THE TUCSON AREA: SEEKING SUSTAINABILITY 112–16, http://ag.arizona.edu/AZWATER/publications/sustainability (follow "Afterword" hyperlink) (last visited Aug. 8, 2006).

4. Jon Talton, *Only Good Can Come from Realistic Water Appraisal*, ARIZ. REPUBLIC, Jan. 2, 2005, at D1. Talton argues for a "reality-based water strategy" based on answers to such questions as, "[a]pproximately what population can be sustained in Maricopa County on Central Arizona Project supplies and other renewable water supplies? Let's assume no new Indian leases and no new aqueducts/pipelines are constructed to bring in additional water from the Colorado River." *Id. See also Study Raises Sobering Water Questions*, PAYSON ROUNDUP, Sept. 27, 2005:

> The people of the Rim Country must work together on the issue of water. Taking water from one community to another is, at best, a stopgap solution to a bigger issue—how many people can the Rim Country's finite water supply support? It's a question that needs to be answered—and not by developers—before another subdivision is approved.

Id.

5. Remarks by Herb Guenther, Dir., Ariz. Dep't of Water Resources, to Rural Water Legis. Study Comm. (Nov. 17, 2005) ("Sooner or later we have to import water. We can't

projected future residential demand assuming "as is" growth and water policies. They contend that this strategy was highly successful in the past and should not be abandoned.[6] Furthermore, few municipalities perceive benefit in integrated regional coordination to achieve a level of growth consistent with available supplies. Instead, the municipal planning and ordinance-making power is jealously protected to promote self growth via the municipal water supply. Decisions on annexation, zoning, growth, water treatment infrastructure, and acquisition of water rights are routinely used by cities in the Phoenix metropolitan area to compete with each other for new development.[7]

This article presents research into questions at the core of the water management controversy. First, does Phoenix have a sustainable regional supply? Second, if it does, what is the carrying capacity of this sustainable water supply? Third, what state policies prevent the sustainable supply from being reallocated as new demands compete with existing uses? The article argues that metropolitan Phoenix needs new water supply policies, not new sources, to better plan for economic growth and to achieve sustainable water management. Current policy relies on state regulations and subsidies that are rigid, ineffective, and inequitable. More importantly, these regulations promote full utilization of supplies rather than sustainability. This research concludes that initiatives are needed to (a) protect the sustainability of finite regional supplies, (b) require integrated regional planning as a prerequisite for

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afford not to have water [for growth]."); Letter from Governor's Representatives on Colorado River Operations to Gail Norton, Sec'y, Dep't of the Interior 3 (Aug. 25, 2006) (requesting a supply augmentation strategy in which the Department implements precipitation management [cloud seeding] and analysis of feasibility of desalination projects in addition to improved management of existing supplies); Shaun McKinnon, *State's Rural Growth Taxing Water Supplies*, ARIZ. REPUBLIC, June 26, 2005.

> Moving water from Star Valley to a Payson development is not only legal, it also represents an emerging, if inelegant, form of water management meant to fill in gaps in state law. Payson is one of a handful of incorporated towns or cities that require builders to provide a source of water for new homes, a policy known as "bring your own water."

Id.

6. RITA P. MAGUIRE, AN ANALYSIS OF THE WATER BUDGETS OF BUCKEYE, PAYSON, AND PRESCOTT VALLEY 4 (2005), http://www.thinkaz.org/documents/AnAnalysisoftheWaterBudgets.pdf ("Historically, water has not operated as a limit on growth in the West. Every time a limit approaches, it has proven possible to find a new source, a different management strategy, a more efficient technology, or a legal change.").

7. *But see* Memorandum from Pima County Bd. of Supervisors on Cooperative Water Supply Org. (Feb. 7, 2006) (recommending endorsement of Southern Arizona Water Users Association proposal to establish a regional organization to optimize existing and secure new water supplies for Tucson and adjacent public water supply providers).

state funds, and (c) develop market-based mechanisms to reallocate existing water entitlements.

The research introduces a theoretical construct, "residential carrying capacity," to develop an intuitive measure of urban water supply. While residential carrying capacity cannot be achieved in actual housing development, it quantifies the relative economic outcomes of water supply options in a relevant unit of measurement and sets a benchmark for comparing various policy options. When carrying capacity is combined with the quantified renewable water supply, planners can accurately communicate complex information about resource use and sustainability.

The four remaining sections discuss the empirical findings and policy arguments. Section II describes the current condition of the regional water supply available to Phoenix and discusses the scientific issues associated with identifying a sustainable water yield. Section III calculates the economic opportunity cost and the hypothetical carrying capacity of the permanent supply that shape the main conclusion of the empirical research. The size of the permanent regional water supply is sufficiently large to meet regional economic needs to the year 2035 and to protect environmental values of the water supply if current institutional arrangements and entitlements are ignored, a critical caveat. Section IV examines policy conclusions that institutional arrangements and entitlements bind the water supply too tightly to existing economic outcomes. Section V returns to the thesis that Phoenix needs new water supply policies rather than new water sources to provide for the future. Section V suggests a broad strategy to refocus policy on protecting and sustaining groundwater resources.

II. BACKGROUND

Sustainable water resource systems are especially important in the desert southwest because precipitation is both scarce and highly variable. There are limits to the amount of water a regional economy may withdraw from desert systems without affecting their stability and function. Sustainable water resource systems provide consistent environmental benefits and functioning ecosystem processes that contribute to the vitality of the regional economy. Stability reduces the likelihood of disruptions in supply that can cause public health and sanitation problems, lost job productivity, and lower economic output. Functional water resource systems prevent the financial losses that accompany problem remediation such as new wells and water treatments.

For the above reasons, a discussion considering the problems with and sustainability of the Phoenix water supply is necessary. Oddly, current public discussion does not focus on the sustainability of the Phoenix regional supply – the extent to which the supply can be renewed at the same volume year after year for an indefinite length of time. Is the current use of existing regional supplies interfering with their long-term sustainability? The question is pertinent because regional groundwater and surface water supplies are being mined, that is, subjected to prolonged and progressive decreases in the amount of water stored in the system.[8] However, it is not the continuing withdrawal of the resource but rather its rate and specific impacts that create problems in sustainability.[9]

A. Current Yield of Regional Water Resources

Metropolitan Phoenix spreads across the Salt River Valley (Valley) in Maricopa County, Arizona, where the Salt and Agua Fria Rivers join the Gila River (see Map). It overlies seven deep subbasins that contain vast amounts of ground water and contribute about half of the Valley's local water supply.[10] While much of this water is too deep to retrieve economically or is contaminated by hazardous and natural materials,[11] significant amounts of potable water are available[12] with few regulatory limits on capture. The basins are part of the Phoenix Active Management Area (AMA), which is supervised by Arizona Department of Water Resources (ADWR). Although officials report progress in

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8. WILLIAM M. ALLEY ET AL., SUSTAINABILITY OF GROUND-WATER RESOURCES 4 (U.S. Geological Surv. Circular 1186, 1999) (defining "mining" as a value-neutral hydrologic term and "overdraft" as a determination of excessive use based on a judgment that associated impacts are unacceptable).

9. *See generally* John D. Bredehoeft, *The Water Budget Myth Revisited: Why Hydrogeologists Model*, 40 GROUND WATER 340 (2002).

10. ARIZ. DEP'T OF WATER RESOURCES, THIRD MANAGEMENT PLAN FOR PHOENIX ACTIVE MANAGEMENT AREA 2000-2010, at 2-1, 2-4 (1999) [hereinafter ADWR, THIRD MANAGEMENT PLAN], *available at* http://www.azwater.gov/dwr/Content/Publications/files/ThirdMgmt Plan/tmp_final/default.htm#Phoenix; Thomas W. Fitzhugh & Brian D. Richter, *Quenching Urban Thirst: Growing Cities and Their Impacts on Freshwater Ecosystems*, 54 BIOSCIENCE 741, 745 tbl.2 (2004).

11. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 2-1.

12. Ariz. Dep't of Water Resources, Estimated Groundwater Storage in Upper 1000 Feet of Alluvial Aquifers in the SRV Model Area in Acre Feet (data file obtained Feb. 7, 2005) (three alluvial aquifers underlying the Phoenix region held 83 million acre-feet [maf] around 1938, declining to 62 maf by 1964). *See also* Memorandum from Lou Bota et al., Ariz. Dep't of Water Resources, Hydrology Division, to Salt River Valley Model File, at 4 (Dec. 1, 2004) (Salt River Valley Model Calibration Update showing a small gain of 6 maf into the late 1990s, followed by declines through 2002).

reversing decades of groundwater mining, from 1.8 million acre-feet annually (pre-1980) to 0.94 million acre-feet (1998),[13] the research reported here assessed data with an annual periodicity but did not find a declining trend. Groundwater withdrawals averaged 0.97 ± 0.16 million acre-feet between 1983 and 2002 and showed little variation from the mean.[14] This indicates a steady withdrawal of around one million acre-feet annually and is consistent with agency projections of future withdrawals between 0.6 and 1.1 million acre feet in 2025.[15]

Phoenix relies on surface water from local sources that are also over allocated. The largest single source of surface water is the reservoir and canal system fed by the Salt and Verde rivers' watersheds located to the north and east of Phoenix.[16] Data indicate that the system manager, Salt River Project (SRP), is under contract to deliver more surface water than is available in most years. Whereas many published reports describe the annual Salt/Verde system yield at one million acre-feet,[17] in actuality data from SRP show a significantly smaller yield between 1983 and 2002, 0.87 ± 0.2 million acre-feet in median annual diversion. Furthermore, Salt/Verde deliveries were augmented in all years with median annual groundwater withdrawals of 84,000 ± 95,000 acre-feet.[18] The recent drought exacerbates the problem, and in 2002, 276,500 acre-feet of aquifer-supplied water were added to SRP deliveries.[19] This practice of using ground water to automatically augment surface

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13. Phoenix AMA Safe-Yield Task Force supp. attachment, *Allowable Groundwater Pumping* 2 (draft Oct. 23, 2000) [hereinafter Phoenix AMA Task Force, *Allowable Pumping*], to Attachment 4, Groundwater Issue Paper #1, *Allowable Groundwater Pumping, in* GOVERNOR'S WATER MGMT. COMM'N, FINAL REPORT OF THE COMMISSION (2001).

14. Memorandum from Lou Bota et al. to Salt River Valley Model File, *supra* note 12, at 24.

15. Phoenix AMA Safe-Yield Task Force, *Allowable Groundwater Pumping, supra* note 13, at 23.

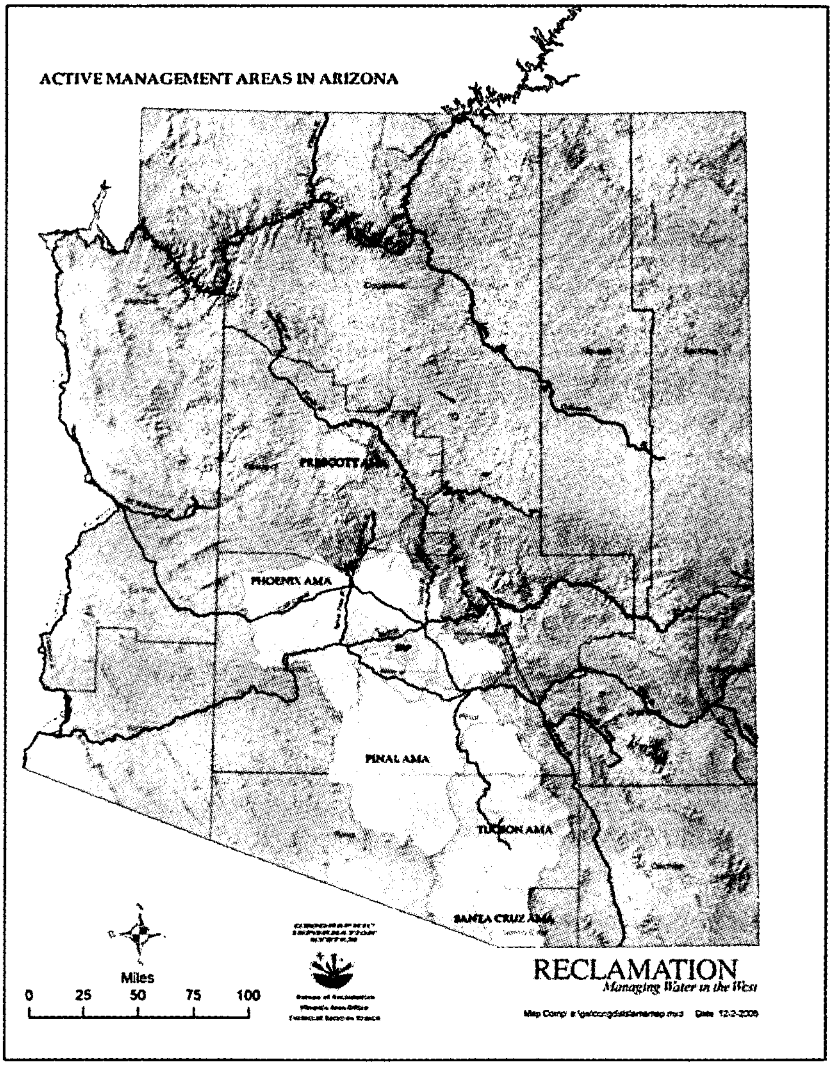
16. *Cf.* Ariz. Dep't of Water Resources, Phoenix AMA Draft Master Budget 2000 (data file obtained Mar. 21, 2005) (showing Phoenix AMA used 600,000 acre-feet of imported Colorado River water).

17. *See, e.g.*, Kathy L. Jacobs & James M. Holway, *Managing for Sustainability in an Arid Climate: Lessons Learned from 20 Years of Groundwater Management in Arizona, USA*, 12 HYDROLOGY J. 54 (2004); ARIZ. DEP'T OF WATER RESOURCES, SECURING ARIZONA'S WATER FUTURE (2005); Fitzhugh & Richter, *supra* note 10, at 745 (data for 1985 and 1995 convert to 1.2 maf and 1.0 maf respectively). *But see* ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 2-19 (long-term median Salt/Verde diversion is 808,000 acre-feet from 1913-1997).

18. Salt River Project, Annual Pumping and Diversion Data 1980-2004 (data file obtained Mar. 21, 2005).

19. *Id. See also Groundwater Adds to Drought Plan*, CONTACT: NEWS FOR SRP RESIDENTIAL CUSTOMERS, June 2006, at 1, http://www.srpnet.com/electric/home/pdfx/contact0606.pdf (noting that SRP plans to restore its annual groundwater pumping capacity to its historic peak of 540,000 acre-feet).

supplies needs re-examination since changing regional hydroclimatology may further reduce yields on a more permanent basis.



Map: Federal and State Units That Manage Groundwater and Surface Water Supplies in Arizona

B. Environmental Impacts

The sustainability of the regional water supply is also affected by the extent and severity of environmental impacts that result from water withdrawal. Impacts on groundwater systems often emerge slowly over decades or centuries.[20] Groundwater withdrawal lowers water tables and may cause increased pumping costs, reduced groundwater quality, land subsidence, disconnection with surface water ecosystems, and permanent loss of aquifer storage. Subsidence causes economic losses from flooding or structural damage to buildings, dams, drainage, and irrigation investments. These consequences are often spatially and temporally separated from the originating water uses, with results felt decades into the future.

Many areas of the Salt River Valley do not receive the benefits associated with a high water table. Five of seven subbasins have experienced serious declines in water table and land surface. These areas, already at risk for future economic losses, will experience continued mining of ground water that further lowers water tables and water quality.[21]

> [Land] subsidence can continue for years after groundwater pumping has stopped in subsidence-prone areas. Compounding the potential for damage in the AMA is the fact that rapid urbanization is now occurring in many areas where significant future subsidence and earth fissuring is anticipated and groundwater level declines as much as 700 to 800 feet are projected. These areas include Apache Junction, the northwest Salt River Valley Subbasin, Queen Creek, and east Mesa, in addition to currently urbanized areas like Paradise Valley where earth fissuring has already occurred.[22]

Given these facts, management of regional aquifers can be viewed as inadequate despite the state's effort to control overuse through its groundwater code.[23] Future recovery of urban supplies

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20. *See generally* Bredehoeft, *supra* note 9; ALLEY ET AL., *supra* note 8.

21. John Keane, *Managing Water Supply Variability: The Salt River Project*, *in* MANAGING WATER RESOURCES IN THE WEST UNDER CONDITIONS OF CLIMATE UNCERTAINTY 303, 322-23 (Colloquium Proc., Comm. on Climate Uncertainty & Water Resources Mgm't, Nat'l Research Council, Nov. 14-16, 1990).

22. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 8-6.

23. ANIL MARKANDYA ET AL., DICTIONARY OF ENVIRONMENTAL ECONOMICS 161 (2001) (defining resource management as "control of the use of natural resources in order to

stored in short-term recharge projects may further destabilize aquifer conditions and exacerbate problems associated with declining water tables.[24] Beyond the valley, hydrologically connected basins are at risk for losing water supply and associated services because they contribute to or receive groundwater flows from Phoenix.[25]

Phoenix regional rivers, as with many western rivers, have been devastated by surface water diversions. The Salt, Verde, and Agua Fria rivers are significantly degraded, and their reduced flows contribute to the poor condition of the Colorado River's ecosystem.[26] Geomorphologic processes associated with the natural water flow regimes were altered or eliminated by dewatering and the loss of natural flooding patterns. Native plants, animals, and fish failed to adapt or compete with exotic species that tolerate dewatered conditions. The Salt River has been especially disrupted:

> Below Granite Reef Dam, the river's flow dwindled until the mid-1940s, at which time the river was almost totally desiccated. Dam operations and changes in sediment transport have led to down-cutting in the channel in areas where sandbars and islands were common before 1940....These changes in ecosystem processes and conditions also contributed to the extirpation of the native fish fauna.[27]

While the altered hydrology in the lower Salt River is decades old, the Verde River avoided the threat of dewatering until recently. Historically, metropolitan Phoenix receives an average of 300,000 acre-feet annually from the Verde watershed via the Salt River Project. The cumulative effects of existing and future water development in the Verde River watershed threaten hydrological functions and ecosystem processes associated with the upper and middle portions of the river. Growth in the Verde Valley has doubled the number of wells, 40 percent

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maximize the benefits that the resource provides, while preventing overexploitation or degradation of the resource base").

24. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 11-25.

25. *See* William M. Alley & Stanley A. Leake, *The Journey from Safe Yield to Sustainability*, 42 GROUND WATER 12, 14 (2004) (analyzing long-term impacts of pumping Paradise Valley ground water near Reno, Nevada, on the groundwater underflow of the adjacent Humboldt River basin). *See also* Memorandum from Lou Bota et al. to Salt River Valley Model File, *supra* note 12, at 24 (estimating very small groundwater inflows into the Valley from a rapidly growing area of Pinal County to the southeast of Phoenix, and very small outflows to a managed basin to the south, Pinal AMA, also growing rapidly).

26. Fitzhugh & Richter, *supra* note 10, at 746.

27. *Id.* at 745.

of which are located near the mainstem or its tributaries.[28] Upstream, towns within the Prescott AMA plan to pump 8,700 acre-feet annually from an alluvial basin that supplies the headwater springs of the Verde River with 80 percent of their flow.[29] Pumping is expected to lower this base flow and produce changes in stream channel morphology that will, in turn, impact the condition and extent of willow-cottonwood forests that support extensive biodiversity.[30] Loss of these riparian forests will intensify the loss of streamflow, impacting Phoenix water supply as well as populations of native fishes that are close to extirpation.[31]

C. Defining Sustainable Yield

A literature review of sustainable urban water management projects finds that most projects used one or more of four elements to define sustainability: (a) needs of the present generation, (b) needs of future generations, (c) carrying capacity of supporting systems, and (d) maintenance of ecological and hydrological integrity.[32] The American Society of Civil Engineers (ASCE) links these socioeconomic and environmental goals into a definition of sustainable water resource systems as "those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity."[33] In Arizona, water planners cite sustainability as a policy goal but confuse it with other approaches to water management.

First, sustainability of supply is often linked syntactically to concerns about reliability. For example, "The primary mission of ADWR is to ensure an adequate quantity of water of adequate quality for Arizona's future. Challenges to providing a sustainable water supply are

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28. Phoenix AMA Task Force, *Impact of Pumping*, *supra* note 1, at 3.

29. *Id.* at 44. *See also* Laurie Wirt, *Synthesis of Geologic, Geophysical, Hydrological, and Geochemical Data*, *in* GEOLOGIC FRAMEWORK OF AQUIFER UNITS AND GROUND-WATER FLOWPATHS, VERDE RIVER HEADWATERS, NORTH-CENTRAL ARIZONA, at G1, G10 (Laurie Wirt et al. eds., 2005) (U.S. Geological Surv. Open-File Report 2004-1411).

30. Shaun McKinnon, *Pumping Endangers State Rivers and Wildlife*, ARIZ. REPUBLIC, June 26, 2005, at A17.

31. R.M. MARSHALL ET AL., AN ECOLOGICAL ANALYSIS OF CONSERVATION PRIORITIES IN THE APACHE HIGHLANDS ECOREGION 40 (2004) (listing 65 conservation targets for the Upper Verde River Watershed, including rare and endemic plants and animals).

32. Michiel A. Rijsberman & Frans H.M. van de Ven, *Different Approaches to Assessment of Design and Management of Sustainable Urban Water Systems*, 20 ENVTL. IMPACT ASSESSMENT REV. 333, 335 (2000).

33. TASK COMM. ON SUSTAINABILITY CRITERIA, WATER RESOURCES PLANNING & MGMT. DIV., AM. SOC'Y OF CIVIL ENG'RS, SUSTAINABILITY CRITERIA FOR WATER RESOURCE SYSTEMS 44 (1998) [hereinafter ASCE].

numerous."[34] Management of water supply for performance issues such as safety and reliability does not necessarily result in sustainability of water supply.[35]

Second, sustainability is sometimes defined as meeting socioeconomic goals with no consideration for environmental and ecological goals. Statements from the 2004 Arizona Town Hall illustrate this point. The report recommends that "[s]ustainability of water supplies should be the primary goal of the state," but narrowly defines sustainability as "the ability of current generations to meet their needs without compromising the ability of future generations to meet their needs."[36] Corresponding environmental objectives, shaped by consideration for the carrying capacity and hydrological integrity of the supplying water resources, are missing.

Third, projects often claim sustainability by virtue of their management practices rather than actual results.[37] Statements from the 2001 Governor's Water Management Commission fit this description. The Commission defined renewable supplies as supplies from surface sources, and recommended proposals to maximize the use of available surface supplies.[38] It wanted to "ensure the long-term adequacy of renewable supplies to achieve a sustainable water supply,"[39] but failed to analyze the impact of three substantive issues on sustainable yield in surface water supplies.[40] Critically, the Commission assumed that the practice of using surface water resources is sufficient to ensure a sustainable supply.

Finally, Arizona water planners incorrectly regard the theoretical safe yield of a water supply as the sustainable yield. For example, "[s]afe-yield is closely related to the concept of sustainability, which

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34. ARIZ. DEP'T OF WATER RESOURCES, TRANSITION REPORT 6 (2002).

35. ASCE, *supra* note 33, at 55 (defining reliability as a statistic of urban water supply measuring water system performance in tandem with resilience and vulnerability; reliability is measured as the ratio of satisfactory to total values obtained).

36. EIGHTY-FIFTH ARIZONA TOWN HALL, ARIZONA'S WATER FUTURE: CHALLENGES AND OPPORTUNITIES 2 (2004), ag.arizona.edu/azwater/publications/townhall/th_report.pdf.

37. Rijsberman & van de Ven, *supra* note 32, at 334.

38. Technical Advisory Committee Issue Paper, *Availability, Reliability, & Utilization of Renewable Supplies* 3 (draft Nov. 19, 2000) [hereinafter *Renewable Supplies* Issue Paper #1], Attachment 4, *in* GOVERNOR'S WATER MGMT. COMM'N, FINAL REPORT OF THE COMMISSION (2001) (defining effluent and surface water from streams and rivers as renewable supplies that "are replenished on an annual or seasonal timeframe").

39. GOVERNOR'S WATER MGMT. COMM'N, FINAL REPORT OF THE COMMISSION, at *vi* (2001).

40. *Cf. id.* at 37 (identifying loss of stream riparian functions and the impact of increased Verde Valley pumping as problems, but failing to examine their effects on the stated goal of sustainable water supply), 13 (predicting loss of excess Colorado River supplies by 2030).

means that resource availability does not diminish over time. Safe-yield is entirely consistent with the goal of ensuring reliable long-term water supplies."[41] The Arizona Revised Statutes define safe yield as "attempts to achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn in an active management area and the annual amount of natural and artificial recharge in the active management area."[42]

In fact, there is lively discussion in the professional literature as to whether safe yield constitutes a sustainable extraction from an aquifer. "A common misperception has been that the development of a ground water system is 'safe' if the average annual rate of ground water withdrawal does not exceed the average annual rate of natural recharge."[43] Scientists from the U.S. Geological Survey view safe yield as "an oversimplification of the information that is needed to understand the effects of developing a ground-water system" and refer to it as the "Water-Budget Myth."[44] What troubles them is that safe yield does not address the systemic nature of groundwater systems and their beneficial effects on surface water systems.[45] Over long periods of time, aquifers stabilize in response to pumping by capturing discharge that formerly left the system as surface flows, groundwater flows, or as transpiration of phreatophytic (water-loving) vegetation. When groundwater withdrawal is large enough, additional recharge from adjacent basins is captured to restore equilibrium.[46] For this reason, groundwater withdrawals that can be defined as safe yield actually threaten surface water resources and their associated ecosystems.[47] In contrast, the methodology to quantify sustainable groundwater yields creates models of future stream-aquifer interactions spanning hundreds of years to

41. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 12-2.

42. ARIZ. REV. STAT. ANN. §§ 45-561, 45-562 (2003). Three of Arizona's 46 groundwater basins are mandated to lower withdrawals to safe yields by 2025.

43. Alley & Leake, *supra* note 25, at 12.

44. ALLEY ET AL., *supra* note 8, at 15. *Cf.* Alley & Leake, *supra* note 25, at 13 (suggesting that safe yield is an early formulation in the progression of the science of managing interconnected water ecosystems).

45. Marios Sophocleous, *From Safe Yield to Sustainable Development of Water Resources – The Kansas Experience*, 235 J. HYDROLOGY 27, 30 (2000).

46. *See, e.g.*, Bredehoeft, *supra* note 9, at 342; MARK T. ANDERSON & LLOYD H. WOOSLEY, JR., WATER AVAILABILITY FOR THE WESTERN UNITED STATES – KEY SCIENTIFIC CHALLENGES 48-68 (U.S. Geological Surv. Circular 1261, 2005).

47. ANDERSON & WOOSLEY, *supra* note 46, at 50 fig. 35.

examine the characteristics of the new equilibrium. It offers a more nuanced approach to the assessment of water development options.[48]

Although many of Arizona's groundwater basins remain integrated, well-connected surface water-groundwater systems, groundwater aquifers in the metropolitan Phoenix area have been largely disconnected from surface water systems. Here, surface flows are entirely controlled by reservoir releases, so the ordinary connection between groundwater aquifers and the river channel does not exist. Biodiversity associated with streamflow also does not occur or depends on artificial water supplies. Levies and reservoirs, not channel geomorphology, regulate occasional large flood releases.

In this local context, the sustainable yield is largely limited to *sustainable increases* in groundwater recharge and *sustainable reductions* in groundwater discharge. It is unfortunate that current artificial recharge projects are a temporary effort to store unused water from the Colorado River rather than an ongoing program to sustain groundwater withdrawals. Moreover, almost all groundwater withdrawals are legally permitted and are not subject to reduction despite the large yearly overdraft. Any assessment of sustainable yield is made more tentative because the available data on natural and incidental aquifer recharge are unmeasured estimates rather than actual wellhead or gravimetric observations.

To summarize this discussion, planning documents on Arizona water supply refer to sustainability in statements of general purpose but actually plan only for reliability, full utilization, and safe yield. To date, the dependencies that promote permanence in the Phoenix regional water resource system have not been quantified or integrated into a working model of water supply. This research defines sustainable water supply as *the maximum persistently available supply capable of contributing fully to present and future societal goals and maintaining the ecological and hydrological integrity of the supplying systems.*

III. ECONOMIC CARRYING CAPACITY OF THE SUSTAINABLE SUPPLY

A. Analytic Model and Research Design

Comprehensive analysis of available water supply requires quantification of the regional system before and after delivery occurs,

48. Sophocleous, *supra* note 45, at 41 (arguing that "sustainability assessment should be understood as a dynamic and iterative process, requiring continued monitoring, analysis, prioritization, and revision").

including available supply, consumption, return flows, and reclamation. This system-level evaluation is not available in reports generated by ADWR. The Phoenix AMA typically uses assessment methodology that accounts for water delivery by economic sector (municipal, industrial, agricultural) and water class (surface water, ground water, effluent).[49] The most recent report, Phoenix AMA Draft 2000 Master Water Budget, uses this format.[50]

This research uses a model of integrated regional water supply originally published by the U.S. Geological Survey (USGS) (see Graphic 1). The model is distinctive in that it incorporates two critical management concepts. Gross water supply, WSg, is the volume theoretically available for use under current conditions.[51] It is the sum of available water sources minus the water that cannot be used consumptively. In the Phoenix region, gross water supply is:

$$WSg = (P+X+S+G+WW) - ET$$

P = precipitation	G = ground water
X = water imports	WW = collected waste water
S = surface water	ET = evapotranspiration

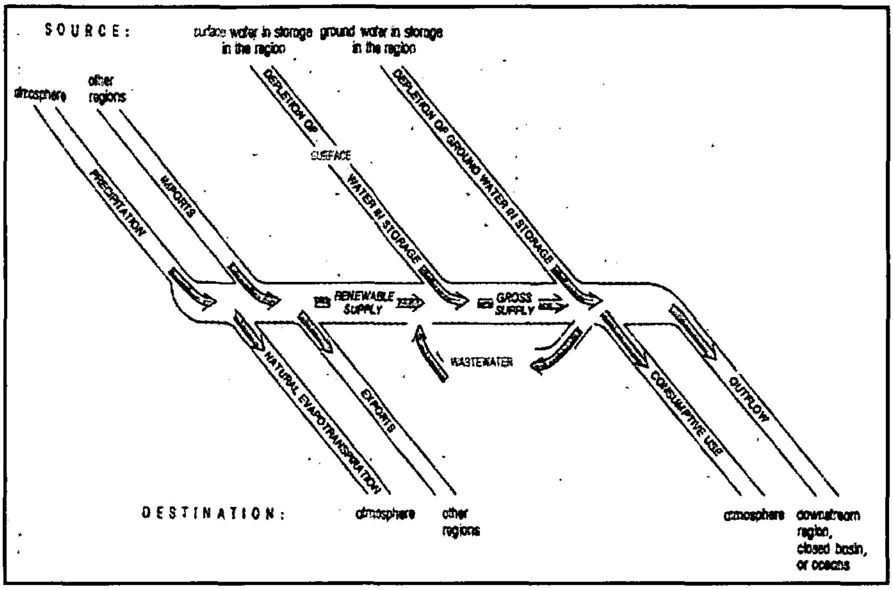
Metropolitan Phoenix imports water via aqueduct from the Colorado River to augment its native supplies. An average 1.6 million acre-feet are delivered through a federal reclamation project, the Central Arizona Project (CAP), to project lands that cover most of Maricopa, Pinal, and Pima counties in the central and south-central portions of the state.

49. Telephone Interview with Philip Jahnke, Hydrologist, Ariz. Dep't of Water Resources, in Phoenix, Ariz. (May 17, 2005). Phoenix AMA collects data based on water classes to facilitate its accounting, reporting, and regulatory functions. Use of these data for broader analysis of regional supply can produce errors because they do not depict hydrologic conditions at the water source.

50. ARIZ. DEP'T OF WATER RESOURCES, *supra* note 16; Ariz. Dep't of Water Resources, Phoenix Active Management Areas, http://www.azwater.gov/WaterManagement_2005/Content/AMAs/PhoenixAMA/default.htm (last visited Oct. 13, 2006) ("Link to Phoenix AMA water budget, coming soon").

51. U.S. Geological Surv., *Hydrologic Perspectives on Water Issues*, *in* NATIONAL WATER SUMMARY 1983—HYDROLOGIC EVENTS AND ISSUES 23-26 (Water Supply Paper 2250, 1984).

Graphic 1: Integrated Regional Water Supply Model[52]



"Renewable water supply" (WSr) is defined as the supply that is theoretically available on an essentially permanent basis.[53] It differs from gross supply in that it subtracts out supplies that cannot maintain a constant averaged volume. This "permanence standard" is an important criterion for quantifying the extent to which water supplies are actually renewable. The renewable water supply functions as a "simplified upper limit to the amount of water consumption that could occur in a region on a sustained basis."[54] The USGS defines specific and separate criteria for quantifying renewable supplies of ground water and surface water. A renewable groundwater supply does not deplete aquifer storage.[55] A renewable surface supply is that volume of regulated flow that can be withdrawn in 49 of 50 years.[56] It may be further reduced if entitlements or contracts require the maintenance of minimum flows or surface-water

52. Adapted from U.S. Geological Surv., *Hydrologic Perspectives on Water Issues, in* NATIONAL WATER SUMMARY 1983—HYDROLOGIC EVENTS AND ISSUES 23 (Water Supply Paper 2250, 1984).
53. *Id.*
54. *Id.*
55. *Id.*
56. *Id.* at 30.

dependent ecosystems.[57] Consideration of whether imported supplies are renewable requires a refinement of the original USGS definition. This research proposes the category of renewable import water, Xr, to accurately represent the permanent supply of water available from the Colorado River net of large pools available on a temporary basis.

The empirical research collected data of the historical supply for the period 1983 to 2002 and calculated the mean gross and renewable volumes. These data were assembled from national and regional sources to include available reserves and streamflows; water diversions and withdrawals; water delivered, consumed, and reused; and return flows to the natural system.[58] Likely future renewable supplies to 2035 were identified and added to the estimate of currently sustainable water supply. The last step derived opportunity cost and economic carrying capacity of the renewable supply (see Table 1 for assessment protocol).

Table 1: Protocol for Estimating Carrying Capacity and Opportunity Cost of Regional Water Supply

1. The theoretical limit of regional supply is operationalized as average annual gross water supply, WSg.
2. The functional or consumptive limit of regional supply is operationalized as the average annual renewable water supply, WSr.
3. The opportunity cost of the regional renewable supply is calculated as the difference, OC = WSg - WSr.
4. Economic carrying capacity of the renewable supply is operationalized as the maximum number of housing units the calculated renewable supply could support, CC = WSr /WD, where WD = assumed level of water delivery per unit.

The concepts of carrying capacity and opportunity cost have little previous treatment in urban water supply research or management although they are common in resource and environmental economics. However, a current Arizona Town Hall report presents carrying capacity as "the size of population or community that can be sustained

57. GOVERNOR'S WATER MGMT. COMM'N, *supra* note 1, at viii (recommending limited protection of designated streams within AMAs, but subsequently rejected by the state legislature).

58. Data were provided by the Arizona Department of Water Resources, Statewide Planning, Hydrology & Water Management Divisions; the Central Arizona Project and its subsidiary Groundwater Replenishment District; Maricopa Council of Governments; the National Oceanic & Atmospheric Administration Western Regional Climate Center; the Salt River Project; and the U.S. Geological Survey National Water Information System and Water-Use Information Program.

indefinitely by the available resources and services."[59] Several researchers suggest carrying capacity as a logical way to operationalize the concept of sustainability.[60] Jonathan Harris proposes the definition of carrying capacity as that level of population and consumption that can be sustained by the natural resource base and that triggers a decline in the standard of living if exceeded.[61] In this research, carrying capacity is operationalized as the maximum number of households the water supply can support without triggering a decline in the standard of living of those households. Opportunity cost is measured as that water supply and associated housing development that would be foregone in order to limit water supply to a sustainable level.

B. Estimated Size of Phoenix Regional Renewable Water Supply

Recall from the previous section that the calculation of renewable water supply requires estimates of the region's gross water supply as well as temporary supplies that do not support a constant averaged volume. The median gross supply available to metropolitan Phoenix was 4.1 million acre-feet and generally declined over the 20-year study period (see Graphic 2). The trend may illustrate the temporary influence of the drought cycles that typify arid-region water resources, or it may result from more permanent causes associated with the over-development of water resources or climate change. Gross supply varied between a high of 8.4 million acre-feet in 1993 and a low in 2002 of 3.5

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59. EIGHTY-EIGHTH ARIZONA TOWN HALL, ARIZONA'S RAPID GROWTH AND DEVELOPMENT: NATURAL RESOURCES AND INFRASTRUCTURE, at iii (2006).

> Current levels of air and water pollution, inadequate water supplies in some areas, and the loss of natural habitats, biodiversity and agricultural lands raise concerns that Arizona may have exceeded its carrying capacity in these areas. However, carrying capacity is a dynamic concept: the draw on available resources varies with population size, consumption levels and regional differences. Implementation of new technology and resource conservation consistent with living in an arid state can increase carrying capacity, as can shifts in lifestyle such as working closer to home, water conservation, and using carpools and public transportation.

Id.

60. *See* MICHAEL JACOBS, THE GREEN ECONOMY: ENVIRONMENT, SUSTAINABLE DEVELOPMENT AND THE POLITICS OF THE FUTURE 87 (1997); JAMES K. LEIN, INTEGRATED ENVIRONMENTAL PLANNING 32, 42 (2003) (cautioning that application of the concept to planning demands "careful treatment" of four assumptions: the existence of resource limits, the ability to identify population thresholds, mutability of resource capacity to support growth, and necessary use of judgment).

61. JONATHAN M. HARRIS, ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS: A CONTEMPORARY APPROACH 30 (2006).

million acre-feet. Groundwater availability correlated highly with surface supplies, which in turn varied with precipitation (see Table 2).

Graphic 2: Phoenix Regional Gross Water Supply 1983-2002

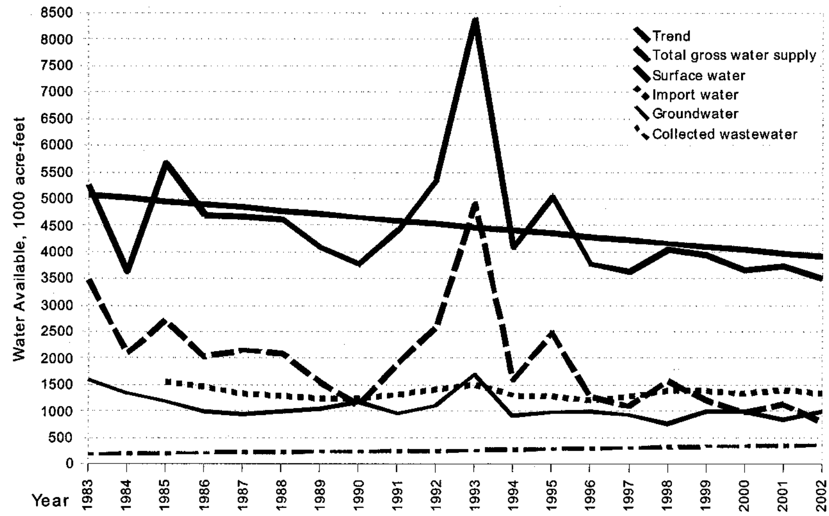

Table 2: Statistical Summary of Gross Water Supply, in 1000 acre-feet[62]

Statistic	Import Xr	Surface water Sr	Ground water Gr	Waste water WW	Total renewable water supply WSr
Maximum	1,560	4,900	1,700	370	8,370
Minimum	1,200	800	760	190	3,500
Correlation to Sr	0.56	1.0	0.78	-0.54	0.94
Correlation to Gr	0.40	0.78	1.0	-0.52	0.68
Standard deviation	90	980	235	60	1.120
Median	1,350	1,750	1,000	260	4,090

62. ADWR THIRD MANAGEMENT PLAN, *supra* note 10, at 2-21; Memorandum from Lou Bota et al. to Salt River Valley Model File, *supra* note 12, at 24 tbl.3; *Arizona Colorado River Article V Accounting All Contractors 1964–2003* (ADWR data file obtained May 4, 2005); Annual Cumulative Deliveries and Revenues by Contract Classification 1985–2003 (Central Arizona Project data files obtained Feb. 7, 2005); Total Reservoir Storage (Salt River Project data file obtained Feb. 10, 2005); Surface Water Streamflow and Statistics, Nat'l Water Info. System Web Data (U.S. Geological Surv. Data files, obtained May 2, 2005 from http://waterdata.usgs.gov/nwis).

The median for temporary water supplies was 1.6 million acre-feet annually for the study period. Colorado River water temporarily available to the CAP service area, around 1.0 million acre-feet annually, was the largest component followed by ground water pumped in excess of recharge. These were subtracted from total gross supply to estimate the permanently available water supply. The total median annual renewable supply for the study period was 2.5 ± 0.2 million acre-feet.

The renewable water supply came from four sources. These were locally extracted ground water, surface supplies from three tributaries of the Gila River, imported water from the Colorado River, and water reclaimed from public systems and reused. Imported water from the Colorado River showed the single largest decline from gross to renewable supply.[63] A relatively small portion of the imported supply, approximately 575,000 acre-feet, is permanently allocated to federal and non-federal sectors in the metropolitan Phoenix area through agreements between the state of Arizona and the Secretary of the Interior (see section IV).[64] The permanent import supply increased slightly as water settlements benefiting Indian communities were signed.

Surface water supplies from the Salt, Verde, and Agua Fria rivers also diminished when the permanence standard was applied. The minimum annual renewable supply for the study period, 800,000 acre-feet, is that amount that could, in theory, have been continuously withdrawn between 1983 and 2002 without supplement from groundwater resources.[65] Actual delivery of this amount would have required capturing flood flows for long-term aquifer storage, which is not currently legal. This volume of renewable supply was barely available during the 2002 drought year. The estimate of annual renewable ground water at 900,000 acre-feet relies entirely on computer modeling of natural, incidental, and program-sponsored aquifer recharge between 1983 and 2002.[66]

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63. Ariz. Dep't of Water Resources, Arizona Colorado River Article V 1964-2003 (data file obtained May 4, 2005) (used to derive total temporary pool supply [including uncontracted, unscheduled, or surplus Colorado River water] from 1.25 million acre-feet in 1987 to 0.92 million acre-feet in 2002 that was available yearly to CAP subcontractors).

64. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 8-10 tbl.8-1 (Central Arizona Project Allocations 1998).

65. This calculation adapts the USGS standard for surface water to the 20-year study period for which annualized data were available. To identify the renewable surface water supply, gross supply was reduced iteratively until an identified volume of water was continuously available in all years.

66. Memorandum from Lou Bota et al. to Salt River Valley Model File, *supra* note 12, at 24 tbl.3 (estimating total inflow for the period 1983-2003 using incidental agricultural and

Estimates for the volume of new, renewable supplies that are likely to be available by 2035 were also analyzed (see Table 3). Metropolitan Phoenix has legal although not physical access to three groundwater basins for importation, but these potential supplies were not used in the analysis because they would incur significant financial, environmental, and social costs. Reclaimed water from effluent will be the largest and most dependable source of additional, renewable supply assuming public policy continues to marginalize residential gray water systems.[67] Additional CAP water will become available as non-Indian agricultural priority water is transferred to urban subcontractors pursuant to the 2004 Arizona Water Settlements Act. The Act also transfers a significant CAP entitlement to the Gila River Indian Community along with authority to enter into lease agreements with local water providers. CAP infrastructure may also be used to transfer water from Indian and non-Indian agricultural uses along the Colorado River as Valley water providers find willing sellers. If the mean renewable supply from existing sources remains at the current level, then a future renewable supply of 3.2 million acre-feet in 2035 is a reasonable estimate (see Table 3). This includes 700,000 acre-feet of new, renewable supplies.

C. Opportunity Cost and Carrying Capacity of the Renewable Supply

What economic benefits would the Phoenix regional economy have to forgo to pursue a sustainable water supply? The opportunity cost of a proposal is a measure of economic trade offs and can be quantified as acre-feet, jobs, or housing development that would be foregone in order to limit water supply to a sustainable level. This research used the volumetric difference between gross and renewable supplies to estimate the opportunity cost. Following this logic, the opportunity cost of confining the regional water supply to the permanent supply is estimated at 1.6 million acre-feet annually between 1983 and 2002 (see Graphic 3).

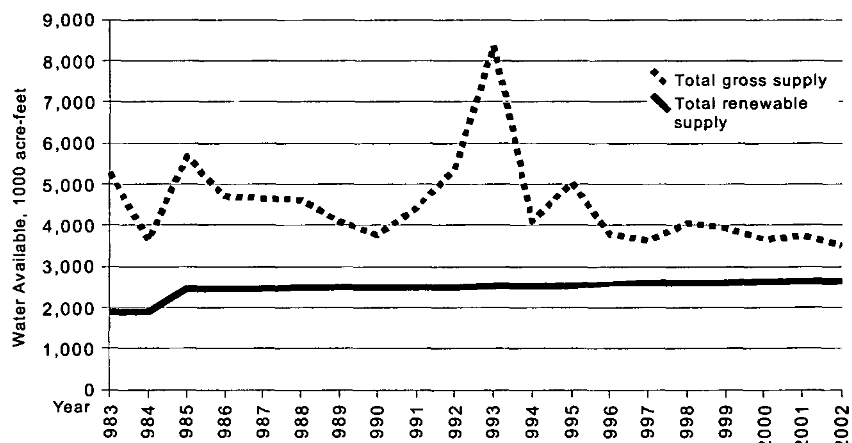
urban recharge, direct recharge including effluent, canal seepage, river and stream flood infiltration, and boundary inflow).

67. *Phoenix Snubs the Idea of Wastewater Reuse*, U.S. WATER NEWS ONLINE, May 2005, http://www.uswaternews.com/archives/arcconserv/5phoesnub5.html (last visited Aug. 27, 2006) (City of Phoenix officials discourage new subdivisions from recycling household gray water to garden uses).

Table 3: Phoenix Renewable Water Supply Projected to 2035, in 1,000 acre-feet[68]

Source	2010	2020	2030	2035	Totals
Reclaimed Water*	120	115	110	70	415
CAP Allocations & Leases	45	130	25	0	200
Colorado River Entitlements & Leases	0	45	45	0	90
Total New Supply	165	290	180	70	705
Regional Renewable Supply 1983-2002	2,510				2,510
Projected Total WSr	2,675	2,965	3145	3215	3,215
* Based on population forecasts *infra* Table 4.					

Graphic 3: Opportunity Cost Associated with Sustainable Water Supply Policy for Metropolitan Phoenix, Estimated at 1.6 million Acre-Feet Annually from 1983-2002



68. Adapted from *Water Supply* Inventory, *in* CENT. ARIZ. GROUNDWATER REPLENISHMENT DIST., PLAN OF OPERATION, app. E, tbl.E-2 (submitted draft, Nov. 8, 2004)

The final analytic step estimates the economic value of the renewable water supply and its opportunity cost in units of housing.[69] This is an attractive innovation because planners, decision makers, and the general public understand the household as a unit of consumption. It puts vast amounts of water on a human scale by identifying the hypothetical capacity of the future regional renewable water supply to support housing. Residential carrying capacity creates a comprehensible benchmark for considering competing policy options. In the case of the likely future Phoenix regional supply, the residential carrying capacity is estimated at between 4.2 and 7.6 million housing units (see Graphic 4). The range is large due to the sensitivity of the analysis to assumptions about the amount of water delivered to each housing unit.[70] However, the estimate readily supports the projected 2.6 million households expected by 2035 (see Table 4). The opportunity cost of limiting supply to the 3.2 million acre-feet of renewable supply is estimated to be between 2.0 and 3.7 million households.

Table 4: Regional Population and Housing Units[71]

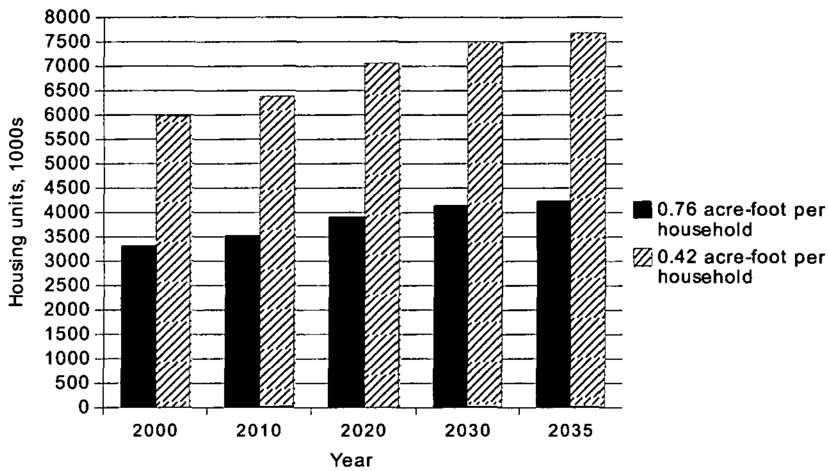
Year	Population	Total Housing Units
1980	1,505,000	611,000
1990	2,122,000	952,000
2000	3,072,000	1,260,000
2010	4,134,000	1,606,000
2020	5,164,000	1,970,000
2030	6,140,000	2,310,000
2035	6,785,000	2,570,000

69. *Cf.* Peter H. Gleick, *Global Freshwater Resources: Soft-Path Solutions for the 21st Century*, 302 SCIENCE 1524 (2003) (suggesting increased economic production per unit of water withdrawn as an alternative measure of economic growth).

70. Ariz. Dep't of Water Resources, Assured Water Supply Program 2004 Schedule AWS (data file obtained Apr. 2005) (reporting Peoria's 0.42 acre-feet per year as the lowest estimate of future delivery to new households and Gilbert's 0.76 acre-feet per year as the highest).

71. Maricopa Ass'n of Gov'ts, Regional Report: A Resource for Policy Makers in the Maricopa Region, at 7 tbl.G-1 (2005); Terri Sue Rossi, Central Arizona Project, Conservation: Growth Manager or Enabler? (Presentation 2005),

Graphic 4: Carrying Capacity of Projected Regional Renewable Water Supply, Using Two Assumptions of Water Delivery per Household



D. Limitations of the Analysis

Although residential carrying capacity is expected to be useful in comparing the relative economic value of alternate water supply policy scenarios, the concept describes theoretical outcomes only. Residential carrying capacity assumes that all renewable water supply is committed to residential development, which is not realistic. In fact, legal, economic, and social constraints operate to prevent the water supply from being devoted entirely to housing. Much of the available, renewable supply is already allocated to economic activity and cannot be easily moved to new uses. This issue is discussed in the next section.

The use of volumetric estimates of renewable water supply should be handled carefully by planners and researchers. They should be treated as an upper bound on the true volume of sustainable water supply available to metropolitan Phoenix for several reasons. First, the estimated annual renewable surface supply does not leave enough water in the system to maintain the geomorphology that in turn provides flow regulation, biodiversity, and aquifer recharge along river segments that are free of modifications. Therefore, the true value of the renewable surface supply is expected to be smaller than the estimate. Likewise, the sustainable groundwater yield is probably significantly lower than the average 0.90 ±0.3 million acre-feet estimated to have been recharged annually between 1983 and 2002.[72] Not only does recharge overestimate the groundwater yield that can be sustained for decades or centuries, but the data include incidental and program-sponsored recharge that are as variable as natural sources of replenishment. Finally, the estimate of reclaimed water at 260,000 acre-feet annually is based on assumptions about the relationship between water delivered and wastewater collected rather than evidence.[73] These limitations in the data mean that the estimates must be carefully handled to avoid misleading decision makers.

Additionally, it is important to keep in mind that this assessment does not consider sub-basin or equity issues. Although the regional supply is sufficient and renewable, sub-basin areas experience serious supply problems.[74] Water quality, water logging, committed legal supply, land subsidence, and increasing depth to water table all directly affect sub-basin supplies. Nor does the analysis assess the latent issue of equity in supply allocation. *Inequities exist where the use of a water supply produces large variations in benefits and costs over time and space.* Impacts on parties at a temporal or spatial distance to water transactions can cause lasting economic and social disruptions, making the region less productive and less livable.

To summarize the central empirical finding, the Phoenix renewable water supply is sufficiently large to meet regional economic goals and at the same time protect many of the environmental functions generated by the regional system. The estimated renewable supply in 2035 of 3.2 million acre-feet is capable of supporting two times the number of predicted households (2.6 million) if the context of existing institutional arrangements and water entitlements is ignored. The assumption that water entitlements will trade more freely in the future is required to reach the conclusion that metropolitan Phoenix can both meet its economic goals and limit its economy to a sustainable water supply. This issue is discussed next.

IV. POLICIES THAT WASTE SUPPLIES AND ECONOMIC CAPACITY

The central question in this section is not whether supplies can grow, but whether economic activity can grow by using supplies more

72. Memorandum from Lou Bota et al. to Salt River Valley Model File, *supra* note 12, at 24.

73. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 2-21 (assuming 0.11 acre-feet produced per person yearly).

74. *Id.* at 12-3.

effectively on a per-acre-foot basis.[75] The regional economy has grown at an unprecedented rate since 1980, with mean population increases of 47 percent in each decade. Phoenix regional population is expected to double from 3.1 to 6.3 million residents between 2000 and 2030, while available water supplies are expected to remain stable or even shrink.[76] The gross regional product in 2002 was $121.7 billion with a total withdrawal of fresh water around 2.4 million acre-feet, suggesting an (admittedly rough) benchmark of economic activity at $51,000 per acre-foot of water supply.[77] Regional economic activity is influenced by federal policies on transportation, agriculture, housing, and environment that stimulate demand for available water supplies.[78] However, control of the economics of managed water supplies rests with key state-based institutions, and these are presented next.

A. Economic Issues with Entitlements

The economic value of water depends on rivalry (competition) for water as well as the excludability (control of access), transferability (sale), and enforceability (civil suit) of the entitlement associated with its use. Arizona statutes establish usufructuary rights to three classes of water: effluent, surface water, and ground water.[79] Water retains its original legal class when it is traded, stored, or retrieved and only loses its designation if it is released back into the natural system.

The 1980 Groundwater Management Act (GMA) established a complex system of administrative permits to control access to Phoenix regional aquifers. Entitlements include grandfathered rights, industrial permits, service area rights, long-term storage credits, and certificates or

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75. Gleick, *supra* note 68, at 1524-27 (suggesting that, while many Americans fear reduced water use will lower their standard of living, the goal of improved social and individual well-being can be achieved simultaneously with reduced water use).

76. MARICOPA ASS'N OF GOV'TS, *supra* note 71, tbl.G-1. *Cf.* ANDERSON & WOOSLEY, *supra* note 46, at 1. U.S. Bureau of Reclamation, Water 2025: Preventing Crises and Conflict in the West (2003), http://www.doi.gov/water2025/supply.html (showing Phoenix as having substantial potential for inadequate supplies to meet urban, farming, and environmental needs).

77. *Adapted from* Gleick, *supra* note 68, *with data from* U.S. CONF. OF MAYORS, GROSS METROPOLITAN PRODUCT OCTOBER 2004 ECONOMIC FORECAST, app., tbl.1, http://www.usmayors.org/metroeconomies/1004/metroeconomiestables_1004.xls (last visited Aug. 27, 2006); SUSAN S. HUTSON ET AL., ESTIMATED USE OF WATER IN THE UNITED STATES IN 2000 (U.S. Geological Surv. Circular 1268, rev. 2005).

78. *See, e.g.*, Lora Lucero & A. Dan Tarlock, *Water Supply and Urban Growth in New Mexico: Same Old, Same Old or a New Era?*, 43 NAT. RESOURCES J. 803, 809-10 (2003) (federal policy continues to support water for growth while new projects face sharply reduced federal funding and compliance on federal environmental regulations).

79. ARIZ. REV. STAT. ANN. § 45-101 (2003).

designations of assured water supply.[80] The stated public policy goals are reduction in groundwater withdrawals; allocation of limited groundwater resources; and transition to renewable supplies.[81] Excludability is a critical issue to groundwater management because current pumping is an order of magnitude larger than can be sustained.

The GMA's record on effective control of access to ground water is controversial. Former ADWR administrators Kathy Jacobs and James Holway argue that, "[b]y providing regulatory certainty, a clear water rights system and the grandfathering of existing users, the GMA has encouraged investments in conservation and use of renewable supplies."[82] Officials at Phoenix AMA (an administrative unit of ADWR) challenge this view, writing,

> Although the overall management goal for the Phoenix AMA is safe-yield, e.g. to bring groundwater withdrawals in balance with natural and incidental recharge, the Groundwater Code (Code) contains very few provisions that actually require water users to limit groundwater pumping and use to levels consistent with this goal. In fact the Code grandfathered significant amounts of historic groundwater pumping, allowed some existing groundwater uses to expand, and permitted the initiation of new uses of groundwater.[83]

There are also problems with the transferability of groundwater entitlements and the regional market for them is very limited.[84] Grandfathered rights to agricultural and industrial uses of ground water have significant limits on transfer. This inflexibility contributes, unintentionally, to the continuing large size of the irrigated agriculture sector and its low conversion rate to urban uses.

Entitlements to Phoenix regional surface flows are established by a state appropriative system. Regional rivers are not only significantly over allocated; they are also threatened by well development that captures river subflow, as in the Verde Valley.[85] A substantial quantity of high-priority water is held by seven irrigation districts that have member

80. Judith M. Dworkin, Water Rights 39–40 (1997) (unpublished paper, on file with Sacks Tierney P.A., Scottsdale, AZ).
81. Jacobs & Holway, *supra* note 17, at 55.
82. *Id.* at 61.
83. Phoenix AMA Safe-Yield Task Force, *Allowable Groundwater Pumping*, *supra* note 13, at 1.
84. Jacobs & Holway, *supra* note 17, at 57 n.11.
85. Phoenix AMA Task Force, *Impact of Pumping*, *supra* note 1, at 42.

lands with attached service rights.[86] The irrigation districts filed lawsuits alleging priority claims to the Salt River, Verde River (and tributaries), and Gila River (upper, lower, and Agua Fria tributary) as early as 1974. The Arizona Supreme Court consolidated all suits into two general stream adjudications in 1981 that are still unresolved. The court will establish the priority and quantity of state appropriable water (surface and subflow) and federal reserved water (including ground water) that right holders actually have claim to use. With 25,000 parties to the Gila River Adjudication, some representing dozens or thousands of landowners, the economic consequences will be enormous.[87] These adjudications cloud surface water rights throughout the Gila River system and impact their transferability.

Economic problems also result from the poor transferability of entitlements related to the Central Arizona Project. These are allocated through interstate agreements, federal legislation, court decisions, and private settlements between parties to three economic sectors: municipal and industrial (M&I), Indian, and non-Indian agriculture. M&I subcontracts do not generally transfer between users within the CAP service area, in part because there is no incentive to trade. Any income from the sale or exchange of CAP water reverts to the Central Arizona Water Conservation District (CAWCD), which operates the CAP.[88] Although exchanges of CAP water between M&I users do occur, there is also little market for credits to CAP water stored underground.[89] The 2004 Arizona Water Settlements Act illustrates the existing reallocation process, with specific quantities and parties legislated rather than allowing free markets to sort out these particulars.[90] Because markets are not used, there is little economic advantage to using water efficiently.

86. ARIZ. REV. STAT. ANN. § 45-172(A)(4) (2003) (irrigation or ditch rights cannot be severed from member lands within the boundaries of the irrigation district, water users' association, or ditch association without approval from the organization); ARIZ. REV. STAT. ANN. § 45-188(C) (2003) (ditch rights are not subject to forfeiture or abandonment if the water provider has maintained an operable system capable of delivering the volume of appropriated water).

87. *Arizona Court Prepares to Examine Federal Reserved Water Rights for State Trust Land*, W. WATER L. & POL'Y REP., June 2005, at 223 (reporting the Arizona Land Department's request for a court declaration of federal reserved water rights for five million acres located in the Gila River basin).

88. RICHARD WAHL, MARKETS FOR FEDERAL WATER: SUBSIDIES, PROPERTY RIGHTS, AND THE BUREAU OF RECLAMATION 242 (1989).

89. *See* Jacobs & Holway, *supra* note 17, at 57 n.13.

90. Arizona Water Settlements Act, Pub. L. No. 108-451, 118 Stat. 3478 (2004) (approving six specific Gila River Indian Community leases to valley cities and directly reallocating 65,000 acre-feet of priority agricultural water to specific municipal water providers; also withdrawing regional agriculture from permanent CAP allocations as

The Master Repayment Agreement between CAWCD and the U.S. Department of the Interior sets up another barrier to efficient transfers of CAP water. Currently, it allows water subcontracts within federal and non-federal allocations to be reassigned by the state that receives applications from entities wanting to initiate or increase their allocation of CAP water.[91] This arrangement creates genuine financial disincentives for potential sellers and favors buyers with the resources to engage in a protracted process. Developing a market for CAP subcontracts under state aegis would introduce much needed incentives for conservation among subcontractors and reduce transaction costs.

B. State Regulatory Programs

The state of Arizona has a major water policy that seeks to transition groundwater users to renewable supplies per the state groundwater code. New or expanding utility systems and subdivisions must demonstrate an assured water supply from primarily renewable supplies. Assured Water Supply Program (AWS) rules require the developer or water provider to demonstrate 100 years of sufficient renewable supplies of adequate quality that are both physically and legally available. Better than 90 percent of the water supply must come from renewable sources. Compliance is required to receive plat or sale approvals from local and state authorities.[92]

Many new subdivisions without direct access to renewable sources make use of the Central Arizona Groundwater Replenishment District (CAGRD) to achieve compliance with AWS rules. CAGRD charges fees and purchases renewable supplies to replenish ground water for members who pump in excess of their AWS designation. However, this recharge does not occur at the point of withdrawal, nor even necessarily in the same sub-basin. CAGRD expects its obligations within the Phoenix AMA to grow substantially from 31,400 acre-feet currently to 186,700 acre-feet annually by 2035.[93] Member subdivisions

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irrigation districts permanently relinquish 197,500 acre-feet of agricultural entitlements in exchange for debt relief and access to excess CAP water at reduced prices through 2030).

91. WAHL, *supra* note 87, at 236–37 (identifying two additional impediments to market transactions: subcontractors are locked in to 50-year contracts, and conversion of irrigation water to M&I use is limited to one acre-foot per acre of converted land regardless of historical consumptive water use).

92. ARIZ. DEP'T OF WATER RESOURCES, ASSURED WATER SUPPLY PROGRAM (rev. Nov. 1, 2001), http://www.azwater.gov/WaterManagement_2005/Content/Forms/AWSBrochure.pdf.

93. CENT. ARIZ. GROUNDWATER REPLENISHMENT DIST., PLAN OF OPERATION 35 tbl. 3.6 & 128 tbl. C-5 (submitted draft, Nov. 8, 2004) (Note the absence of discussion on hydrological impact of pumping by CAGRD members. According to ADWR, the west Salt River Valley

and service areas avoid the expense of transporting renewable supplies through pipelines or canals, a major cost for land developers and utilities. Without CAGRD, they would have to build infrastructure to directly use surface or effluent supplies in compliance with the AWS program. For these reasons, CAGRD significantly weakens the effectiveness of the Assured Water Supply Program to control access to ground water. Also, it further undermines the hydrological integrity of regional aquifers.

The state of Arizona has a second major water policy to fully utilize the state's entitlement to 2.8 million acre-feet of Colorado River water. This effort stimulated experiments to conjunctively manage water supplies and led to the state's Augmentation and Recharge Program in 1989.[94] Conjunctive management deliberately stores and commingles surface water and ground water to coordinate their use for a common purpose. The Phoenix region has significant natural capacity for direct recharge of water to underground storage, in addition to 18 engineered sites. Underground storage capacity is important because no new aboveground reservoirs are planned for the region.[95] However, by 2002 only 2.2 million acre-feet (combined CAP and effluent) had been artificially recharged for future urban uses.[96]

Arizona has the institutional framework, physical setting, and infrastructure to have made wider use of surface water for direct recharge, but statutory programs, regulations, and financing are missing. For instance, right holders of regional surface supplies such as SRP and irrigation districts cannot legally store water underground for periods of more than one month. This precludes Salt/Verde water supplies from being conjunctively managed, a technique widely regarded by the

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sub-basin is at risk for subsidence, compaction of aquifer storage capacity, and water quality reductions as the lagged effects of historic agricultural pumping affect the groundwater system. CAGRD allows 135,200 new housing units demanding 100,400 acre-feet annually in this same area by 2035. The potential impact on the sub-basin should draw questions about the potential for CAGRD to undermine the management goals of Phoenix AMA).

94. *See* WILLIAM BLOMQUIST ET AL., COMMON WATERS, DIVERGING STREAMS: LINKING INSTITUTIONS AND WATER MANAGEMENT IN ARIZONA, CALIFORNIA, AND COLORADO 22-37 (2004) (natural recharge facilities include streambeds and irrigation districts that exchange storage credits for groundwater left in-situ).

95. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 8-17.

96. Ariz. Dep't of Water Resources, Annual Longterm Storage Credit 1989-2003 by Water Source [hereinafter ADWR, Storage Credit 1989-2003] (data file obtained Apr. 25, 2005).

industry as beneficial.[97] Second, water utilities are not required to proactively store water for future drought mitigation and system reliability purposes.

In fact, fully 70 percent of current recharge projects are indirect (in-lieu), with farmers receiving low-cost CAP water for irrigation. The cost of this water is subsidized by municipalities that receive credits for the ground water not pumped, to recover in the future.[98] Stated differently, twice as much water is committed to new obligations on the existing groundwater resource as is directly injected, which gives short-term relief to water table or pumping lift problems.[99] Economically, there is no rationale for M&I water providers to subsidize agriculture when that low-cost water could be directly used to attract job-intensive industries or remediate regional aquifers. Most recharge projects use temporarily available CAP supplies that will be eliminated by 2030. The region needs a program for long-term remediation of aquifers using market mechanisms and public funds.[100]

C. Direct and Implicit Subsidies

Policy makers consider that the state policy of full utilization of Colorado River water justifies the use of public funds to subsidize water, primarily for agriculture. CAP makes nearly 60 percent of its deliveries under subsidized contracts.[101] CAWCD, which operates CAP, creates pricing incentives to sell excess water to irrigators through short-term contracts. Water that is uncontracted, unscheduled, or surplus (called "pool water" and estimated to be worth $250 per acre-foot at full cost) is offered by CAWCD to irrigation districts at $21 per acre-foot.[102] CAWCD's pricing behavior is viewed as a rational response to the

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97. *See* BLOMQUIST ET AL., *supra* note 93, at 12. *But see* Anderson & Woosley, *supra* note 46, at 63 (inaccurately citing SRP as an example of conjunctive management). In fact, SRP currently mines ground water to augment deliveries. *See* Part 2.A *infra*.

98. BLOMQUIST ET AL., *supra* note 93, at 89; Jacobs & Holway, *supra* note 17, at 59.

99. BLOMQUIST ET AL., *supra* note 93, at 89.

100. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 8-31 (recommending the permanent replenishment of just 32,000 acre-feet annually through the purchase and retirement of groundwater entitlements).

101. Jacobs & Holway, *supra* note 17, at 58; ADWR, Storage Credit 1989-2003, *supra* note 95.

102. Phoenix AMA Safe-Yield Task Force, supp. attachment, *Agricultural CAP Water Availability and Use* 2 (draft Nov. 13, 2000, to Attachment 4, *Renewable Supplies* Issue Paper #1, *supra* note 38, Availability, Reliability & Utilization of Renewable Supplies, *in* GOVERNOR'S WATER MGMT. COMM'N, FINAL REPORT OF THE COMMISSION (2001).

federal rules governing its loan repayment requirements.[103] Participating municipalities contribute to the price subsidy in exchange for future access to valuable ground water. CAWCD underwrites the subsidies by collecting ad valorem property taxes at the rate of four cents per $100 of property valuation in Maricopa, Pima, and Pinal counties, in addition to other revenues.[104] Subsidies to agriculture are deemed necessary to retire CAP debt, to stimulate utilization, and, most recently, to satisfy the terms of the 2004 Act.

The Salt River Project also subsidizes water users. The Salt River Project Agriculture Improvement and Power District (District) operates the Salt River Project (SRP), the Valley's original federal reclamation project, through contracts with the Salt River Valley Water Users Association (Association).[105] The District assumes obligations for the federal water infrastructure and contracts with the Association to operate an irrigation system. The District has contributed electricity revenues to support water operations for decades, with $32.2 million, $44.2 million, $62.9 million and $56.7 million for fiscal years 2002, 2003, 2004, and 2005, respectively.[106] District and Association service areas overlap, so this water subsidy benefits SRP electricity customers. Still, the subsidy distorts users' choices about water by making the price unrealistically cheap.

The third direct subsidy comes through the Central Arizona Groundwater Replenishment District. Arizona Revised Statute section 48-4463 permits CAGRD members to use valuable ground water and calculate replacement volumes at a fraction of the actual withdrawal. In addition, suburban developers and municipal water providers avoid the expense of piping otherwise required renewable supplies to new developments and receive a second major subsidy.

These agency programs exacerbate a core economic problem with Arizona water supplies: the price of water in most of Arizona is too low to benefit the social welfare.[107] The first recommendation of the 2004

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103. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 8-9 (CAWCD loan repayment costs drop as agricultural use of CAP water rises because no interest is due for water supplied to agricultural uses.).

104. Ariz. Water Banking Auth., Background: Funding, http://www.awba.state.az.us/backgrnd/funding.html (last visited Aug. 27, 2006).

105. SALT RIVER PROJECT, 2004 ANNUAL REPORT 46.

106. SALT RIVER PROJECT, 2003 ANNUAL REPORT 51; SALT RIVER PROJECT, 2005 ANNUAL REPORT 56, http://www.srpnet.com/about/financial/ar/pdfx/pdf05/EntireReport.pdf.

107. *See* Michael J. Pearce, *Water Law and Policy Update*, ENRLS UPDATE (ST. B. OF ARIZ.), May 2005, at 4. *See also* Thomas S. Maddock & Walter G. Hines, *Meeting Future Public Water Supply Needs: A Southwest Perspective*, 31 WATER RESOURCES 317, 319 (1995) (adjusted for inflation, water costs less in the Southwest than it did in 1965); Larry MacDonnell, *Water as a Commodity*, SOUTHWEST HYDROLOGY, Mar.-Apr. 2004, at 16 (proposing a two-tiered

Arizona Town Hall is that water pricing should reflect its long-term cost because "conservation is the most important method to increase the longevity of existing water sources."[108] Normally, water prices recover only immediate (distribution and treatment) costs, and even these are sometimes subsidized. Economists advocate that water prices should reflect full costs, including the cost of damages to water resources incurred by water development, in order to avoid its overuse. "Efficient pricing would set price equal to marginal social cost to limit use to the point where the benefits derived from use of the last unit are equal to the costs of producing that unit."[109]

The ADWR acknowledges two impacts of subsidies—incentives, as the Department calls them—created by provisions in its agricultural, municipal, and industrial conservation programs that intend to encourage renewable surface water use.[110] First, target pricing of temporary water supplies stimulates consumption that would otherwise not occur. Second, it favors some groups at the expense of others. ADWR admits that it is difficult to design policy to maximize water use without compromising efficiency and equity.[111]

The failure of Arizona's programs and entitlements to incorporate environmental costs into water prices creates an implicit subsidy that distorts the regional economy.[112] First, water is tied up in low-value economic activity, often agricultural production, where the marginal value of the water is well under $50 per acre-foot.[113] These goods are effectively subsidized by the artificially low price of water, giving them a competitive advantage over substitute products made locally or similar products made elsewhere. Also, cheap water encourages waste through the continuing use of inefficient technologies—flood irrigation is a local example of an arcane practice that survives because water is cheap. Finally, the public is deprived of its

approach to water pricing: essential water (a life-line quantity of 50 liters per person per day) and non-essential water (consumptive and non-consumptive uses)).

108. EIGHTY-FIFTH ARIZONA TOWN HALL, *supra* note 36, at 3.

109. Kenneth D. Frederick, *Economic Consequences of Climate Variability on Water in the West*, *in* MANAGING WATER RESOURCES IN THE WEST UNDER CONDITIONS OF CLIMATE UNCERTAINTY, *supra* note 21, at 217. *See generally* HOLLY STALLWORTH, WATER AND WASTEWATER PRICING (EPA 832-F-03-027), http://www.azwifa.gov/QuickLinks/Pricing Guide.pdf.

110. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 8-37.

111. *Id.* at 8-38.

112. Garth Porter, *Natural Resource Subsidies, Trade, and Environment: The Cases of Forests and Fisheries*, http://nautilus.org/archives/papers/enviro/TEPP/porterTEPP.html (last visited Aug. 27, 2005).

113. Kenneth D. Frederick, *Marketing Water: The Obstacles and the Impetus*, RESOURCES, Summer 1998, at 7, 8.

resource without appropriate compensation, leaving both the state water agency and local water providers strapped for financial resources that should be used to better manage the water supply. *Pricing water appropriately is critical to long-term socioeconomic goals.*

V. CONCLUSION AND RECOMMENDATIONS

Phoenix and Arizona need a new generation of water supply policies. This article presented new methodology to identify and quantify the economic carrying capacity of the sustainable water supply of metropolitan Phoenix. It examined state policies that will restrain regional economic growth as existing entitlements and subsidies incur increasingly onerous environmental costs and constrict the spontaneous movement of available water supplies to new uses. While the regional renewable water supply is large and robust, expected growth will outstrip its economic capacity without deliberate new policy making. The single most effective change would be to *require local units of government that seek state funding of their water infrastructure projects to participate in the development of regional water supply plans.* Beyond that, *tax and trade for sustainable groundwater yields and enhanced recharge* would better serve the growing regional economy than the present system of entitlements and subsidies.

Groundwater use must be more tightly linked to sustainable aquifer conditions. Officials attribute the ongoing groundwater mining to decisions by agricultural and industrial users, and to a lesser extent undesignated municipal water providers, to use low-cost ground water.[114] In reality, the problem is caused by regulatory failure to effectively link the choices these entities make to the groundwater management goal.[115] Public policy should connect groundwater access to sustainable aquifer conditions: "You take out what you have put in, where you put it in" is an unambiguous, enforceable, credible aquifer protection and utilization policy.

Combining groundwater tradable permits with pumping taxes would establish financial rewards for water providers who align their management decisions with public policy targets. A groundwater pumping tax based on the long-term environmental costs of pumping would raise the cost of ground water, making alternate supplies more

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114. ADWR, THIRD MANAGEMENT PLAN, *supra* note 10, at 11-25.

115. Stuart Whitten et al., *Tradable Recharge Rights in Coleambally Irrigation Area* 3 (2004) (presented at 48th Ann. Conf. of Austl. Agric. & Res. Econ. Soc'y), http://www.ecosystemservicesproject.org/html/publications/docs/Markets_Tradeable_Credits.pdf ("Linking targets to actions and outcomes is the key to framing effective instruments.").

attractive and tradable. Two objectives would be achieved: the introduction of much needed efficiencies to the water allocation process and reductions in groundwater withdrawals. Tradable permits would incorporate newly defined property rights to attributes of healthy aquifers such as storage, inexpensive access to high-quality water, and land stabilization. They would be allocated to existing right holders and pro rated to the sustainable yield of the groundwater sub-basin. Tradable permits could be sold at a profit by entities that recharge water or manage to use less to entities seeking to avoid taxation.

This market framework expands compliance options within a regulatory system. Another mechanism for expanding options is to offset the proposed new use by reducing existing demand for ground water in proportion to the new use, thereby maintaining the relative size and scarcity of the resource.[116] Offset policy allows an applicant to design and implement a joint project with an existing user, for example, retrofits to reduce withdrawals by a turf irrigator or industrial operator. The private transaction transitions saved water to a new use and provided less-costly options for compliance with a groundwater pumping tax, making the regulation more acceptable and more successful.

Embedding a market within a groundwater withdrawal taxing program has another objective, to vastly increase the scope of aquifer recharge activity. Public water providers need an economic incentive to better utilize two water sources entirely within their control—treated effluent and water saved through targeted conservation programs.[117] A tax and trade program would reward M&I water providers that manage recharge programs by earning them tradable groundwater permits. It would enable private entities such as utilities, non-profits, and irrigation districts to operate recharge programs within state guidelines.

The tax and trade scenario illustrates the potential to enlarge the economic capacity of existing regional Phoenix water supplies for 2035 and beyond. Arizona needs new water supply policies, lest it confound the vital water resources that metropolitan Phoenix enjoys.

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116. JACOBS, *supra* note 60, at 90.

117. ADWR, Storage Credit 1989-2003, *supra* note 95 (by 2003, only 260,000 acre-feet of treated wastewater had been stored underground; just 124,000 acre-feet of Salt/Verde water was stored and 116,000 acre-feet had already been retrieved because it is not eligible for long-term storage credits); ARIZ. DEP'T OF WATER RESOURCES, TRANSITION REPORT 66 (2002), http://azwater.gov/dwr/Content/Publications/files/news/adwrtransition2002.pdf (noting that private water companies litigated to avoid implementing water conservation programs).