To: City/County Water and Wastewater Study Oversight Committee
From: Mike Letcher
City Manager
Chuck Huckelberry
County Administrator

Date: May 12, 2009

Re: City/County Stormwater Management Technical Paper

As part of Phase II of the City/County Water and Wastewater Study, the City and the County have evaluated how we can best use stormwater and rainwater as a supplemental water source. The attached paper serves as an introduction and overview of the best use of stormwater and rainwater as supplemental water. It considers four criteria in evaluating the "best" use as follows:

- Availability and reliability of stormwater and rainwater as a supplemental water source.
- Viability of using stormwater or rainwater to recharge groundwater.
- Legal constraints associated with water rights and water quality.
- Cost effectiveness of obtaining stormwater or rainwater as a supplemental source.

This paper includes a discussion of both rainwater and stormwater harvesting. It separates the existing built (constructed) environment from stormwater management that will occur in future development where new strategies and planning can be used to make the most efficient use of stormwater. It looks at options appropriate for retrofitting the existing built environment as well as options appropriate for future growth areas where new development provides an opportunity for larger scale stormwater harvesting solutions.

As you will find in the attached report, staff found that there are several opportunities to harvest rainwater and stormwater at different scales, i.e. regional to lot level. However, there are physical and legal challenges that impact our ability to use stormwater as a supplemental source including the variability of annual and seasonal rains, surface water rights, and water quality regulations.

The recommendations in the paper include:

1. Encourage Maximum Use of Rainwater and Stormwater at the Lot Scale

Rainwater can be harvested at the lot scale to eliminate some of the needs for potable water. Drought-tolerant native plants can typically be grown on passively-harvested water alone after supplemental water has been used to get them established. Rainwater harvesting in tanks is useful as a supplemental source for plants that are not drought-tolerant. Specific recommendations are as follows:
Existing Built Environment: In the built environment, the City of Tucson and Pima County should develop joint education and outreach about rainwater harvesting on why, how to, and where it can be utilized. Furthermore, estimating the volume of water available at the lot scale from increased impervious surfaces would allow the potential uses of this water to be better assessed.

Future Development: The City of Tucson and Pima County should pursue the development of joint landscape, building and zoning standards that increase the potential for on-site capture, storage, and use of rainwater. Incentives to HOAs and builders should be considered.

2. Encourage Maximum Use of Stormwater at the Neighborhood Scale

Future development should be built to maximize the potential for use of stormwater at the neighborhood scale. Supporting vegetation using harvested stormwater will eliminate the need for some landscape watering. Stormwater flow paths can be depressed to encourage the potential for infiltration and native vegetation can be planted that will thrive in these depressed flow paths. In some cases, development standards and HOA regulations may need to be modified to accommodate this strategy. Such a strategy will have the additional benefit of reducing flood peaks and improving stormwater quality. The viability of using dry wells should be re-evaluated in new subdivisions where sediment loads are expected to be low, and there is a reasonable possibility for the water to be recharged.

3. Limit Floodplain Encroachment on Regional and Tributary Watercourses

Because Regional Watercourses, and their associated floodplains, are important conduits for recharge, they should not be encroached upon so that they function during large events that are so important to recharge. Likewise, limiting encroachment will limit the possibility of movement of contaminants into the regional watercourses.

4. Manage Tributary Watercourses for Recharge or Stormwater Capture

Where the built environment has resulted in an abundance of impervious surfaces, stormwater capture should be considered. Where future development occurs, Tributary Watercourses should be managed to reduce flood peaks and encourage infiltration on Regional Watercourses. This can be accomplished using structural means, such as the construction of detention basins, or non-structural means, such as floodplain management, to limit encroachment. The City of Tucson and Pima County should develop a joint policy for regional planning of multi-use facilities for stormwater harvesting, recreation and restoration.

5. Consider the Overall Economic Benefits of Rainwater and Stormwater Harvesting

Water harvesting has multiple benefits, especially at the lot and neighborhood scale. These benefits include increased floodwater retention, and limiting the migration of contaminants. Vegetation grown on harvested rainwater and stormwater reduces the demand on potable resources, mitigates the urban heat island, provides habitat, requires less energy, and reduces dependence on imported water sources. The synergy between these elements should be considered in evaluating the costs and benefits of rainwater and stormwater harvesting.
6. Advocate for a Legal Framework Conducive to Use of Stormwater

The City and County should continue to work with ADEQ to develop water quality standards and designations specific for groundwater recharge and habitat restoration for inclusion in the next triennial review.

In the Phase 1 report of this Water/Wastewater Study, the Committee recognized that rainwater and stormwater are valuable water resources that must be considered and put to use as part of our community’s future overall water resource portfolio. The full costs and benefits of utilizing these sources needs to be compared to the costs and benefits of new imported water resources. The Additional Water Resources paper that is scheduled to be presented to the Committee in August will include this cost comparison information.

Recommendation

It is respectfully recommended that the Committee review this report and provide input to the City and County on its recommendations.

Attachment

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City of Tucson and Pima County
Stormwater Management
Technical Paper

May 2009

This paper was prepared by a joint team of City of Tucson and Pima County staff from the following departments: Pima County – Regional Flood Control District, Regional Wastewater Reclamation Department, the County Attorney’s Office, and the County Administrator’s Office. City of Tucson – Tucson Water, Office of Conservation and Sustainable Development, Department of Transportation, Development Services, and City Manager’s Office.
City of Tucson and Pima County
Stormwater Harvesting and Management as a Supplemental Water Source Technical Paper

Water and Wastewater Infrastructure, Supply and Planning Study, Phase II

May 2009

As part of the scope of the Joint City of Tucson/Pima County Water and Wastewater Infrastructure, Supply and Planning Study (WISP), the County has asked the following question:

*How can we best use stormwater and rainwater as a supplemental water source?*

1. Introduction

Purpose of this White Paper

The purpose of this white paper is to discuss the best use of stormwater and rainwater as supplemental water. It considers four criteria in evaluating the ‘best’ use as follows:

- Availability and reliability of stormwater and rainwater as a supplemental water source.
- Viability of using stormwater or rainwater to recharge groundwater.
- Legal constraints associated with water rights and water quality.
- Cost effectiveness of obtaining stormwater or rainwater as a supplemental source.

Furthermore, this paper assumes that ‘supplemental’ means that this rainwater or stormwater is used to augment the potable water supply, either by replacing a current use of potable water, or by increasing potential recharging of the aquifer. For example, rainwater that is captured for direct use on land that is has historically been irrigated, is considered a supplemental use. However, if the rainwater is captured and only irrigates the capture area it is not supplemental water, although there may be significant other benefits to project. Captured rainwater may also be considered a supplemental source if it is a potential source to replace other potable water uses such as water use in evaporative coolers and cooling towers. Stormwater can be captured for direct use for irrigation or used to recharge the aquifer.

For the purposes of this paper, the following definitions are used:

*Rain or Rainfall* is precipitation that falls as liquid.

*Rainwater* is rain prior to migrating off an individual property. Rainwater harvesting is collection of rainwater before it leaves a property boundary.
Stormwater is rain that has moved off a lot. Stormwater harvesting includes efforts to recharge groundwater with stormwater or the capture of stormwater for direct use. (This definition is different than the term ‘Stormwater’ used in surface water adjudication).

Scope of this White Paper

This paper includes a discussion of both rainwater and stormwater harvesting. It separates the existing built (constructed) environment from stormwater management that will occur in future development where new strategies and planning can be used to make the most efficient use of stormwater. It also considers stormwater as a supplemental water source for Regional Watercourses, Tributary Watercourses, Neighborhood-scale Drainage, and Lot-scale Drainage.

This paper characterizes ‘use’ generally as either recharging the aquifer or capture for direct application, but does not identify specific methods to accomplish this ‘use’.

The issues listed in the Table 1 below are addressed.

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*Regional Watercourses: Santa Cruz River, Rillito Creek, Pantano Wash, Tanque Verde Creek, Canada Del Oro Wash, Brawley Wash, Black Wash*

*Tributary Watercourse is a tributary to a Regional Watercourse*

The entities within Pima County and the City of Tucson that regulate of stormwater are described in Appendix A.

2. Background

Hydrologic Cycle in the Tucson Basin

Assuming an average rainfall of 12 inches per year (yr), about 2,500,000 acre feet (ac-ft) of rainfall falls on the Tucson Active Management Area (TAMA), the 3,866 square mile groundwater management area that includes the Upper Santa Cruz River and Avra Valley. However, stormwater outflow from the TAMA at Trico Marana Bridge is only about 33,800 ac-ft (which includes some effluent), or about 1.5 percent of the total.
rainfall. Since about 15,750 ac-ft/yr of stormwater enters the TAMA from the Santa Cruz Active Management Area, the net outflow is only about 0.75 percent of the total rainfall falling on the area, which indicates that on the scale of the Regional Watercourses, there is very little actual supplemental water available to harvest.

A greater portion of all rainfall recharges the aquifer. Recharge accounts for about 3% of the total rainfall on the TAMA. The accepted estimates for recharge are 38,900 acre-feet per year from mountain front recharge and 37,700 acre-feet per year from stream channel recharge (Arizona Department of Water Resources [ADWR], 2000). About 82% of the stream channel recharge and 70% of the mountain front recharge occurs in the Upper Santa Cruz valley, while 18% of the stream channel recharge and 30% of the mountain front recharge occurs in Avra Valley.

Overall, about 96% of all rainfall on the TAMA exits the basin as Evapotranspiration (ET). In Pima County, potential evapotranspiration (ETo) is much greater than rainfall. In an average year the evaporative demand (as measured by ETo) is 77 inches at Campbell Avenue farm, while average rainfall is about 11 inches. As such, the evaporative demand and transpiration from plants will be pulling water back out once it infiltrates into the soil, so that it will not infiltrate to the water table.

Availability and Reliability of Rainwater and Stormwater as a Source

• **Rainfall**

Rainfall is highly variable from year-to-year. The National Weather Service recorded extremes for annual rainfall totals are 24.17 inches in 1905 and 5.07 inches in 1924. According to long-term averages at Tucson International Airport, 52% of the annual rainfall occurs between July and September during the summer monsoon and 29% occurs during the winter rainy season between December and March. The reliability of rainfall and stormwater as a water supply is controlled by the annual volume of rainfall and the distribution of that rainfall throughout the year.

For Tucson, the normal rainfall volume is 12.17 inches. However, we are currently in a drought. In the last ten years the average rainfall volumes have averaged 10.02 inches per year, which is equivalent to a ten-year deficit of 21.51 inches. In addition, individual intense summer storms provide much of this rainfall. For example, in 2005, only 9.57 inches of rainfall was received and one single summer storm event on August 23, 2005 accounted for 2.29 inches of rainfall or 24% of the total for the year. The sporadic nature of rainfall requires that proposed uses be adaptable to the seasonal rainfall patterns and yearly ranges that are typical of this climate.

• **Rainwater and Stormwater**

The most efficient use of supplemental rainwater or stormwater is at the lot scale, and about 40% of potable water is used on lot-scale outdoor water use. The close proximity of where the rain falls to where it is put to use results in little loss through conveyance, intervening infiltration, evaporation and other losses. Development actually creates opportunities to harvest water. As Figure 1 shows, in the case of an undeveloped lot, (green dashed line) less than 10% of all rain that falls on that lot leaves the lot. The
remainder infiltrates into the soil, is lost to evaporation, or is lost to plant transpiration. However, with urbanization and increased impervious surfaces, the amount of possible rainfall that can be harvested increases greatly. On a rooftop, if a 0.05 inch rainfall threshold is assumed (i.e. losses to depressions, storage or evaporation off a hot roof), 83% of the rainfall is available to harvest in an average year. Other impervious surfaces on a lot prevent the infiltration of rainwater into the soil, thus generating rainwater runoff that can be used elsewhere on the lot, or stormwater runoff that can be used off site.

Close to the point of runoff generation, the primary opportunity for the use of this water is to irrigate drought-tolerant plants using the practice of passive water harvesting, because these plants are adapted to the ephemeral nature of desert rainfall and runoff patterns. Passive water harvesting is the collection of rainwater or stormwater directly into water harvesting infiltration areas without the temporary storage in a tank. In essence, the soil is the storage location for water for future use by the plant. The deeper the rootzone of the plant, the greater the potential storage. The larger the area diverted to the planted area, the larger the volume of water stored in the soil, and the greater available to the plant during prolonged periods without rain. Through active water harvesting, in which rainwater is stored in tanks, and through greywater use, more prolonged and predictable alternative water sources can be obtained to support vegetation such as fruit trees.

Figure 1 – Percent of Total Rainfall Available as Harvestable Rainwater and Stormwater (Data is included Appendix B and Description of Mass-balance Model is included in Appendix C)
The farther from the point of runoff generation, the less reliable stormwater flow is. Regional Watercourses flow only after a significant storm event or as a result of snow melt. On the average, the Santa Cruz River flows only 11% of the year, or 40 days, and the Rillito flows only 8% of the year, or 29 days (Katz, 1987). Annual flow volumes are more varied than annual rainfall values. The water yield on the Santa Cruz River at the Continental stream gauge in 1983 was 117,250 ac-ft, or about seven-and-a-half times greater than the long-term mean value of 15,750 ac-ft (Figure 2). The lowest annual flows on the Santa Cruz River and the Rillito River were 976 acre-feet (1924) and 297 acre-feet (1956), respectively.

![Figure 2 – Annual Water Yield on the Santa Cruz River at the Continental Stream Gauge](image)

Viability of Using Stormwater to Recharge Groundwater.

- **What Has Been Done Elsewhere**

Other communities in the southwest are actively managing stormwater recharge. However, in many cases, differences in watershed and aquifer characteristics make these methods inappropriate for use in Pima County.

Since the 1930s, Los Angeles has used off-channel spreading to divert surface water and recharge ground water. Inflatable dams have been used to divert flows from the perennial Los Angeles and San Gabriel Rivers to 2400 acres of spreading basins. Spreading continues 365 days a year, 24 hours a day resulting in the recharge of about 300,000 acre-ft of water a year.
The inflatable dams serve an important role in these recharge projects in Los Angeles County, but the conditions are substantially different than those encountered in Pima County. Upstream dams, such as Prado Dam on the Santa Ana River, allow for flows year round that are relatively free of sediment. Regional Watercourses in Pima County are ephemeral, flowing for 40 days in an average year. When flows occur in Pima County they are sediment rich, which means this sediment can settle upstream of an inflatable dam essentially eliminating the capacity of the dam to trap flows.

California has evaluated numerous methods to increase availability of water including cloud seeding. http://www.waterplan.water.ca.gov/strategies/index.cfm.

Chandler AZ has constructed over 4000 dry wells (Geosystems, 2004), which collect surface water from subdivision-scale developments and route it to the aquifer. In general, these dry wells are in neighborhoods where runoff has little fine sediment, and drains into a relatively poor-quality shallow aquifer. Since Chandler still has farmland, there is a potential to use this poor-quality water for irrigation.

Conditions are different in Pima County. The regional aquifer tends to be deeper and better quality. Previous attempts to use dry wells in Pima County have generally been unsuccessful. They require maintenance and tend to clog. Still, there may locations in Pima County where dry wells could be used.

- **Natural Recharge Characteristics in Pima County**

Studies have shown that the Regional Watercourses of the Tucson Basin are efficient natural infiltration galleries recharging storm runoff, flood flows and snow melt into the aquifer after passing it through many feet of a natural sand filter. Faults and underlying materials impact the quantity of runoff that is recharged along the various reaches of the Regional Watercourses. Infiltration into Regional Watercourses in Pima County and southern Arizona has been widely studied. Burkham (1970) developed equations for infiltration (also called transmission losses) for most of the Regional Watercourses including the Santa Cruz River, Rillito Creek, Tanque Verde Creek, Canada Del Oro Wash, and Pantano Wash.

In southern Arizona, natural channels can contain the 5-10 year event, and water can flow up out of the banks if flows exceed channel capacity. Overbank flows are slowed by vegetation and other obstructions and conditions that create “roughness”. Slowing the flows and expanding the wetted area increases the potential for recharge.

In contrast, water tends to flow deeper, in narrower flowpath and faster in bank-protected reaches. The opportunity for infiltration is diminished, as the footprint of the flooding and duration of flow decrease. Therefore, encroaching on natural channels can dramatically reduce the potential for natural recharge.

**Surface Water and Stormwater Legal Framework**

There are numerous state and federal regulations that may apply to projects and programs that use stormwater and other waters including Clean Water Act regulations.
and aquifer protection regulations. The most critical for the harvesting and use of stormwater are water rights statutes and water quality regulations, see Appendix D.

Water Rights

Arizona has a bifurcated system for allocating water rights, differentiating groundwater from surface water. Surface water means the water of all sources, flowing in streams, canyons, ravines and other natural channels as well as natural lakes, ponds and springs (ARS § 45-101(8)). Surface water includes flood flows in channels. Appropriation of surface water rights is allocated based on first in time, first in right. This means the first water user to put the surface water to beneficial use has first right to use the water which is critical in times of drought. The Santa Cruz River is a tributary to the Gila River and claims of surface water rights for the Santa Cruz River and its tributaries are subject to the Gila River Adjudication. For all practical purposes, all of the surface water in the Santa Cruz Watershed has been appropriated. There are administrative procedures to obtain surface water rights and the County has successfully obtained a certificate of surface water rights for the Kino Environmental Restoration Project at the Ajo Detention Basin.

Stormwater in the form of overland flow or sheet flow is distinguished from channel flow and is not subject to appropriation until it reaches a river, stream, lake or other natural surface water feature (ARS § 45-141). Stormwater can be, and is being harvested, as a supplemental and primary source to establish and maintain vegetation.

In order to receive recharge credits for stormwater, it must be demonstrated that the stormwater would otherwise have left the Tucson Active Management Area (TAMA). Because flood flows historically have only left the boundaries of the TAMA in extreme events such as the 1983 Flood, it is difficult, if not impossible, to demonstrate that stormwater would have left the TAMA.

When evaluating stormwater harvesting and recharge programs in other states it is important to consider the state’s statutes for water ownership and use rights. Colorado allocates surface water based on first in time for beneficial use, first in rights doctrine; however, unlike Arizona, stormwater is considered surface water. Colorado allows the detention and spreading of stormwater for new developments so long as the purpose is to maintain pre-existing runoff rates and to improve water quality. Colorado does not allow for stormwater harvesting for “beneficial use” including landscape irrigation or rainwater harvesting cisterns. California has a varied and complex water rights system which has allowed some California municipalities to collect and recharge stormwater for water supply purposes. California recognizes pueblo rights derived from Spanish law whereby pueblos rights are paramount to the beneficial municipal use of all needed, naturally occurring surface and subsurface water from the entire watershed. California water laws have allowed municipal water providers to harvest and recharge stormwater runoff.

Water Quality

Water quality regulations also impact the use of stormwater and surface water as well as reclaimed water and effluent. In December 2002, the Environmental Protection Agency...
(EPA) authorized and delegated primacy to Arizona to manage the permit program for the National Pollutant Discharge Elimination System (NPDES) under Section 402 of the Clean Water Act. The Arizona Department of Environmental Quality (ADEQ) now regulates and permits reclaimed and effluent uses under the Arizona Pollutant Discharge Elimination System (AZPDES) permits as part of the Clean Water Act.

The change of permitting agency, from the EPA to ADEQ, has had a significant impact on the permitting requirements for the use of stormwater and reclaimed water. When Pima County and the US Army Corps of Engineers (Corps) constructed the Kino Environmental Restoration Project (KERP) at the Ajo Detention Basin, EPA permitted the facility under NPDES to operate using guidance of best management practices as a created wetlands system. Under Arizona regulations, ADEQ is treating the use of reclaimed water as a point source discharge of effluent and changed the designation from created wetlands to Aquatic and Wildlife Ephemeral (A&We). As a result, whole effluent toxicity monitoring is required. Reclaimed water chlorination requirements are in conflict with effluent water quality requirements and the water must be dechlorinated prior to being released.

When developing the Swan Wetlands project, ADEQ was going to require whole effluent toxicity monitoring if any reclaimed water irrigation occurred within the 25-year floodplain of the Rillito and its tributaries. The project was redesigned to avoid this monitoring requirement. The City had proposed release of effluent into Atterbury Wash for environmental restoration. This project is on hold due to the conflict with the water quality standards. Blending of stormwater and reclaimed water is desirable to make projects economical and to provide the greatest benefits.

The County and City formed a stakeholder group to discuss the issues with ADEQ and to develop a new designated use strictly for recharge and habitat restoration which would provide more appropriate regulatory requirements and consider the net ecological benefit. ADEQ supported this concept but the changes did not make it into the latest triennial review. The City and County will continue to pursue these designated uses along with their own set of water quality standards.

**Cost Effectiveness**

Managing rainwater and stormwater can provide economic benefits (Appendix E). Some of these benefits include flood mitigation, pollutant mitigation, urban heat island mitigation, provision of wildlife habitat, continued function of riparian habitat, and increasing the “quality of life” of neighboring residents through reduced hazards and an enhanced environment. One lesson learned is that managing floodplains for continued natural functioning provides a significant benefit in terms of avoiding costs associated with loss of this natural function including costs for downstream regional detention storage, storm drain construction, and damage due to flooding. In the built environment, considerable funds have been required to retrofit drainage networks at the Kino Environmental Restoration Project and the Arroyo Chico Restoration Project to prevent downstream flooding in the central urban area of Tucson, see Figure 3. Current Pima County Regional Flood Control District (RFCD) and City of Tucson (COT) policies are to map floodplains and limit encroachment into these floodplains.
The beneficial use of stormwater provides benefits that potable water cannot. Rainwater and stormwater are self-delivered. The capture and use of these resources reduces the need for the construction or augmentation of potable water delivery systems that in part serve landscape irrigation. Stormwater also mobilizes and removes contaminants produced in the urban environment from their source to centralized collection areas, which allows for the management of these contaminants. Finally, only stormwater can provide the volumes and flow dynamics to maintain native riparian and wildlife corridors.

**Figure 3- Stormwater Detention Within the Urban Environment**

### 3. Stormwater Recharge in Regional Watercourses

**Trade-off between Capture and Maintaining Downstream Habitat**

The City of Tucson and Pima County value riparian vegetation and seek to ensure that some water continues to flow in channel to support riparian vegetation, in contrast to Los Angeles, which has chosen to harvest water that would otherwise flow in channels.

Pima County Code (Title 16) explicitly protects mapped riparian vegetation. The City of Tucson explicitly protects riparian areas through the Environmental Resource Zone (ERZ), the Watercourse Amenities, Safety and Habitat (WASH) regulations, the Floodplain Ordinance, and Development Standard 9-06. Combined, these ordinances and standards delineate how riparian habitat is determined, what impacts are allowed,
and what mechanisms are required to address mitigation for habitat loss. These ordinances and standards are described in Appendix F.

The City of Tucson and Pima County share a stormwater manual (PCDOT&FCD and COT, 1984) that encourages strategies that detain the flow of water as a technique to limit flooding rather than retain (i.e. capture) stormwater. By detaining, rather than retaining flood flows, flood peaks are reduced while the flow period is prolonged and riparian vegetation continues to thrive.

**Stormwater Recharge in Regional Watercourses**

A recent study using chemical isotopes (Eastoe et al 2004) tracked the source and age of water in the Tucson aquifer. Much of the water in the aquifer is from mountain sources, and is thousands of years old. However, water with tritium, indicating post-war origin, was found along the Regional Watercourses, which indicates that these are the pathways for recharge. The study also confirms that recharge from Tributary Watercourses on the valley floor provides a relatively minor contribution to the aquifer.

Concerns about particular watercourses were noted in the study. Tanque Verde Creek is a particularly important watercourse, because even small rainfall events (< ½ inch) recharge the aquifer, which indicates that preserving floodplain function is particularly important along Tanque Verde Creek. Along Rillito Creek, some of the greatest potential for recharge is south of the current channel in what was once the floodplain, which now has facilities that may be sources for groundwater contamination. For this reason, infiltration in these encroached areas south of the current Rillito Creek may actually pose a threat to the aquifer.

**Capacity of Natural Watercourses to Infiltrate Individual Events**

Natural floodplain function significantly attenuates flood flows. For example, on July 22, 2008, a large rainfall event occurred in the Santa Rita Mountains. This resulted in a 10,000 cubic feet per second (cfs) peak flow at Cienega Creek where it crosses Interstate-10 (I-10) (ALERT Gauge 4283). This flow decreased to 2500 cfs on the Pantano Wash where the flow crossed under Broadway Boulevard downstream of the confluence of Cienega Creek and Rincon Creek (Figure 4 a, b). The water volume decreased from about 2000 ac-ft at I-10 to 663 ac-ft at Broadway, which suggests that 1337 ac-ft of the water infiltrated into the sediments under the stream channel during this event. This indicates that natural floodplain function aids in attenuation of floods and recharging ground water. This volume does not account for the additional runoff supplied to the stream from Rincon Creek, a major tributary.
Large Flood Events Have an Inordinately Large Impact on Groundwater Recharge
Water yield on the Santa Cruz River at the Continental gauging station in 1983 of 117,250 acre-feet was about seven-and-a-half times greater than the mean value of 15,750 acre-feet, and the groundwater levels recovered about 50 feet (Figure 5 a,b). The groundwater also recovered about 20 feet following the 1993 flood flows.

*Figure 5a - Location of Flow Gauge and Well*

*Figure 5b - Well Recovery Following Large Events*
The well recovery shown in Figure 5 illustrates that natural floodplain function is extremely important in providing a conduit for recharging groundwater when large floods occur.

4. Regional Stormwater Capture

Managing Regional Watercourses for Enhanced Recharge

The average annual flow in the Santa Cruz River at Congress Street is 16,300 ac-ft. Large flood events, such as the 1983, 1993 and 2006 floods are responsible for most of the large flows that leave Pima County as stormwater and it is not feasible to fully capture these flows. Furthermore, even if it was feasible to capture all the stormwater in Regional Watercourses, it would supply about 10% of Tucson Water’s need, which is currently about 140,000 acre-ft/yr.

That being said, there are essentially two ways to increase the potential for stormwater recharge. First, modifications can be made to the watercourse to increase the likelihood that stormwater will recharge. Second, stormwater entering the Regional Watercourse can be managed to increase the duration of flow, which will increase the likelihood of recharge.

Modification of Channel to Encourage Recharge - Rillito Recharge Project

While the idea of capturing water with an inflatable dam and allowing it to recharge seems reasonable on face value, the ephemeral flows on the Rillito tend to recharge anyway. As noted previously, water flows in the Rillito only 29 days a year on average. As Figure 4 documented on the Pantano, most moderate flows on Regional Watercourses infiltrate and recharge. Furthermore, during the large flows that recharge the regional aquifers (Figure 5), inflatable dams would have to be deflated, thereby negating the recharge benefit.

In addition, flows in the Rillito are sediment rich so sediment would pond behind a dam, reducing storage capacity and allowing fine-grained particles to settle and clog channel pore spaces. Maintenance of the structure would be expensive, reducing the cost effectiveness of this approach to recharge.

In Los Angeles and other regions where inflatable dams have been successfully used to recharge aquifers, the following elements are present:

- a perennial water source (or flows of long duration)
- low sediment content; and
- a location with good hydraulic connection for off-channel recharge.

Since these conditions do not exist on the Rillito this limits the potential for increasing stormwater recharge beyond what naturally occurs there. Most small and moderate flows already infiltrate and large flood flows cannot be feasibly captured.

Managing Tributary Watercourses
Perhaps the most effective way to increase recharge potential in the Regional Watercourse is to detain flows and slowly release them on Tributary Watercourses to increase the length of time during which moderate flows would persist in the Regional Watercourse, as discussed in the section below.

5. Tributary Scale Stormwater Recharge

Built Environment

Isotopic and infiltration studies have shown that a relatively small portion of aquifer recharge occurs in Tributary Watercourses. Therefore, the greatest opportunity for enhanced stormwater recharge is to manage Tributary Watercourses to increase recharge in Regional Watercourses. In the built environment in-line detention basins, such as the one constructed along the Arroyo Chico, have been built to limit the potential for flooding and increase the possibility of recharge in the Santa Cruz River.

Existing Detention Basin Storage and Release – Arroyo Chico

One approach that has been used is to detain flows on Tributary Watercourses in order to decrease flow rates and increase durations of flows on the Regional Watercourses, so that more water can infiltrate in the Regional Watercourse.

Because the neighborhoods along the Arroyo Chico Wash were built prior to 1968, they were built without floodplain mapping, and the wash was heavily modified and encroached upon. In order to mitigate the potential for flooding, conveyance was improved in the encroached portions east of Randolph golf course, and large multi-use turf basins were built at Randolph Golf course, Cherryfield and Quincy-Douglas Park to detain flood flows.

A study conducted by the US Army Corps of Engineers noted that the these encroached valley-floor Tributary Watercourses are not particularly important for groundwater recharge, but they could be managed to slow flows and increase the opportunity for recharge on Regional Watercourses. The modeled impact of the Park Avenue basin is shown in Figure 6. Flood peaks are dropped to approximately one-fourth of the original discharge and durations were dramatically extended.

These simulations do not account for the infiltration in the basins themselves, some of which may recharge to the groundwater. However, they do illustrate that valley-floor Tributary Watercourses can be managed to increase the potential for regional recharge.
Future Regional Detention Basin Development Opportunities

Many of the potential areas of future development are located on alluvial fans. The Lee Moore Wash Watershed area south of Tucson is expected to be the site of future growth because it is close to existing development and infrastructure, and is partially outside the more protected areas of the Conservation Land System.

Unlike the pre-National Flood Insurance Program (NFIP) construction that occurred in central Tucson, drainage constraints are being considered early in the planning process for the Lee Moore Wash Watershed, see Figure 7. This long range floodplain management and flood control study has been undertaken by Pima County with participation of the City of Tucson, Town of Sahuarita and the State Land Department. Designated flow corridors have been proposed in this area to pre-establish the Tributary Watercourses that will remain natural so their floodplains can attenuate flood peaks. This is a more cost-effective approach to flood control than that practiced along the Arroyo Chico, where older, concrete lined channels increased conveyance and necessitated detention basins designed to reduce peaks.

Co-locating Recreation Facilities with Stormwater Detention Basins

While the Lee Moore Wash Watershed will be developed to allow for natural floodplain function along the Tributary Watercourses, there will still be a need to build stormwater detention facilities. With that in mind, it is possible to co-locate passive recreation facilities like bird watching or riparian open space, with detention facilities. While it is not anticipated in Lee Moore, it is also possible to use detention facilities for active collection of stormwater and irrigation of turf facilities.
6. Tributary Scale Stormwater Capture – Direct Use

Existing Direct Use of Stormwater

The Ed Pastor Kino Environmental Restoration Project (KERP) is a 125-acre multi-purpose environmental restoration project constructed within the Ajo Detention Basin located on Julian Wash. The project was completed under a cooperative agreement with the US Army corps of Engineers, Pima County and the Pima County Flood Control District. The project objectives were to:

- preserve the basin’s functionality as a flood control facility by controlling drain flow in the basin to minimize flood impacts downstream;
- re-establish ecosystems representing Arizona’s southwest riparian environment throughout the detention basin;
- detain and store stormwater and reclaimed water to reduce groundwater usage, particularly at the adjacent Kino Hospital and Kino Sports Complex, and;
- integrate natural wildlife and water features as amenities into a public park setting.

The project reconfigured a large, barren detention basin to accommodate these natural resource benefits. The large detention basin now features four arroyos containing several in-stream ponds. One impoundment is solely for reclaimed water and two impoundments serve as reservoirs for stormwater mixed with reclaimed water collected after overland flow through the arroyo system (Figure 8). In this way, the project harvests
stormwater for use on vegetation within the KERP project limits and for irrigation of surrounding facilities, including the athletic fields’ turf as well as landscaping on the roadway medians and hospital grounds. Irrigation is supplemented with reclaimed water from the City of Tucson Reclaimed Water System. The water required to irrigate the sports complex, medians and hospital landscaping was estimated at 410 acre-feet a year and 172 acre-feet a year to irrigate the vegetation within the environmental restoration basin. The combined estimated water required is 582 acre-feet a year.

The Pima County Regional Flood Control District holds a surface water right certificate for 105 acre-feet per year at the Ajo Detention Basin for recreation and wildlife uses. A permit for 410.7 acre-feet per year for irrigation on 105 acres and 171.7 acre-feet per year for wildlife and recreation was issued in May 2002 and the certificate of water right from ADWR is pending.

The volume of stormwater collected varies from year-to-year depending on seasonal weather patterns. In years with low rainfall, less stormwater is harvested and more reclaimed water is required to supplement irrigation. Maximum stormwater harvesting occurs when water from abundant winter rains is stored and used throughout the spring. Reclaimed water provides supplemental irrigation until water from the summer monsoon season replenishes the basins. Estimated stormwater harvesting, reclaimed water purchased and annual rainfall is summarized in Table 2.
### Table 2 – Water Demand and Harvested Stormwater at KERP

<table>
<thead>
<tr>
<th></th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand (in acre-feet)</td>
<td>582</td>
<td>582</td>
<td>582</td>
<td>582</td>
<td>582</td>
</tr>
<tr>
<td>Reclaimed Water</td>
<td>330</td>
<td>180</td>
<td>395</td>
<td>160</td>
<td>188</td>
</tr>
<tr>
<td>Stormwater Ball Field Irrigation</td>
<td>31</td>
<td>65</td>
<td>0</td>
<td>66</td>
<td>96</td>
</tr>
<tr>
<td>Stormwater Wildlife and Recreation</td>
<td>221</td>
<td>337</td>
<td>187</td>
<td>326</td>
<td>298</td>
</tr>
<tr>
<td>Total Stormwater Harvested</td>
<td>252</td>
<td>402</td>
<td>187</td>
<td>422</td>
<td>394</td>
</tr>
<tr>
<td>Annual Rainfall (in inches)</td>
<td>7.60</td>
<td>9.57</td>
<td>11.81</td>
<td>9.78</td>
<td>8.67</td>
</tr>
</tbody>
</table>

1. Log readings at Kino Sports Park showed the reclaimed volume for 2008 to be 194 acre-feet.
2. No stormwater was used for ball field irrigation in 2006 due to equipment problems.

Even though annual rainfall has been below normal since construction of KERP, an average of about 330 ac-ft/yr have been harvested at KERP, which is very near the 371 ac-ft estimated at design for an average year. Furthermore, the lowest volume of harvested water occurred in the year with the greatest rainfall, which shows that the actual timing and occurrence impact what is available.

Physically harvesting the water is less complex than obtaining the rights to use it. Because there are two sources of water used at KERP--stormwater and reclaimed water--there is an alphabet-soup of regulations that must be satisfied to permit and operate the facility as described in the legal section above.

A facility such as KERP represents the type of Green Infrastructure that EPA is encouraging through its Municipal Separate Storm Sewer System (MS4) permit program and other water quality initiatives. Watercourses with enhanced vegetation can improve stormwater quality by trapping sediment, adsorbing metals, and providing biologic uptake of nutrients. Side benefits of carbon dioxide reduction and mitigation of urban heat-island effects may also be realized.

Not all stormwater detention basins lend themselves to stormwater harvesting on a large scale. Factors to consider include size of the watershed and its impact on volume of stormwater available, nearby uses with significant demand for harvested stormwater (e.g. large turf areas) and availability of reclaimed water for conjunctive use because stormwater is not consistent enough as a supply for many irrigation purposes.

### 7. Neighborhood Scale Capture

#### Neighborhood Stormwater Management (built environment)

Stormwater runoff from the many neighborhoods in the City and County contributes to regional management challenges, inducing water flow in streets, stormdrains and...
washes that do not have adequate capacity. While jurisdictions address regional-scale stormwater management, there are neighborhood-scale strategies that can assist in stormwater management.

Regional watersheds can be divided into any number of smaller sub-watersheds based on land contours. The first water harvesting principle is to start harvesting water at the “top” of the watershed over which you have control (City of Tucson Water Harvesting Guidance Manual, 2005).

At the neighborhood scale, the top of the watershed will be the point of highest elevation in the neighborhood. Stormwater run off from this high point may cross multiple lots picking up additional runoff from each. Street runoff may pool at a low point before draining away. Such neighborhood-scale problems might be improved with neighborhood-scale water harvesting-strategies. These include constructing passive water harvesting structures (earthworks) beginning at the top of the watershed and continuing throughout the neighborhood, installing water harvesting tanks to contain rooftop runoff for future use, increasing vegetation cover and adding organic material to the soil to intercept and slow the transmission of stormwater as it moves through the subwatershed. This slowing allows more time for water infiltration, increases soil moisture that supports plants, and helps attenuate the floodpeak in--and downstream of--the neighborhood. It has corresponding water quality benefits as well.

Once stormwater collects in streets it typically flows to stormdrains or local watercourses, then to the tributary and regional drainages. Intercepting this street runoff prior to it leaving the built environment can assist both in improving neighborhood conditions and reducing stormwater discharges. Right-of-way (ROW) water can be utilized by cutting openings in street curbs and funneling ROW water to depressed planting basins located several feet inside the curb. Native trees and shrubs planted in the depressed basins can be supported by stormwater diverted temporarily from the street. These trees in turn provide neighborhood shade, bird habitat, aesthetic improvements, and other benefits. A permit is required from the City to divert street water to ROW plantings. The City Transportation Department issues these permits and has created templates for appropriate designs for curb cuts and associated ROW planting basins, which are available at: http://dot.ci.tucson.az.us/stormwater/pdfs/Water%20Harvesting%20Curb%20Cut%20Detail.pdf

When landscape irrigation with potable water is replaced with harvested rainwater, the rainwater is considered a supplemental water source. Unless potable water is replaced, the voluntary use of stormwater harvesting may not be considered a ‘supplemental’ source, but it still provides considerable benefits by supporting vegetation that helps cool the city, provide wildlife habitat, and improve aesthetics.

- Integration of Rainwater Harvesting with Stormwater BMPs Using a Decentralized Approach
The Watershed Management Group (WMG), a nonprofit advocacy dedicated to use of locally-generated renewable supplies, received a 2-year grant from ADEQ to teach neighborhood residents how to reduce non point source (NPS) pollution through stormwater Best Management Practices (BMPs). The project is taking place in the Rincon Heights neighborhood in the City of Tucson, through which High School Wash flows. The project focuses on hands-on workshops that teach neighborhood residents how to implement BMPs for mitigating stormwater quality issues (Figure 9 [courtesy of WMG]). WMG is teaching residents the sources of pollution, so they can reduce these on their own properties. The idea is to reduce the source of pollution and reduce the amount of flooding or stormwater in the neighborhood, which transports NPS pollution into the nearby wash. WMG is teaching residents how to install BMPs such as bioretention basins, vegetated swales, and infiltration trenches in the public right-of-way. All water catchment features are planted with native vegetation and use mulch to increase infiltration rates and create a biological filter for NPS pollutants that enter the features. Many of the features incorporate curb cuts to harvest stormwater off the street. So far about 70 BMPs have been installed. Through the two year project, stormwater BMPs will be installed on at least 10 city blocks, all using volunteer labor.

- **Harvesting for Riparian Enhancement in an Existing Neighborhood**

At the Highland Vista Park in Central Tucson, an example of a neighborhood scale water harvesting project which reduces peak runoff, protects downstream properties, provides water quality benefits, enhances riparian and wildlife habitat and increases the ‘quality of life’ for the neighborhood residents can be found. It is important to note that since the harvested water is used to irrigate the newly improved area, this is not considered ‘supplemental’ water in the sense of off-setting an existing use of potable water. However, the benefits of projects such as this are many (Figure 10).
Neighborhood Stormwater Management (new construction)

- **Supplemental Use of Stormwater at Neighborhood Scale**

The City of Tucson and Pima County have shared a floodwater detention/retention manual (COT & PRCRFD, 1984) that mandates that new development limit floodpeaks offsite. Both Pima County and the City of Tucson have moved toward strategies that more beneficially use stormwater and rainwater. RFCD is in the process of revising their stormwater policy to include methods that quantify the detention and retention capabilities of water harvesting, so these strategies can be encouraged. Likewise, some new neighborhoods may have locations suitable for dry wells.

- **Commercial Water Harvesting Ordinance to Provide Supplemental Water**

In October 2008, the City of Tucson Mayor and Council adopted a commercial Rainwater Harvesting Ordinance (No. 10597) that quantified water-harvesting requirements for the commercial sector. This ordinance mandates that new commercial development utilize water harvesting practices to meet 50% of the site landscape water requirements. This ordinance takes effect in June 2010. In the interim, City staff has worked with commercial sector experts to create a Development Standard to guide implementation of the Commercial Water Harvesting Ordinance. The City is also working with the commercial sector to establish pilot projects to test elements of the ordinance and development standard prior to the 2010 implementation date of both. Educational programs are being developed for designers, installers, and property managers to assist them in constructing and using water harvesting techniques.

Since the mid-1990s, the City’s Land Use Code has required that sites make maximum use of site stormwater runoff for supplemental irrigation. The sites subject to Land Use Code requirements include new commercial sites, common areas of subdivisions, public buildings, and public rights-of-way. This qualitative requirement does not specify that a certain amount of rainwater be used. With adoption in 2005 of the City’s Water
Harvesting Guidance Manual, more specific information was made available on how to design and implement water harvesting at these other sites.

The Water Conservation Technical Paper that was developed as part of this City/County Water/Wastewater Study included the following recommendation with regard to the City’s commercial rainwater harvesting ordinance: When completed, Pima County should evaluate integrating the City of Tucson’s Rainwater and Greywater Harvesting Codes and Standards as appropriate into its development codes, standards and guidelines.

- **Supplemental Water for Environmental Mitigation**

On-site stormwater management techniques can be used to assist in mitigation of sites where riparian habitat is already compromised or will be disturbed by new development. Placement and design of retention/detention basins adjacent to impacted washes provides an opportunity to use the ephemeral pooling of stormwater in the basin to sustain riparian vegetation planted in the basin (which was the approach used at Highland Vista Park, Figure 10). Vegetation perforating the basin floor will increase infiltration rates over time. A natural spongy mulch will accumulate at the bottom of the basin from leaf and twig drop from plants. This natural mulch will assist in breaking up clay deposits that can form in the bottom of the basin and impede infiltration.

Appropriate selection of native riparian plants will improve habitat characteristics in the basin, augmenting habitat for species of wildlife that are using the adjacent wash. Standard basin design should be adapted to accommodate this use by reducing the side-slope of basins and increasing basin capacity to allow for space that will be taken up by native plants. Access for maintenance should be carefully planned to minimize damage to riparian vegetation. Positioning a low point in the basin at the bottom of the access ramp to collected sediment will simplify maintenance of the basin.

Placement of drought tolerant native plants in commercial landscape borders and other planting areas that harvest stormwater can provide restoration benefits as well. These plantings increase forage and nesting sites, add shade to large expanses of hardscape, and will be well adapted to the seasonal rainfall patterns typical of the Sonoran Desert.

Water harvesting benefits the City and its residents by reducing the volume of stormwater flowing in streets or onto adjacent properties, and by helping keep potential stormwater pollutants out of watercourses and groundwater. Federal regulations established under the Clean Water Act require large municipalities to implement measures to reduce pollutants in stormwater to the “maximum extent practicable.” As a result, Tucson has been required to obtain a Municipal Stormwater Quality permit from the Environmental Protection Agency. To effectively implement the federal permit, Tucson must implement a Stormwater Ordinance that reflects federal requirements that development include permanent structural controls to reduce pollutants discharged from a site. Water harvesting can help fulfill this function.

### 8. Individual Lot-scale Capture
Individual lots are Beneficial Locations to Implement Stormwater BMPs and Beneficially Use Rainwater

Individual lots are in effect subwatersheds unto themselves where the top of the site watershed is the roof of a building, and the annual rainfall at the site can be harvested and put to beneficial use supporting vegetation that directly benefits the site. Residential lots frequently have a relatively large area of soil where harvested water can be infiltrated compared to commercial lots. The use of low water use native plants will mean plant water needs are timed to our current rainfall seasons. Besides several years of establishment and supplemental water during extreme heat or drought, carefully selected native plants should thrive on harvested rainwater.

Individual Lot (existing construction)

Water harvesting on existing sites requires retrofitting the site with new techniques. This is relatively easy on a residential lot and can be accomplished using passive water harvesting techniques (earthworks) or active water harvesting techniques (tanks). Retrofitting existing sites requires care in avoiding disturbance of the roots or existing trees and shrubs, and adapting the retrofit around existing vegetation or converting it to new vegetation, particularly native species. Retrosfits of commercials sites are challenging since the hardscape is in place, subsurface infrastructure may be present that might be disturbed if new basins are added, and it is expensive to change existing landscape conditions. If a commercial site is undergoing major renovation that involves regrading and adding or changing landscaping, then water harvesting retrofits could be feasible.

There are currently no requirements for water harvesting at the residential scale, though there is a large amount of public interest in retrofitting sites for water harvesting. A number of resources are now available in Tucson to assist residents including new books and free pamphlets, numerous water harvesting classes and volunteer projects where residents can learn hands-on techniques, and a growing number of vendors who install earthworks and tanks.

The retrofitting of existing residences to harvest rainwater and reduce the use of potable water to irrigate their landscaping is considered as providing supplemental water.

Individual Lot (future development)

Application of water harvesting techniques ideally occurs in new construction where it can be designed into the site from the start. When designed in accordance with landscaping requirements, this water can be considered supplemental in that it is used to offset potable water that would otherwise be used to grow plants.

For both retrofits of existing sites, and incorporation into new sites, the most cost effective water harvesting approach is storing water passively in the soil. The storage capacity of the soil is high, the water is immediately available to plant roots, the plants adapt to the available soil moisture, and there is no tank to construct and maintain. Tanks are an appropriate technique to provide rainwater beyond the normal rainfall
season, such as for growing fruit trees (Canfield and Shipek, 2007). Since rainwater is lower in total dissolved solids than groundwater and CAP water, it may be a good water source for use in evaporative coolers. As with all nonpotable water sources, consideration of water quality in determining appropriate uses is important.

It is possible to estimate the impact of different Best Management Practices (BMPs). The mass-balance model developed by RFCD (described in Appendix C) indicates that a simple 6-inch deep, 3 foot wide swale on the edge of a property will substantially increase the amount of rainwater that stays on a lot (Figure 11). Clearly, with additional earthworks, and water collection tanks, it should be possible to collect virtually all the water on a lot.

![Graph showing harvestable stormwater yield for different property areas](image)

*Figure 11- Impact of a Three-foot Wide, Half-foot Deep Swale on Harvesting Water at the Lot Boundary (Calculations in Appendix C)*

Using this model, it is also possible to evaluate the feasibility of using the stormwater to grow plants. The water harvesting model can be used to estimate how frequently water is available to plants. Modeling the case of two 20-foot diameter Mesquite trees planted in the swale on the 1/5 acre-lot (i.e. the smallest lot size in Figure 11), shows that on-average, rainfall will not be available to satisfy the plant water requirement (ET) for the Mesquite trees in the spring months (Figure 12). During the spring, the root zone of the tree must store the water until water becomes available when the monsoon begins in July.
The model can also be used to determine how much supplemental water can be provided to these two Mesquite trees using the range of rainfall that has occurred during the 105 years of rainfall data collected at the University of Arizona. The model shows that between 200 cubic feet and 800 cubic feet of water can be supplied with stormwater, though even more is harvested in the swale (Figure 13). The range accounts for the fact that some of the water required is provided by rainfall, and more rainfall occurs in some years than in others. The results of the model show that on average, more water is provided than required, though there are years when supplemental water will be required. This model can be used to evaluate other practices, such as other passive water harvesting practices (Landcaster, 2007) and the suite of BMPs described in the stormwater management strategy called Low Impact Development (e.g. County of San Diego, 2007).
Figure 13 - Supplemental Water Supplied, and Harvested Stormwater from a Lotside Swale on a 1/5 acre lot

Building and zoning standards should can be used to encourage water harvesting on the lot scale.

9. Conclusions

General Conclusion

The greatest opportunities to harvest rainwater and stormwater are closest to the point of generation. In general, the further the point of generation, the less volumes are available for use, and the greater the losses, so the reliability as a supply decreases.

Regional Watercourse – Recharge

Estimates are that about 3% of all rainfall is recharged in Regional Watercourses. Isotopic studies show that Regional Watercourses provide good conduits for recharge of groundwater. Small and moderate events are recharged. Sporadic large events result in most groundwater recharge. New construction can be built to maintain floodplain function and help maximize recharge.
Regional Watercourse – Capture

Less than 1% of all rainfall exits Pima County as stormwater. Most of this 1% is attributable to large flood events. Trying to capture these events is not feasible because the cost would be prohibitive and obtaining surface water rights would be problematic. Natural floodplains provide better conditions for slowing floodpeaks and ensuring recharge than constructed channels. Given the fact that large volumes of stormwater are rarely available, and are usually sediment-laden, constructed recharge for stormwater makes little sense. Inflatable dams will do little to increase stormwater recharge and are not well suited to conditions in our Regional Watercourses.

Tributary Watercourse – Recharge

Isotopic studies show that little recharge occurs in Tributary Watercourses, so that efforts to encourage recharge on these watercourses would be fruitless. However, in the built environment, tributaries, such as Arroyo Chico, can be managed to detain or delay flood peaks so that the duration of flows in the Regional Watercourse increases, in turn increasing the potential for recharge in the Regional Watercourse. Limiting encroachment on Tributary Watercourses is critical to maintaining the natural floodplain function of detaining floodwater so that flood flows release more slowly and recharge in Regional Watercourses.

Tributary Watercourse – Capture

In the built environment stormwater can be harvested from impervious surfaces. Where impervious surfaces dominate both channels and uplands, such as occurs in the watershed draining to the Ajo Detention Basin/Kino Environmental Restoration Project (KERP), harvesting stormwater for habitat support and for direct use on adjacent properties is a viable option. Over the five year life of the KERP project, over half the water needed for irrigation on adjacent turf has been supplied by stormwater. KERP provides habitat, flood control and stormwater benefits, which further justify the cost. Legal and permitting hurdles to building KERP were substantial, so reproducing this approach at another site could be equally challenging.

Neighborhood Scale – Capture

At the neighborhood scale, there are great opportunities to use stormwater to irrigate native vegetation. Drought-adapted native vegetation is ideally suited to thrive on passively-harvested stormwater since its water needs are timed to the existing rainfall seasons. Native plants may loose leaves in hot dry periods, but will leaf out again when the rains start. Native plants have multiple benefits for people and wildlife.

Passively harvesting stormwater at the neighborhood scale also reduces the potential for contaminants to enter watercourses regulated under the clean water act.

Synergies between BMPs for water quality and stormwater detention make water harvesting a useful strategy at the neighborhood scale. Opportunities for retrofit to enhance water harvesting are available in the built environment, but future development can be designed to provide the maximum practicable benefit from stormwater, and
provide supplemental water by supplying water for landscapes. Some legal constraints to beneficial use may exist.

Lot Scale – Capture

At the lot scale, the availability and viability of using rainwater are greatest. There are no legal constraints to capture and use at the lot scale in eastern Pima County. Passive water harvesting is the simplest option, and native vegetation has the best opportunity to thrive on this passively-harvested water. However, the possibility of harvesting rainwater in tanks opens the possibility of using rainwater to support non-native vegetation such as fruit trees, that require water during periods when we typically receive little rainfall. Likewise, since rainfall is typically lower in dissolved solids, it is an excellent source of water for evaporative coolers.

10. Recommendations

1. Encourage Maximum Use of Rainwater and Stormwater at the Lot Scale

Rainwater can be harvested at the lot scale to eliminate some of the needs for potable water. Drought-tolerant native plants can typically be grown on passively-harvested water alone after supplemental water has been used to get them established. Rainwater harvesting in tanks is useful as a supplemental source for plants that are not drought-tolerant. Specific recommendations are as follows:

   Existing Built Environment: In the built environment, the City of Tucson and Pima County should develop joint education and outreach about rainwater harvesting on why, how to, and where it can be utilized. Furthermore, estimating the volume of water available at the lot scale from increased impervious surfaces would allow the potential uses of this water to be better assessed.

   Future Development: the City of Tucson and Pima County should pursue the development of joint landscape, building and zoning standards that increase the potential for on-site capture storage and use of rainwater. Incentives to HOAs and builders should be considered.

2. Encourage Maximum Use of Stormwater at the Neighborhood Scale

Future development should be built to maximize the potential for use of stormwater at the neighborhood scale. Supporting vegetation using harvested stormwater will eliminate the need for some landscape watering. Stormwater flow paths can be depressed to encourage the potential for infiltration, and native vegetation can be planted that will thrive in these depressed flow paths. In some cases, development standards and HOA regulations may need to be modified to accommodate this strategy. Such a strategy will have the additional benefit of reducing flood peaks and improving stormwater quality. The viability of using dry wells should be re-evaluated in new subdivisions where sediment loads are expected to be low, and there is a reasonable possibility for the water to be recharged.
3. Limit Floodplain Encroachment on Regional and Tributary Watercourses

Because Regional Watercourses, and their associated floodplains, are important conduits for recharge, they should not be encroached upon so that they function during large events that are so important to recharge. Likewise, limiting encroachment will limit the possibility of movement of contaminants into the regional watercourses.

4. Manage Tributary Watercourses for Recharge or Stormwater Capture

Where the built environment has resulted in an abundance of impervious surfaces, stormwater capture should be considered. Where future development occurs, Tributary Watercourses should be managed to reduce flood peaks and encourage infiltration on Regional Watercourses. This can be accomplished using structural means, such as the construction of detention basins or non-structural means, such as floodplain management to limit encroachment. The City of Tucson and Pima County should develop a joint policy for regional planning of multi-use facilities for stormwater harvesting, recreation and restoration.

5. Consider the Overall Economic Benefits of Rainwater and Stormwater Harvesting

Water harvesting has multiple benefits, especially at the lot and neighborhood scale. These benefits include increased floodwater retention, and limiting the migration of contaminants. Vegetation grown on harvested rainwater and stormwater reduces the demand on potable resources, mitigates the urban heat island and provides habitat. The synergy between these elements should be considered in evaluating the costs and benefits of rainwater and stormwater harvesting.

6. Advocate for a Legal Framework Conducive to Use of Stormwater

The City and County should continue to work with ADEQ to develop water quality standards and designations specific for groundwater recharge and habitat restoration for inclusion in the next triennial review.
11. References


Pima County Department of Transportation & Flood Control, City of Tucson. 1984. Stormwater Detention/Retention Manual


Appendix A
Pima County and City of Tucson Stormwater Regulations

Floodplain and Stormwater Management

Pima County Regional Flood Control District

Over the past thirty years, flood control engineers have come to recognize that structural measures used to remedy flooding and erosion may create other problems by increasing flooding and erosion in downstream areas. A more holistic approach to watershed and floodplain management that includes nonstructural methods as well as structural measures where necessary is now the preferred approach to flood control. More recently communities are beginning to understand that stormwater is a resource.

Since the mid-1980 the Pima County Regional Flood Control District has taken a watershed approach to flood control and floodplain management. Preservation of natural riverine systems, especially in the upper watershed areas, is critical to managing flood peaks as well as providing natural recharge. Since 1984 the County has acquired over 14,000 acres of floodprone lands including Cienega Creek, Santa Cruz River at Canoa Ranch and the Upper Canada del Oro Wash. Harvesting and re-use of stormwater has also been included in such projects as the Kino Environmental Restoration Project.

The Arizona Revised Statutes provides authority to flood control districts to enact and enforce floodplain regulations. The adoption and enforcement of these regulations is mandatory for communities wishing to participate in the National Flood Insurance Program (NFIP). Residents and property owners may obtain flood insurance only if the community implements a responsible floodplain management program. Pursuant to this authority, the Pima County Regional Flood Control District (District) currently enforces the Floodplain and Erosion Hazard Management Ordinance No. 2005-FC2 (Ordinance). The purpose of this Ordinance is to promote public safety and minimize the potential for flood and erosion damage for developments that are impacted by the 100-year or base flood. Floodplain management and flood control improvements increase public safety, reduce flood and erosion hazards, and protect public and private property.

Pima County’s Ordinance provides regulations for single lot and development standards for the following areas:

- Floodplain management and permits
- Erosion hazard and setback
- Riparian habitat protection
- Sediment control
- Stormwater detention/retention

City of Tucson
The regulation of development along watercourses is based upon the delegation of regulatory authority from the State to the City for the purpose of managing flooding and floodplain areas under A.R.S. Section 48-3609 and 48-3610. This statutory authority focuses on the hydrological and public safety aspects of floodplain management. State authority is separately delegated to the City under A.R.S. Section 9-462, which authorizes the regulation of land uses and structures under the City's zoning codes. This statutory authority provides for broader regulation of floodplain areas to achieve community aesthetic, cultural and resource preservation goals.

The initial City direction for regulation of watercourses was the adoption of the Interim Watercourse Improvement Policy (IWIP) by the Mayor and Council on June 27, 1988. The IWIP contains specific policies that encourage the preservation of natural watercourses and the design of landscaped, natural-appearing channels. The IWIP also contains policies restricting the use of concrete for bank protection and channelization. The IWIP continues to apply to watercourses that are not otherwise subject to WASH or ERZ regulations.

The fundamental policy direction of the City was restated in Resolution 15269, adopted on April 2, 1990:

"The Mayor and Council find that protection and preservation of natural drainage systems should be the primary emphasis of City stormwater management efforts. Nonstructural solutions to flooding hazards shall be the preferred strategy over structural solutions."

The implementation of this fundamental policy direction in the management of watercourses and floodplains has been established by ordinances, resolutions, administrative interpretations, and development standards including: Chapter 26 of the Tucson Code, the Floodplain and Erosion Hazard Management regulations; the adoption of the Environmental Resource Zone (ERZ) by Ordinance 7450 on July 3, 1990 as an overlay zone, LUC § 2.8.6; adoption of the Watercourse Amenities, Safety and Habitat (WASH) regulations by Ordinance 7579 on March 25, 1991, Tucson Code, Chapter 29, Article VIII, approval of further phases of the Tucson Stormwater Management Study (TSMS) and by adoption of the Floodplain, WASH, and environmental Resource Zone (ERZ) Standard (Development Standard 9-06) by Resolution 20505 on November 6, 2006.

**Stormwater Quality**

The Federal Clean Water Act requires that municipalities above a threshold population, implement programs to prevent stormwater pollution and improve stormwater quality. Both Pima County and the City of Tucson have municipal stormwater quality permits that were issued by the EPA.

**City of Tucson**

The City of Tucson has a municipal stormwater quality permit issued by EPA, which sets program requirements and establishes penalties for noncompliance. One of the requirements is to enact a stormwater quality ordinance, which allows the City to prohibit
activities that can negatively impact stormwater quality. The City enacted the Stormwater Quality Ordinance in October 2005.

The Stormwater Management Section of the Department of Transportation is responsible for administration of the City's municipal stormwater permit and either provides guidance to or implements the following mandated stormwater quality programs:

- An Industrial Facilities Inspection and Enforcement program - Under this program, the City inspects certain industrial facilities also targeted under the Clean Water Act to ensure that these facilities have effective stormwater pollution prevention programs in place.
- A Construction Site Inspection and Enforcement Program - This program requires inspection of all construction sites where 1 or more acres of land is disturbed to ensure that these construction sites are operating under effective stormwater pollution prevention plans. (Again these sites are also regulated under the Clean Water Act).
- A Post Construction Pollution Control Program - This program ensures that development incorporates measures to reduce pollution and preserve environmentally sensitive areas, open space, and vegetated areas. Also included under this program are native plant protection, the City's WASH and ERZ ordinances, water harvesting requirements, maintenance of retention/detention basins, maintenance of the City's stormwater drainage system, and street sweeping.
- An Illicit Discharge Detection and Elimination Program - Under this program, the City inspects the stormwater drainage system for illegal dumping or nonstormwater connections, and ensures that any spills reaching the stormdrain system are properly cleaned up. The City can utilize the stormwater quality ordinance to require responsible parties to clean up and/or elimination of pollutant sources. Also under this program, the City operates 5 stormwater sampling stations and is required to collect and analyze samples from a minimum of 10 storm events annually.
- A municipal facilities program - This program ensures that City run facilities employ stormwater pollution prevention practices.
- Public Outreach Program- The goal of this program is to educate the community on measures they can employ to reduce or eliminate stormwater pollution (ie fix leaking vehicles, properly disposing of Household Hazardous Waste, picking up animal wastes, properly applying fertilizers, pesticides and herbicides, etc)
- A Public Participation Program - The Stormwater Management Section sponsors the Stormwater Advisory Committee where community members can participate in development of stormwater quality programs.

**Pima County**

Pima County has a municipal stormwater quality permit issued by EPA, which sets program requirements and establishes penalties for noncompliance. One of the requirements is to enact regulations, which allows the County to prohibit activities that can negatively impact stormwater quality. The County regulates activities that would
impact stormwater quality under Title 7 Environmental Quality, which is enforced by the Pima County Department of Environmental Quality; the Industrial Wastewater Ordinance (13.36), which is enforced by the Regional Wastewater Reclamation Department; and Title 16, the "Floodplain Management Ordinance.

The Pima County Department of Environmental Quality is the primary department responsible for administration of the County’s municipal stormwater permit and either provides guidance to or implements the following mandated stormwater quality programs:

- An Industrial Facilities Inspection and Enforcement program - Under this program, the County inspects certain industrial facilities also targeted under the Clean Water Act to ensure that these facilities have effective stormwater pollution prevention programs in place.
- A Construction Site Inspection and Enforcement Program - This program requires inspection of all construction sites where 1 or more acres of land is disturbed to ensure that these construction sites are operating under effective stormwater pollution prevention plans.
- A Post Construction Pollution Control Program - This program ensures that development incorporates measures to reduce pollution and preserve environmentally sensitive areas, open space, and vegetated areas. Also included under this program are native plant protection, riparian habitat protection, retention/detention basins, and maintenance of the County's stormwater drainage system, and street sweeping.
- An Illicit Discharge Detection and Elimination Program - Under this program, the County inspects the stormwater drainage system for illegal dumping or nonstormwater connections, and ensures that any spills reaching the stormdrain system are properly cleaned up.
- A municipal facilities program - This program ensures that County run facilities employ stormwater pollution prevention practices.
- Public Outreach Program - The goal of this program is to educate the community on measures they can employ to reduce or eliminate stormwater pollution (ie fix leaking vehicles, properly disposing of Household Hazardous Waste, picking up animal wastes, properly applying fertilizers, pesticides and herbicides, etc.)
## Appendix B

Data Used To Show Percent Harvestable Water at Different Scales

<table>
<thead>
<tr>
<th>Name</th>
<th>Area (mi²)</th>
<th>Source</th>
<th>Record (yrs)</th>
<th>Mean Annual Rainfall (in)</th>
<th>Mean Annual Runoff (ac-ft)</th>
<th>% Harvestable Stormwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rooftop</td>
<td>0.00005</td>
<td>RFCD Lot Model</td>
<td>105</td>
<td>11.20</td>
<td>9.29</td>
<td>82.90%</td>
</tr>
<tr>
<td>1/5 -ac Lot</td>
<td>0.00031</td>
<td>RFCD Lot Model</td>
<td>105</td>
<td>11.20</td>
<td>5.74</td>
<td>51.20%</td>
</tr>
<tr>
<td>1-ac Lot</td>
<td>0.00156</td>
<td>RFCD Lot Model</td>
<td>105</td>
<td>11.20</td>
<td>3.60</td>
<td>32.10%</td>
</tr>
<tr>
<td>High School Wash</td>
<td>1.0</td>
<td>Data used to Design KERP</td>
<td>11</td>
<td>12.00</td>
<td>1.54</td>
<td>77.78%</td>
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<tr>
<td>Railroad Wash</td>
<td>2.3</td>
<td>Data used to Design KERP</td>
<td>9</td>
<td>12.00</td>
<td>1.25</td>
<td>153.5%</td>
</tr>
<tr>
<td>Atterbury Wash</td>
<td>5.0</td>
<td>Data used to Design KERP</td>
<td>9</td>
<td>12.00</td>
<td>0.62</td>
<td>165.3%</td>
</tr>
<tr>
<td>Tucson Arroyo</td>
<td>8.2</td>
<td>Data used to Design KERP</td>
<td>37</td>
<td>12.00</td>
<td>1.46</td>
<td>638.2%</td>
</tr>
<tr>
<td>KERP</td>
<td>13.7</td>
<td>Empirical Equation</td>
<td></td>
<td></td>
<td></td>
<td>4.22%</td>
</tr>
<tr>
<td>Airport Wash</td>
<td>23.0</td>
<td>Data used to Design KERP</td>
<td>17</td>
<td>12.00</td>
<td>0.25</td>
<td>308.7%</td>
</tr>
<tr>
<td>Arivaca Creek</td>
<td>56.8</td>
<td>USGS Gage Data 9486580, Rainfall assumed 12 in</td>
<td>6.0</td>
<td>12.00</td>
<td>0.21</td>
<td>621.6%</td>
</tr>
<tr>
<td>Canada Del Oro Wash</td>
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<td>USGS Gage Data 9486350, Rainfall assumed 12 in</td>
<td>26</td>
<td>12.00</td>
<td>0.10</td>
<td>1391.1%</td>
</tr>
<tr>
<td>Pantano at Vail</td>
<td>457.0</td>
<td>USGS Gage Data 09484600, Rainfall assumed 12 in</td>
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<td>12.00</td>
<td>0.18</td>
<td>4349.1%</td>
</tr>
<tr>
<td>Altar Valley at Three Points</td>
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<td>USGS Gage Data 09486800, Rainfall assumed 12 in</td>
<td>23</td>
<td>12.00</td>
<td>0.15</td>
<td>3788.9%</td>
</tr>
<tr>
<td>Santa Cruz at Tucson</td>
<td>2222.0</td>
<td>USGS Gage Data 09482500, Rainfall assumed 12 in</td>
<td>77</td>
<td>12.00</td>
<td>0.14</td>
<td>16300.0%</td>
</tr>
</tbody>
</table>

Regression Equation: \( y = 0.0748e^{-0.5992A} \) \( R^2 = 0.9075 \)
### Regression Data for the Undeveloped Condition

<table>
<thead>
<tr>
<th>Name</th>
<th>Area (mi²)</th>
<th>Source</th>
<th>Record (yrs)</th>
<th>Mean Annual Rainfall (in)</th>
<th>Mean Annual Runoff (ac-ft)</th>
<th>% Harvestable Stormwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH 6' x 12' plot</td>
<td>0.000000258</td>
<td>Data from the Agricultural Research Service</td>
<td>2</td>
<td>11.65</td>
<td>2.60</td>
<td>0.00</td>
</tr>
<tr>
<td>1/5 acre lot</td>
<td>0.0003</td>
<td>RFCD Lot Model</td>
<td>105</td>
<td>11.20</td>
<td>1.19</td>
<td>0.32</td>
</tr>
<tr>
<td>Santa Rita 1</td>
<td>0.0063</td>
<td>Data from the Agricultural Research Service</td>
<td>28</td>
<td>13.70</td>
<td>0.05</td>
<td>205.0</td>
</tr>
<tr>
<td>Santa Rita 2</td>
<td>0.0068</td>
<td>Data from the Agricultural Research Service</td>
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<td>0.60</td>
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</tr>
<tr>
<td>Santa Rita 4</td>
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<td>13.72</td>
<td>0.48</td>
<td>165.0</td>
</tr>
<tr>
<td>Flume 105</td>
<td>0.0007</td>
<td>Data from the Agricultural Research Service</td>
<td>10</td>
<td>10.80</td>
<td>0.12</td>
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</tr>
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<td>Flume 106</td>
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</tr>
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<td>10.69</td>
<td>0.97</td>
<td>165.0</td>
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<tr>
<td>Flume 104</td>
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<td>Data from the Agricultural Research Service</td>
<td>10</td>
<td>10.53</td>
<td>0.61</td>
<td>165.0</td>
</tr>
<tr>
<td>Flume 4</td>
<td>0.8750</td>
<td>Data from the Agricultural Research Service</td>
<td>10</td>
<td>11.32</td>
<td>0.47</td>
<td>165.0</td>
</tr>
<tr>
<td>Atterbury Wash</td>
<td>4.97</td>
<td>Data used to Design KERP (Tetra-Tech, 2001)</td>
<td>9</td>
<td>12.00</td>
<td>0.62</td>
<td>165.0</td>
</tr>
<tr>
<td>Arivaca Creek</td>
<td>56.80</td>
<td>USGS Gage Data</td>
<td>6.0</td>
<td>12.00</td>
<td>0.21</td>
<td>621.6</td>
</tr>
<tr>
<td>CDO</td>
<td>250.0</td>
<td>USGS Gage Data</td>
<td>26</td>
<td>12.00</td>
<td>0.10</td>
<td>1,391.1</td>
</tr>
<tr>
<td>Pantano at Vail</td>
<td>457.0</td>
<td>USGS Gage Data</td>
<td>30</td>
<td>12.00</td>
<td>0.18</td>
<td>4,349.1</td>
</tr>
<tr>
<td>Altar Valley at Three Points</td>
<td>463.0</td>
<td>USGS Gage Data</td>
<td>23</td>
<td>12.00</td>
<td>0.15</td>
<td>3,788.9</td>
</tr>
<tr>
<td>Santa Cruz at Tucson</td>
<td>2222.0</td>
<td>USGS Gage Data</td>
<td>23</td>
<td>12.00</td>
<td>0.14</td>
<td>16,300.0</td>
</tr>
</tbody>
</table>

Regression Equation: $y = 0.035e^{0.339\log(A)}$  $R^2 = 0.8368$
Appendix C
Description of the Mass Balance Model

To: Evan Canfield
From: Dave Stewart
Subject: Modeling Runoff Reduction from On-site Storage Design at the Lot Scale
Date: 5/4/2009

Abstract:
On-site storage of stormwater in water harvesting basins or similar features is often credited as providing a reduction in runoff volume leaving a site. A model was developed to quantify the reduction in stormwater volume for a given water harvesting basin design at the lot scale. The model is based on conservation of mass, uses 105 years of historical rainfall data to simulate runoff, and uses soil moisture accounting to adjust soil storage for infiltration and evapotranspiration for the duration of the period of record. Simulated runoff volume varies by lot characteristics and basin design. Simulated runoff from lots with water harvesting basin can approach predeveloped conditions for small rainfall events, but often approaches post-developed conditions for large events or successive days of rain depending on the design. The model estimates the harvestable stormwater for the pre-developed and post-developed conditions as a percent of rainfall depth, and calculates the reduction in harvestable stormwater from the user-specified water harvesting basin design.

Introduction
On-site storage is often considered to have an effect on the runoff volume produced at the lot scale. A model was developed based on conservation of mass to evaluate the effect of water harvesting basin design on runoff volume for a given lot. The model is applicable to the design of water harvesting basins located either on-site, or in an adjacent right-of-way or public space; however the model is not intended for use with areas larger than the lot scale (approximately 1 acre) where transmission losses and routing are expected to be a significant factor. The model uses a mass balance approach with 105 years of rainfall data and the Soil Conservation Service (SCS) Curve Number (CN) method to simulate soil storage and runoff volume leaving the site on a daily time step. The model estimates the event runoff volume for the lot, the reduction in runoff volume from the water harvesting basin design, the monthly average soil moisture of the water harvesting basin, and the amount of stormwater that is available for harvesting at the lot scale for a given site. The on-site storage for this study is assumed to be a water harvesting basin.

Objectives
- Evaluate the effects of water harvesting basin design on runoff volume at the lot scale
- Evaluate the amount of harvestable stormwater for the pre-developed and post-developed conditions at several scales
Methods
Rainfall Data:
The 105 years of daily rainfall data used in the model were collected at the University of Arizona from 1895 to 2000 and obtained from the National Climatic Data Center (NCDC) (http://www.ncdc.noaa.gov/oa/ncdc.html).

Input Parameters
Lot Dimensions and Characteristics
The required model inputs for the lot are the:

- Total area of the lot including the water harvesting basin,
- Percent of directly connected impervious and unconnected impervious area,
- Percent of the pervious and impervious area diverted to the water harvesting
- CN values for the lot’s pervious, impervious, and water harvesting basin areas

“Connected impervious area” is considered in the model as an area that produces runoff that does not flow over any pervious areas while leaving the site. A schematic of how the model may be applied to the lot scale is shown in Figure 1. The percent of pervious, connected and unconnected impervious areas are specified by the user. The interface for the model was created in Microsoft Excel and is shown in Figure 2. An evaporation coefficient must be specified to represent losses in soil moisture at a daily time step relative to the average reference evapotranspiration (ET), which was obtained from the Arizona Meteorological Network (AZMET).

Water Harvesting Basin dimensions
The required water harvesting basin design variables are the basin length, width, depth, side slopes, porosity (if filled), and a crop coefficient to account for ET losses from vegetation. An optional minimum allowable soil moisture depth may be entered in inches based on the vegetation for the model to calculate the average number of days for each month simulated below the threshold value using the current design.

Assumptions
- The lot scale is small enough that losses from overland flow of runoff to leave the site are negligible
- Infiltration and evapotranspiration occurs on a daily time step
- The soil moisture reaches saturated hydraulic conductivity at AMC III
- Any additional assumptions made in the input parameters (the simulation can only be as accurate as the input parameters)
Figure 1. Schematic of the model applied to an example lot with pervious, directly connected impervious, and unconnected impervious areas.
Water Harvesting Basin Soil Moisture Accounting

Lot Dimensions

<table>
<thead>
<tr>
<th>Type</th>
<th>% Area</th>
<th>Area ft²</th>
<th>Curve Number</th>
<th>S (in)</th>
<th>0.2S (in)</th>
<th>Moisture Cap. (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly Connected Impervious</td>
<td>0.0%</td>
<td>0</td>
<td>99.5</td>
<td>0.0503</td>
<td>0.0101</td>
<td>0.034</td>
</tr>
<tr>
<td>Unconnected Impervious</td>
<td>30.0%</td>
<td>6212.7</td>
<td>99.5</td>
<td>0.0503</td>
<td>0.0101</td>
<td>0.034</td>
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<tr>
<td>Pervious</td>
<td>70.0%</td>
<td>14496.3</td>
<td>88</td>
<td>1.3636</td>
<td>0.2727</td>
<td>0.882</td>
</tr>
<tr>
<td>Basin</td>
<td></td>
<td>88</td>
<td></td>
<td>1.3636</td>
<td>0.2727</td>
<td>0.882</td>
</tr>
</tbody>
</table>

Basin Dimensions

- Length: 130.0 ft (Assumed to be front lot width unless specified)
- Width: 3.0 ft
- Area: 390.0 ft²
- Depth: 0.5 ft
- Side slopes (H:V): 0.0
- Base width: 3.0
- Porosity: 1.0
- Volume: 195.0 ft³ (Assuming Trapezoidal)
- Water Harvesting ET₀ Coefficient: 0.26
- Evaporation Coefficient: 0.26

Lot Area Diverted to Swale by Type

<table>
<thead>
<tr>
<th>Type</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly Connected Impervious</td>
<td>0.0%</td>
</tr>
<tr>
<td>Unconnected Impervious</td>
<td>100.0%</td>
</tr>
<tr>
<td>Pervious</td>
<td>100.0%</td>
</tr>
<tr>
<td>Total Area diverted</td>
<td>20709 ft²</td>
</tr>
</tbody>
</table>

Vegetation

- Minimum Allowable Soil Moisture: 0.75

Avg. Days Below Minimum Allowable Soil Moisture using Current Design:

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imp Predev</td>
<td>31.0</td>
<td>29.0</td>
<td>31.0</td>
<td>30.0</td>
<td>31.0</td>
<td>30.0</td>
<td>31.0</td>
<td>30.0</td>
<td>31.0</td>
<td>30.0</td>
<td>31.0</td>
<td></td>
</tr>
<tr>
<td>Harvestable Stormwater Q/P (%)</td>
<td>82.96%</td>
<td>19.44%</td>
<td>38.48%</td>
<td>25.57%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change from Predev (%)</td>
<td></td>
<td></td>
<td>19.04%</td>
<td>6.13%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Water Harvesting Reduction: 12.91%

Figure 2. Interface for the on-site storage design model.
Estimation of Runoff Volume

The SCS Curve Number (CN) method is used to estimate runoff volume by calculating soil storage, $S$, in inches from the CN value as:

$$S = \frac{1000}{CN} - 10$$

(1)

The runoff depth, $Q$, in inches is estimated for each area based on daily rainfall depth, $P$, in inches and soil storage:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

(2)

Where 0.2S is considered to be the initial abstraction, and runoff depth is zero for rainfall depths less than 0.2S.

Soil moisture accounting is performed in the model by updating soil storage on a daily time step as a simple mass balance. The soil storage decreases by the depth of infiltration which is found as the difference between rainfall and runoff depth. The soil storage increases each day with evapotranspiration. The change in storage each day can be summarized as:

$$\Delta S = ET - (P - Q)$$

(3)

The soil storage is assumed to have a minimum value at saturated conditions equal to the SCS CN Antecedent Moisture Condition III (AMC III). Therefore, infiltration will continue to occur under saturated conditions. Impervious surfaces are often assumed to have a CN of approximately 99, with some storage to account for shallow depressions that are filled under saturated conditions.

Due to soil moisture accounting, the model will simulate higher volumes of runoff for successive days of rainfall in the period of record due to saturated conditions.

The water harvesting basin storage is calculated using the same method, with storage increasing from ET and storage decreasing with runoff volume diverted to the basin. The percent of the lot diverted to the water harvesting basin must be specified in the model input parameters. When the basin storage is at capacity, the additional volume runoff overflows and is assumed to leave the site.

The total volume of runoff leaving the site each day is calculated as the sum of the runoff produced by all areas not diverted to the water harvesting basin, and any overflow from the basin.

Model Output

The output from the model includes:

- A stormwater analysis that calculates the percent of simulated total runoff depth relative to total rainfall depth for the impervious area, the pre-developed
condition, and the post-developed condition with and without the basin design. In addition, the reduction in runoff from the water harvesting basin design relative to post developed conditions is calculated.

- Graphs of simulated runoff event volume for the pre-developed condition, the post-developed condition, and the post-developed condition with the water harvesting basin design for the rainfall period of record
- A soil moisture analysis that produces the monthly average number of days that the water harvesting basin soil moisture is below the specified minimum allowable soil moisture.

Results and Discussion
The efficiency of the water harvesting basin design in capturing stormwater and reducing runoff volume depends on several factors including the volume of the basin, the total area diverted to the basin, as well as the overall CN and impervious area of the site that determines the “harvestable stormwater” or runoff coefficient.

Simulated Runoff Volume
Depending on water harvesting basin design, graphs of event runoff volume indicate that runoff volume can be decreased close to pre-developed levels for smaller rainfall events (Figure 3). However, for large rainfall events or successive days of rainfall, the runoff volume from sites with the water harvesting basin design approach the post-developed runoff volume due to reduced storage capacity. The pre-developed condition runoff volume also approaches post-developed runoff condition after several days of rainfall due to saturated soil conditions but does not reach the post-developed runoff volume due to the higher saturated hydraulic conductivity simulated from the pre-developed condition.

Harvestable Stormwater
The “harvestable stormwater” or long-term runoff coefficient is estimated for each condition as a ratio of the total simulated event runoff depth to total rainfall depth for the period of record. A determining factor in the amount of harvestable stormwater is the impervious area and overall CN. At a small scale, the simulated harvestable stormwater for an almost completely impervious area such as a rooftop is in the range of 70-90% of the annual rainfall depth depending on assumptions in losses in shallow depressions and the material of the roof (Table 1). For larger areas such as a 1/5 acre lot, there is an increase in pervious area and a decrease in impervious area. Assuming 50% impervious area with a CN of 99.5, and pervious area with a CN of 88 (PC-Hydro, Arroyo Engineering 2007), the harvestable stormwater is simulated as 51.2% of the annual rainfall depth. For ½ acre and 1 acre lots with assumed impervious areas of 30% and
Figure 3. Simulated runoff volumes for the post-developed, post-developed with an example water harvesting basin.
design, and pre-developed conditions for the rainfall period of record.
20% respectively (Arroyo Engineering 2007) and the aforementioned CN values, the simulated harvestable stormwater for the annual rainfall depth is 38.5% for \( \frac{1}{2} \) acre lot and 32.1% for a 1 acre lot. The simulated harvestable stormwater for the pre-developed condition with a CN of 88 and 0% impervious area is 19.4% at all scales.

**Table 1.** Simulated harvestable stormwater as a percent of annual rainfall depth with increasing scale and decreasing impervious percent.

<table>
<thead>
<tr>
<th>Scale</th>
<th>A (ac)</th>
<th>Imp % Pervious</th>
<th>Impervious</th>
<th>Harvestable Stormwater Predeveloped</th>
<th>Harvestable Stormwater Post Developed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rooftop</td>
<td>0.03</td>
<td>100</td>
<td>88</td>
<td>99.5</td>
<td>19.4%</td>
</tr>
<tr>
<td>1/5 ac lot</td>
<td>0.20</td>
<td>50</td>
<td>88</td>
<td>99.5</td>
<td>19.4%</td>
</tr>
<tr>
<td>1/2 ac lot</td>
<td>0.50</td>
<td>30</td>
<td>88</td>
<td>99.5</td>
<td>19.4%</td>
</tr>
<tr>
<td>1 ac lot</td>
<td>1.00</td>
<td>20</td>
<td>88</td>
<td>99.5</td>
<td>19.4%</td>
</tr>
</tbody>
</table>

**Rooftops or Other Completely Impervious Areas**

For a single large rainfall event, rooftops may have a runoff coefficient of close to 0.99. However, if a CN of 99.5 is assumed for a rooftop, the initial abstraction or initial losses due to shallow depressions is calculated as 0.01 inches. For every rainfall event in the simulation, the initial loss of 0.01 inches must be satisfied before runoff is produced. The average number of rainfall events per year for the 105 years of U of A data is 42 events. In addition, the assumed CN of 99.5 has a storage component of 0.05 inches that decreases with rainfall to a minimum storage of 0.0165, and is restored through evaporation in the simulation. The initial losses of the rooftop are small for a large rainfall events but become significant for the smaller rainfall depths that contribute to the annual rainfall depth. The harvestable stormwater for a rooftop with a CN of 99.5 is simulated as 82.9% of the annual rainfall depth. The losses from the annual rainfall depth on the rooftop may be attributed to repeated storage in shallow depressions and saturation of the roof surface before runoff is produced.

**Water Harvesting Basin Efficiency**

The reduction of the “harvestable stormwater” or long-term runoff coefficient from the addition of the water harvesting basin to the post-developed condition provides a measure of the efficiency of the water harvesting basin design. Factors affecting the ratio of total runoff depth simulated from total rainfall depth include the impervious percent of the lot, CN values, water harvesting basin volume, the percent of the lot area diverted to the basin or the “catchment ratio”, and the ET coefficients chosen for the model.

**Conclusions**

The lot scale water harvesting basin model was created to evaluate the design of water harvesting basin design on runoff volume. The reduction of runoff volume simulated by the model varies depending on lot characteristics and the specific water harvesting basin design. The findings from the model include:
• Runoff volume varies by lot characteristics and water harvesting basin design. For small rainfall events, runoff volume from the water harvesting basin can approach predeveloped conditions. For large rainfall events or successive days of rainfall, the runoff volume from the water harvesting basin approaches post-developed conditions due to reduced basin and soil storage.

• The simulated harvestable stormwater from rooftops or other completely impervious areas was from approximately 70-90% of the annual rainfall depth depending on assumptions in shallow depression storage and roof material.

• The simulated harvestable stormwater decreases with increasing area and decreasing percent of impervious area.

• The efficiency of the water harvesting basin design can be measured as the reduction in the harvestable stormwater from the post-developed condition.
Appendix D
Legal Issues and Permit Requirements

Water Rights

The State of Arizona uses a bifurcated system for allocating water rights, differentiating groundwater from surface water. The State’s regulations regarding surface waters rights and the use of water resources are contained in Title 45 of the Arizona Revised Statutes. Title 45 defines surface water as:

"... the waters of all sources, flowing in streams, canyons, ravines or other natural channels, or in definite underground channels, whether perennial or intermittent, floodwater, wastewater or surplus water, and of lakes, ponds and springs on the surface. For the purposes of administering this title, surface water is deemed to include central Arizona project water." (ARS § 45-101(9)).

Arizona governs the use of surface water in accordance with the prior appropriation doctrine, which dictates that surface water rights be allocated using a first in time, first in right methodology. This means that a water user who can apply “x” amount of surface water to a beneficial use has priority to that amount of surface water over any later user. This prioritization of use is critical during periods of drought or when a particular surface water source is over-allocated. The State of Arizona is currently adjudicating all surface water rights issued or claimed within the State, by watershed, to determine the validity and relative priority of each right. Included in the Statewide adjudication will be all surface water rights related to the Santa Cruz River. Since the Santa Cruz River is a tributary to the Gila River, all surface water right claims to the Santa Cruz River and its tributaries will be adjudicated with the Gila River Watershed Adjudication. And although, for all practical purposes, all of the surface water in the Santa Cruz Watershed has been appropriated by existing claims, it is still possible to file an application to appropriate surface water from the Santa Cruz River if a user can show a diversion and beneficial use.

In some situations, a surface water right may be claimed for the containment and use of stormwater. Stormwater typically begins in the form of overland flow or sheet flow, but will gradually flow into streambeds, ravines, canyons and other natural channels. Under the Doctrine of Prior Appropriation, stormwater is not subject to appropriation until it is contained within one of these natural channels. Once collected or contained, Stormwater may be applied to a beneficial use. Stormwater harvesting has, therefore, the potential to provide an additional water source for recharge, irrigation, riparian and wildlife preservation and recreational purposes.

Keep in mind that the construction and use of a stormwater detention basin does not, in and of itself, require a surface water right. Rather, it’s the act of putting the contained stormwater to beneficial use that triggers the need for a surface water right. A.R.S. § 45-151(A) defines beneficial uses as: domestic (which includes the watering of gardens and lawns not exceeding one-half acre), municipal, irrigation, stockwatering, water power, recreation, wildlife including fish, nonrecoverable water storage, and mining uses.
A good example of a flood control project in Pima County that utilizes stormwater is the Kino Environmental Restoration Project (KERP). The KERP was developed from an existing flood control structure that was expanded into a multi-purpose facility. The new multi-purpose facility was designed to collect and distribute surface and reclaimed water for the purpose of irrigating public ball fields and park areas containing wildlife and riparian habitat. The surface water used at KERP is stormwater that is trapped during normal rainfall events and then redistributed throughout the KERP facility. Since the stormwater collected at KERP is appropriable surface water according to the Prior Appropriation Doctrine, the Pima County Flood Control District filed for a surface water right for the stormwater it collects and uses at the KERP facility.

The KERP project demonstrated that the current Federal and State regulatory systems that regulate some aspect of local water use are not set up to deal with multiple use facilities. Surface water rights, riparian protection laws, and water quality regulations fit under separate regulatory frameworks that are not designed to operate in unison when faced with a multi-purpose facility like KERP. If the future includes more multi-purpose facilities as is anticipated, it will be necessary for the various federal, state and local agencies that regulate water uses to develop inter-modal programs to address these hybrid water use facilities. Furthermore, such changes will most likely need to be driven by the local jurisdictions that will be forced to make these new, innovative hybrid facilities fit within the State and Federal programs that regulate them.

**Water Quality**

Water quality regulations that may apply to a stormwater harvesting endeavor will depend on the project’s location, scale, and whether or not the stormwater is supplemented with reclaimed water. Arizona’s regulations administered by the Arizona Department of Environmental Quality (ADEQ) protect groundwater quality with Aquifer Protection Permits (APP), protect surface water quality with Arizona Discharge Elimination System (AZPDES) permits, and protect the public from exposure to pathogens with Reuse permits for reclaimed water. The following discussion presents the way in which state water quality regulations may apply to a range of stormwater harvesting projects with the following categories in mind:

- residential or commercial, lot-scale rainwater harvesting;
- neighborhood-scale stormwater retention/detention including a stormwater harvesting component;
- Tributary Watercourse scale retention/detention incorporating passive stormwater harvesting components;
- capture of stormwater for direct use including irrigating landscape, turf, or riparian vegetation or creating recreational lakes (beneficial uses), and;
- groundwater recharge using collected stormwater from Regional Watercourses.

**Aquifer Protection Permits (APP)**

*Stormwater Exemptions:* Many aspects of stormwater discharge are exempted from APP regulations in A.R.S. §49-250, including the following activities:
1. Household and domestic activities.
2. Household gardening, lawn watering, lawn care, landscape maintenance and related activities.
3. Ponds used for watering livestock and wildlife.
4. Facilities used solely for surface transportation or storage of groundwater, surface water for beneficial use or reclaimed water that is regulated pursuant to Reuse Permit regulations.
5. Surface impoundments used solely to contain storm runoff, except for surface impoundments regulated by the federal clean water act.
6. Application of water from any source, including groundwater, surface water or wastewater, to grow agricultural crops or for landscaping purposes.
7. Surface impoundments and dry wells that are used to contain storm water in combination with discharges from one or more of the following activities or sources: fire fighting system testing and maintenance; potable water sources, including waterline flushings; irrigation drainage and lawn watering; routine external building wash down without detergents; pavement wash water where no detergents have been used; air conditioning, compressor and steam equipment condensate; foundation or footing drains; OSHA or MSHA safety equipment.

Because drywells represent a special type of injection well that receives stormwater only, and because there is a separate provision for drywell registration and rules in Title 49, Chapter 2, Article 8, drywells are excluded from APP requirements according to A.A.C. R18-9-102.1. ADEQ has not yet developed rules for stormwater drywells, except for an APP general permit to address drywells located in areas where hazardous materials are stored and one for drywells at gas stations. Item #7 in the list of exemptions above describes the only sources of non-stormwater that can be combined with it and still maintain the exemption. Whenever reclaimed water is combined with stormwater, exemptions from APP no longer apply.

**Stormwater General Permits**

Item #5 in the list of exemptions above contains an exception for stormwater impoundments that might be required to have an AZPDES permit. This type of facility is covered by a simple APP general permit provided in A.R.S. §49-245.01. There are two other stormwater general permits listed in the APP statutory provisions. A.R.S. §49-245.02.A.1. allows disposal in vadose zone injection wells of stormwater mixed with reclaimed water or groundwater, or both, from man-made bodies of water associated with golf courses, parks and residential common areas. A companion provision in A.R.S. §49-245.02.A.3. allows point source discharges to Waters of the U.S. from man-made bodies of water associated with golf courses, parks and residential common areas that contain only groundwater, stormwater or reclaimed water, or a combination thereof. Both of these latter general permits require that the water meet Aquifer Water Quality Standards, except for the standard for microbiological contaminants.

**Individual APP Required for Stormwater Only when Mixed with Non-stormwater**

In general, stormwater discharge to groundwater does not require APP coverage. However, if it is mixed with reclaimed water, the discharge remains exempted from APP
only if it can be covered by a reuse permit. Reuse permit provisions for A, B, and C class reclaimed water prescribe lining requirements for impoundments and irrigation rates that prevent exceeding the demand of the vegetation type at the site. For A+ and B+ reclaimed water, these discharge provisions are waived. When stormwater and reclaimed water are combined in a project and circumstances are such that the project cannot comply with reuse permit provisions, an individual APP would be necessary. Mixing of stormwater runoff with water that has contacted industrial or mining wastes or with other non-stormwater sources precludes its eligibility for APP exemption or general permit coverage. Also, an individual APP may be required by ADEQ in instances where activities covered by general permits still result in an exceedance of Aquifer Water Quality Standards.

Summary

Generally, lot-scale stormwater harvesting is exempted from APP regulation. In specific instances, commercial lots using drywells require general permit coverage if the business stores hazardous materials or serves petroleum products. It is difficult to imagine a scenario that would draw neighborhood-scale stormwater harvesting projects into APP permitting. The only possible exception is for a neighborhood lake that incorporates reclaimed water as a source.
Appendix E
Review of Cost Effectiveness of Water Harvesting

The cost effectiveness of water harvesting should be considered in the context of both water supply and stormwater benefits. Traditionally, stormwater has been treated as a waste-product that is shunted from the urban environment as quickly as possible in expensive storm drains and other infrastructure. The large volumes of stormwater running off the broad impervious surfaces typical of the urban environment increase flood peaks and nuisance flows, yet at the same time create opportunities. Harvesting stormwater runoff and using it to support landscaping can offset demand for potable water. One strategy to harvest and infiltrate water close to the point of generation has been termed Low Impact Development (San Diego County, 2007). Studies of the cost-effectiveness of this strategy have shown that harvesting stormwater is cost-effective simply as a means to reduce the cost of building downstream drainage infrastructure (EconNorthwest, 2007).

The primary cost for water harvesting is capturing and storing the water. The least expensive way to harvest stormwater is by capturing and infiltrating it into depressions in the soil. Harvested stormwater can fully support the growth of many native plant species once they are established in urban landscapes, and can augment irrigation water for nonnative landscape plants.

Landscapes of native trees and shrubs improve urban aesthetics, provide recreational locations, mitigate the urban heat island effect, and provide urban wildlife habitat. Studies at the University of Arizona show that people are willing to pay more for housing near riparian areas (Bark-Hodgins & Colby, 2007), so fostering the development of native riparian vegetation using stormwater harvesting may increase property values.

Actively harvesting water in cisterns is more costly than passively storing water in soil. The cost of cistern storage ranges from around $1 to $3.50 per gallon depending on the type of cistern used (plastic, metal culvert, etc) and whether it is self-installed or professionally installed (Technicians for Sustainability, 2009). Cistern storage costing $1 per gallon is approximately equivalent to the cost of 500 gallons of potable water at Tucson Water’s average residential rate. In essence, the cistern must be filled to the top 500 times with rainwater before the cost saving for potable water offsets the purchase price of cistern storage. However, a study of cistern cost-effectiveness in Las Vegas concluded that they are cost-effective when both stormwater and water supply benefits are considered (French, 1988).

In urban areas, where space is at a premium, water harvesting strategies may increase the developable area of sites. For commercial sites and subdivisions, the amount of land area required to temporarily retain site stormwater runoff can be reduced by designing passive water harvesting areas that double as landscape borders and stormwater retention areas, and/or by retaining stormwater temporarily in cisterns. Increasing a site’s developable space could have substantial financial benefits to offset the cost of active and passive water harvesting.
In rural areas, where infrastructure is lacking, the cost of active water harvesting may be less than the cost of conventional water supply infrastructure. The cost of harvesting water that is delivered “free” from the sky and collected in a tank at the location where it will be used, could be considerably less than digging wells, extending water lines to remote areas or trucking water long distances.

In areas that have historically had abundant surface water, there are likely to be existing surface water appropriations that claim flow in streams. Rainwater is the source of much of what becomes flowing surface water. Therefore, the question of when surface water emerges in the hydrologic cycle in such areas may arise. The requirement to retain stormwater—often in large stormwater detention or retention basins—is well established in Pima County and the jurisdictions within it based on the public safety-based need to manage stormwater and control flooding. Harvesting water before it would otherwise be detained or retained at a site in a large stormwater retention basin, and putting the harvested water to beneficial use has the additional benefit of offsetting potable water use that would otherwise be needed to water landscape or meet other water needs.

References


Appendix F

Regulations Protecting Riparian Habitat

City of Tucson

The City’s Office of Conservation and Sustainable Development (OCSD) staff members work with Development Services Department staff to negotiate with applicants to reduce encroachment into protected riparian habitat. This habitat is regulated pursuant to the City’s Floodplain Ordinance, WASH Ordinance and ERZ Overlay Zone. OCSD is currently facilitating the Resource Planning Advisory Committee, a Mayor and Council-appointed citizen’s committee, to revise the City’s watercourse protection regulations.

WASH and other watercourse protection ordinances including recharge element - The regulation of development along watercourses is based upon the delegation of regulatory authority from the State to the City for the purpose of managing flooding and floodplain area. This statutory authority focuses on the hydrological and public safety aspects of floodplain management. State authority is separately delegated to the City authorizing the regulation of land uses and structures under the City’s zoning codes. This provides for broader regulation of floodplain areas to achieve community aesthetic, cultural and resource preservation goals. The fundamental policy direction of the City was stated in a resolution in 1990: "The Mayor and Council find that protection and preservation of natural drainage systems should be the primary emphasis of City stormwater management efforts. Nonstructural solutions to flooding hazards shall be the preferred strategy over structural solutions." The implementation of this fundamental policy direction in the management of watercourses and floodplains has been established by ordinances, resolutions, administrative interpretations, and development standards including: Chapter 26 of the Tucson Code, the Floodplain and Erosion Hazard Management regulations; the adoption of the Environmental Resource Zone (ERZ) by Ordinance 7450 on July 3, 1990 as an overlay zone, LUC § 2.8.6; adoption of the Watercourse Amenities, Safety and Habitat (WASH) regulations by Ordinance 7579 on March 25, 1991, Tucson Code, Chapter 29, Article VIII, approval of further phases of the Tucson Stormwater Management Study (TSMS) and by adoption of the Floodplain, WASH, and Environmental Resource Zone (ERZ) Standard (Development Standard 9-06) by Resolution 20505 on November 6, 2006. Combined, these ordinance and standards delineate how riparian habitat is determined, what impacts are allowed, and what mechanisms are required to address mitigation for habitat loss.

By their nature, riparian areas require periodic stormwater flows to survive and thrive. Urban development, which results in increased urban runoff, has mixed impacts on riparian areas. These impacts range from the benefits of somewhat longer stormwater flows due to the slow release of water from detention areas, to the negative effects of erosion caused by clean water scour. Water conservation efforts can be designed to benefit riparian areas in several ways. Site water harvesting can reduce erosive flows to the wash while at the same time, if water harvesting areas that are planted with native riparian species are located near washes, they can augment the volume of riparian habitat at a site. Water saved through conservation earmarked to benefit riparian areas
could be used in several ways: by the slow release of piped water to these areas or by decreased pumpage in areas of shallow ground-water dependent riparian habitat.

Pima County

Pima County Floodplain and Erosion Hazard Management Ordinance (Floodplain Ordinance) - Pima County’s Floodplain Ordinance is based on the necessary and desirable goal of maintaining a balanced and cooperative relationship between human development and the land and resources that maintain them. The intent of the Floodplain Ordinance is to preserve natural floodplains and riparian habitat wherever possible. The highest and best use of regulatory floodplains is for the maintenance of the natural hydrologic and hydraulic stream flow processes with consideration for groundwater recharge, natural open space and riparian and wildlife resources.

Pima County first began regulating riparian habitat in 1994 to preserve and protect these ecosystems, preserve natural washes systems and reduce erosion hazards. In 2005, the County adopted additional regulations and detailed riparian habitat maps developed with the Sonoran Desert Conservation Plan (SDCP) was initiated in 1998 to update the County Comprehensive Land Use Plan. The SDCP provided a science based resource and conservation plan and the Comprehensive Plan directs growth to areas with the least natural, historic and cultural resource values. The Conservation Lands System (CLS) was adopted in 2002 as part of the Comprehensive Plan update and includes protection of Important Riparian Areas.

With regard to riparian habitat protection, the 2005 amendment to Title 16, adopted the Important Riparian Areas as well as other riparian areas, increasing the acreage of regulated riparian areas from 26,252 acres (1994) to 87,273 acres (2005).

The County’s Comprehensive Plan Water was amended by the Board of Supervisors in December, 2007 to include the Resources Element, which requires comprehensive plan amendments and rezonings to include a robust examination of the available water service and renewable water supply options for the sites in question. The intent of the policy is to inform the land use decision makers of the currently available surface water, groundwater, and effluent supplies to provide pertinent information about the impacts of a proposed new development on water resources. For comprehensive plan amendments, staff conducts a water resource impact review to identify pertinent rezoning policies that should apply at later stages of land development. These include policies to minimize the adverse impacts of water supply development upon groundwater-dependent ecosystems of Pima County, including springs, perennial and intermittent streams, and shallow groundwater areas.