GUIDELINES FOR THE DESIGN OF MITIGATED RIPARIAN HABITAT IN DETENTION BASINS OF PIMA COUNTY, AZ

PIMA COUNTY REGIONAL FLOOD CONTROL DISTRICT

This document was prepared by Matthew Bossler as a Report for the degree of Master of Landscape Architecture at the University of Arizona. This work was undertaken under contract to Granite Construction Company for Pima County Regional Flood Control District, Marisa Rice, Project Manager, 2009-2010.

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INTRODUCTION

Problem Statement and Significance

Stormwater detention basins within the Tucson basin and beyond are often engineered, constructed and maintained for a single purpose: safe control of urban floodwaters during storms of high magnitude. However, the simple "accepted design practices" of designers of these basins are not robust enough to include other programmatic goals, including active and passive recreation, aquifer recharge, wildlife habitat, mosquito control, off-site irrigation, water treatment, and environmental education within an urban setting. While under-utilized, designs providing for these other uses are not appropriate in each case due to a variety of physical, biological, and social factors. While certain guides do exist for the design of stormwater detention basins from an engineering perspective, a landscape architecture perspective, and that of a home-owner, there is a lack of "state-of-the-art" guidance for the multi-purpose design of detention basins from the scale of the neighborhood to the regional detention basin.

Goal

The goal of this document is the development of design guidelines for the incorporation of mitigated riparian habitat within private and public retrofitted and newly designed urban detention basins from the scale of the neighborhood or commercial complex to the regional detention basin.

Methods

These guidelines include a categorized graphic design typology of solutions. These categories have been chosen to highlight the major features of a typical detention basin incorporating mitigated riparian habitat. Based upon extensive literature review, interviews with practicing professionals, and case study visits in multiple cities in the southwestern U.S., each category includes examples of both existing basins and figures depicting processes and forms that can be employed for their successful design and implementation.

RIPARIAN ECOLOGY

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Figure 2.1.1: Bass Canyon, Cochise County

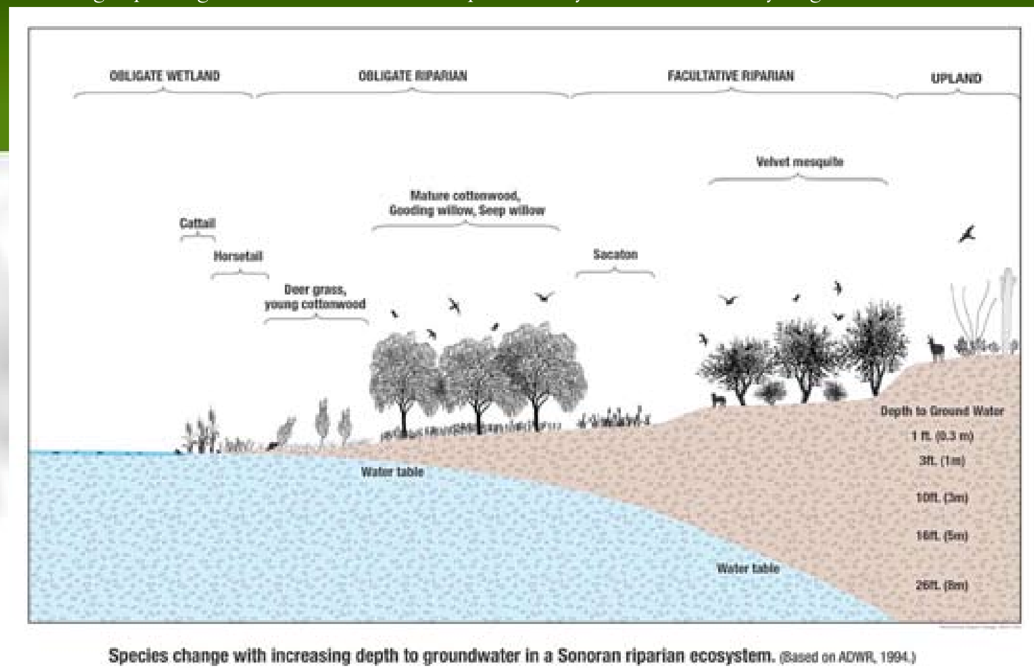
Riparian systems of Pima County floodplains provide refuge to native plant and animal communities both within and outside of developed areas, and, when biologically functional, exhibit the following characteristics:

Riparian biotic communities are those lands, in drainage ways and adjacent floodplains, whose generally porous soils are hydrated for longer periods of time than adjacent lands due to prolonged submergence from flooding, dispersed flow, or ponding of runoff from adjacent lands (Brown 1994). As a result of this increased availability of soil moisture, vegetation within riparian areas is often denser, taller, and more diverse than adjacent uplands (PCRFCD 2008, a). Small-scale (cover, seed source) and regional (linear connectivity within deserts) structural qualities bestow a habitat value to these systems disproportionate to their limited geographic extent (Brown 1994). Terrestrial animals are highly dependent upon connectedness, while native bird density in Tucson is correlated with high vegetative volumes in urban washes (The Arizona Wildlife Linkages Workgroup 2006; Mills et. al 1989).

Riparian communities are generally classified as either hydroriparian, mesoriparian, or xeroriparian. The primary difference in environmental condition between these ecosystem types is the proximity of the groundwater table to the soil surface, and result in varying levels of total amount of vegetation, which have been delineated via remote sending and field measurement. Xeroriparian habitat is primarily characterized by limited, ephemeral water supply above ground and throughout the rooting zone, and is found in riparian strands and scrubland; it is further categorized by the county into classes A, B, C, and D based upon density and plant associations. Mesoriparian habitat is associated with shallow ground water and are found in riparian deciduous forest, woodlands, and scrubland. Hydroriparian habitat is associated with perennial watercourses, and are found in interior marshlands and submergent communities (Brown 1994; Pima County Department of Transportation and Flood Control District 1993; PCRFCD 2008, a).

Field determination of class type of disturbed habitat must correlate with the acreage to be mitigated (PCRFCD 2008, a).

Figure 2.1.2: Within a typical Sonoran Desert perennial or ephemeral stream, while emergent wetland species survive in perennially inundated or saturated soils, the roots of obligate mesoriparian species must be in constant contact with groundwater, and facultative xeroriparian species can survive without perennial contact with groundwater (modified from "Species change with increasing depth to groundwater in a Sonoran riparian ecosystem." Pima County Regional Flood Control District 2010).



1. Geomorphology and Habitat Structure

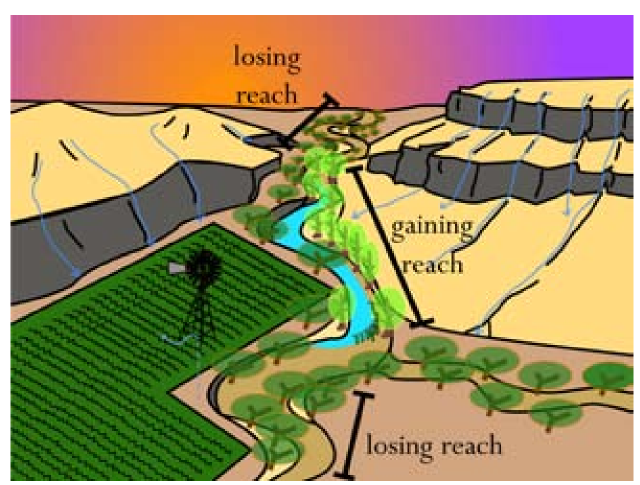


Figure 2.1.3: Environmental and anthropogenic factors influence how close groundwater is to the surface. Gaining reaches occur where aquifer recharge exceeds withdrawal and/or groundwater is pushed towards the surface by proximate subsurface impermeable bedrock, resulting in stretches of hydro- and mesoriparian vegetation, a condition that is analogous to the dam of a detention basin.

2. Hydraulic Dynamism

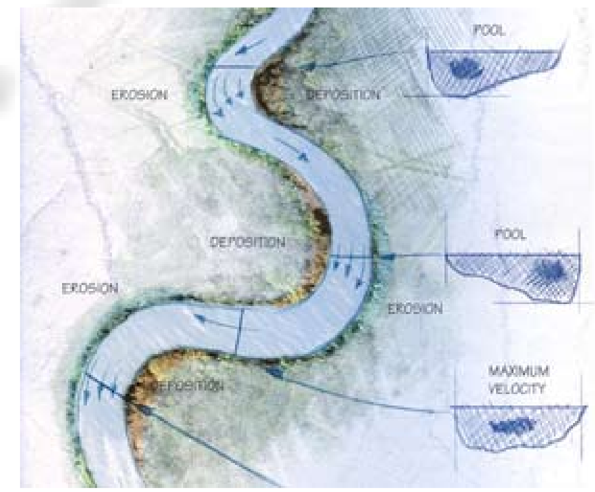


Figure 2.1.4: Floodplains are dynamic systems that are altered over time by the hydraulic energy and sediment transport within them. Vegetation is altered as erosion occurs along the high-energy outside of meanders, while deposition occurs on the low-energy inside, and in point bars. Detention basins are opportunities for this dynamic process to alter the form of riparian habitat over its life (Daniels 2008, p. 51).

3. Biome

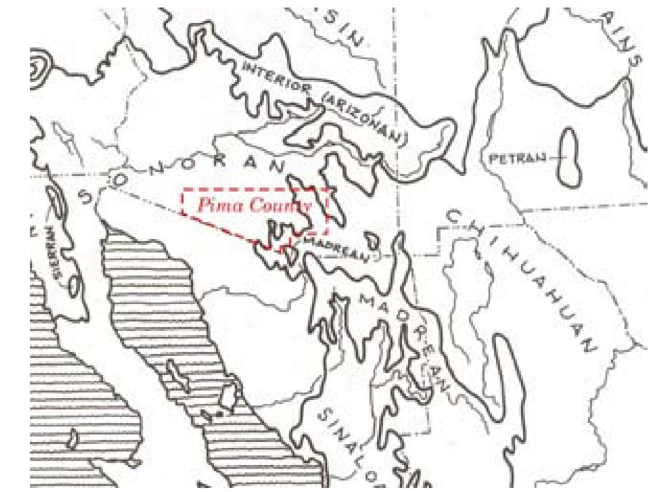


Figure 2.1.5: Eastern Pima County lies on an ecological transition zone between the Sonoran and Chihuahuan biogeographic provinces, or biomes, each of which is characterized by a different set of plant species. Site location within these provinces should inform the plant selection for riparian basins (image modified from Brown 1994, p. 13).

Key Questions for Design Decision

1. What is the nearest biologically-functioning ecological network (major river, minor wash, etc.?)
2. What biotic communities exist on-site or locally and how might the diversity of the local ecosystem structure be improved?
3. How can the design minimize barriers to wildlife movement between the basin and adjacent corridors and biologically-functional uplands?
4. What is the required habitat mitigation acreage and what are the benefits to be had by introducing elements of human circulation? How can these two design goals be synthesized in a mutually beneficial manner?

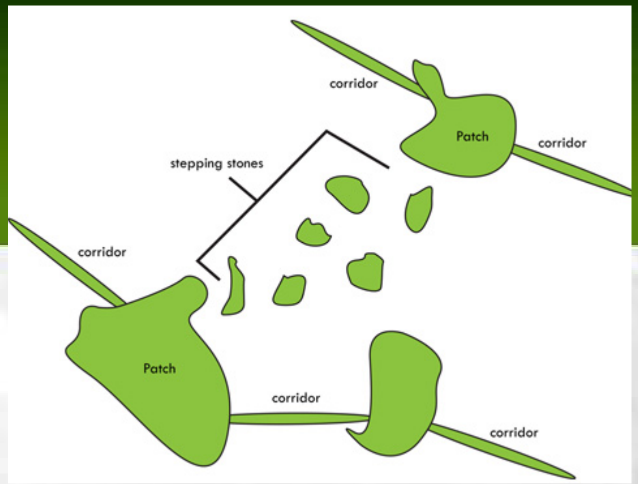


Figure 2.1.6: "Patches" of habitat with a high ratio of area to edge are undisturbed preserves of biological diversity and abundance whose value can be greatly enhanced by linear biological "corridors" connecting them. Disconnected patches between are also of value as "stepping stones" for wildlife, particularly flying animals, to inhabit between large "patches."

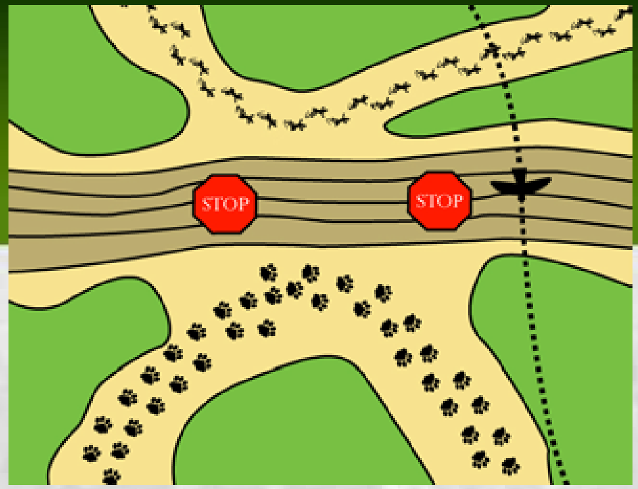


Figure 2.1.7: Barriers to animal passage and stream process along riparian habitat networks can take the form of hardscape structures or denuded areas such as bare side-slopes, decreasing the value of habitat on both sides. While flying animals can pass over them, terrestrial animals may be reluctant to pass these open areas.

4. Connectivity

5. Edge Effects

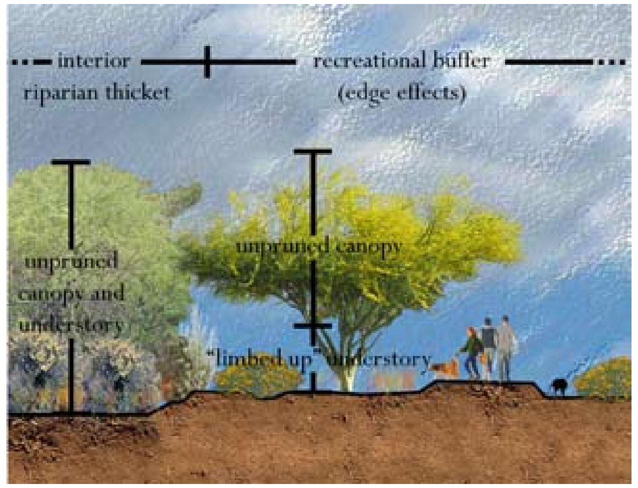


Figure 2.1.8: Interior habitat is generally a refuge for sensitive species that are easily disturbed by factors associated with edges with disturbed areas, such as motion disturbance, noise, and introduced species. Therefore, dense thickets of riparian scrub, aquatic plants, and riparian obligate species, due to their high habitat value, are best positioned within undisturbed interiors of habitat patches.

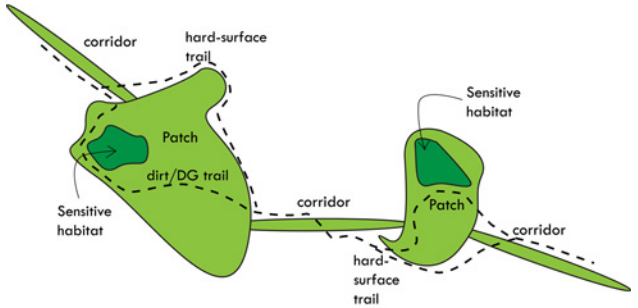


Figure 2.1.9: Inserting trails or other areas of human circulation into habitat patches typically downgrades high-quality interior habitat to low-quality edge habitat, though community use of these areas can foster appreciation, a sense of public ownership and pride, and ultimately, civic support for their continued existence.

Permitting, Maintenance, & Monitoring

1. Permit review of adjacent developments should emphasize connectivity of functional biological corridors through the use of open channels.
2. Pruning and brush removal should be limited to the recreational buffer along the perimeter of interior habitat areas in order to minimize edge effects.
3. Natural stream dynamics (deposition areas, cut banks) should be allowed within the basin and inflow channels where they do not cause flooding risks.
4. As climate and water resources change regionally, plant palettes may need to be revised to accommodate altered environmental conditions.

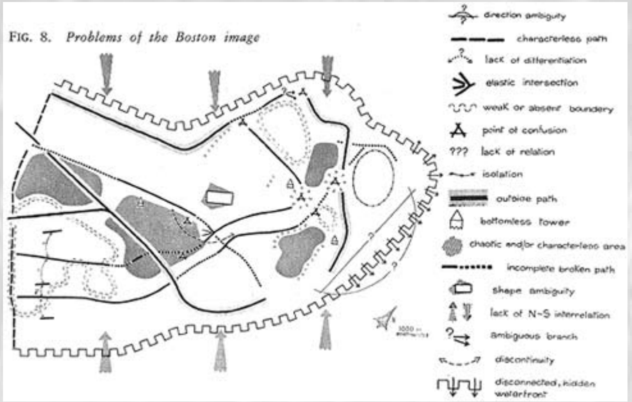


Figure 2.1.10: The model of habitat patches and corridors is analogous to the paths and nodes of Kevin Lynch's 'Image of the City' model of human communities. In it, circulatory paths, activity nodes, and edges, among other features, shape the way that humans move and congregate within and urban area. Detention basins can serve as nodes of human activity (Lynch 1960).

Additional Resources

The Arizona Wildlife Linkages Workgroup. *Arizona's Wildlife Linkages Assessment*. Phoenix: Arizona Department of Transportation, 2006.

Brown, David E. ed. *Biotic Communities: Southwestern United States and Northwestern Mexico*. Salt Lake City: University of Utah Press, 1994.

Dramstad, Wenche E., James D. Olson, and Richard T.T. Foreman. Landscape Ecology Principles in Landscape Architecture and Land-Use Planning. Washington, D.C.: Island Press, 1996.

Harris, Larry D. "Edge Effects and Conservation of Biotic Diversity," Conservation Biology v. 2:4 (1988): 330-332.

Hellmund, Paul C. and Daniel S. Smith. Designing Greenways: Sustainable Landscapes for Nature and People. Island Press, Washington, D.C. 2006.

Lynch, Kevin. The Image of the City. MIT Press, Cambridge, 1960.

Mills, G. Scott, John B. Dunning, Jr., and John M. Bates. "Effects of Urbanization on Breeding Bird Community Structure in Southwestern Desert Habitats," *The Condor*, 91 (1989): 416-428.

Pima County Regional Flood Control District. "DRAFT Regulated Riparian Habitat Mitigation Standards and Implementation Guidelines, Supplement to Title 16 Chapter 16.30 of the Watercourse and Riparian Habitat Protection and Mitigation Requirements. Ordinance No. 2005-FC2,"Tucson: Pima County Regional Flood Control District, 2008.

ADJACENT PARCELS

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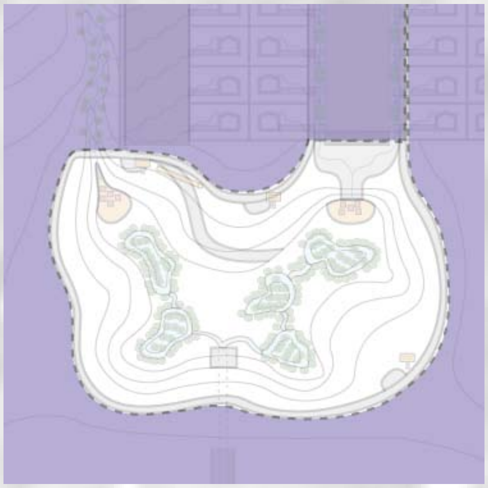


Figure 2.2.1: Adjacent Parcels (in blue)

The form of a riparian detention basin's interior and edges is greatly influenced by the hydrological, biological, and developed nature of adjacent lands. Design should therefore be mindful of the following attributes of the site:

Prior to designing a detention basin, great care must be applied to analyzing the contributing watershed. Design should consider multiple, separate, contributing watersheds, from the primary upstream inlet taking the vast majority of the volume, to smaller-scale watersheds along the sides of the designed basin, with seemingly insignificant sources of flow. If unaccounted for, these latter areas can become drainage problem areas by developing erosion rills that can head-cut into maintenance rights-of-way, multi-use trails, and planting areas on the slope-top, or into adjacent property parcels. In order to properly maintain form, capacity, and strength of a basin, all contributing watersheds, regardless of size, should either be made non-contributing by complete retention in storms up to 100-year storms by water-harvesting tanks and earthworks, and/or retention basins internal to the site, or be directed into designed inlets through a combination of levees, berms, swales, and microbasins that prevent them from forming their own erosive routes over the side-slopes.

The quality of life of places of work, residence, or outdoor gathering in adjacent parcels can be greatly improved by views on to the riparian basin. These developments can range from utilitarian, agricultural landscapes to traditional, residential communities to urban multi-storied hotels and offices. A common complaint about successful riparian growth in stormwater infrastructure in Pima County is that it looks overgrown in comparison to the manicured landscape of the home, and appears to be a hinterland that attracts inhabitation by the homeless and unsupervised youth. Therefore, in order to improve public perception and acceptance of riparian areas as socially-beneficial amenities, the transition zone between the neighboring building and manicured landscape should either be gently transitioned from formal to natural or designed in a way that embraces the contrast between the two as a positive element of design instead of an accidental, uncomfortable clash.

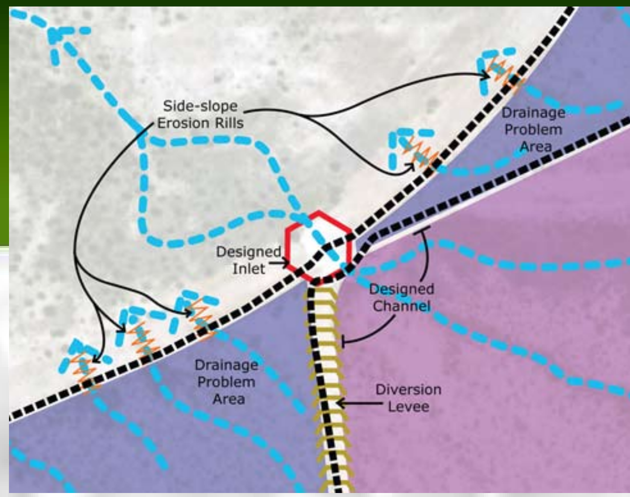
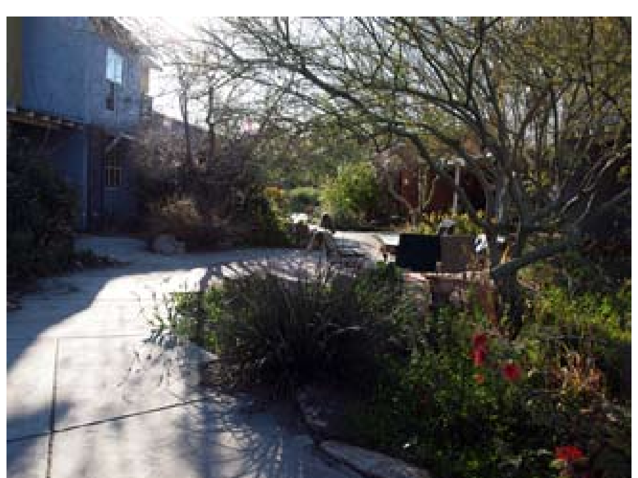


Figure 2.2.2: Small areas of drainage not designed for (in blue) can cause numerous, large erosion problems (in orange,) as at Kolb Road Basin in Pima County, AZ.

Figure 2.2.3: When the drainage from adjacent parcels is unaccounted for, side-slope rill erosion can develop and head-cut into slope-top improvements such as multi-use paths or building foundations ("Field Report for: Kolb Road Basin." PCRFCD 2008).

1. Drainage Flow

2. Permeability



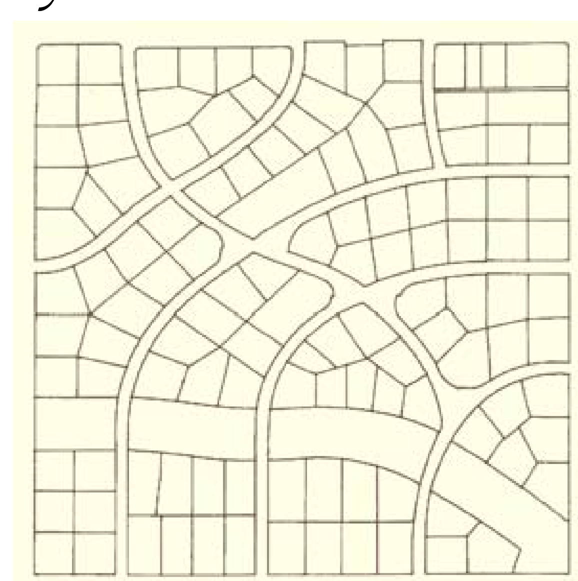
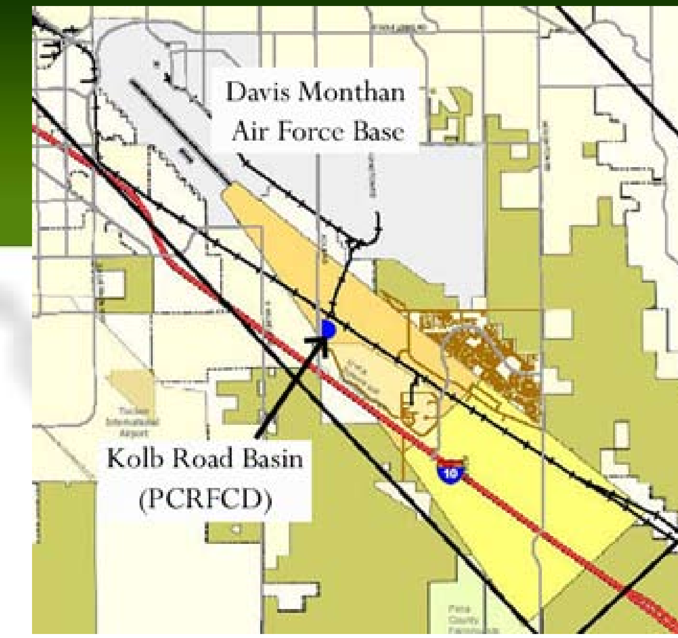


Figure 2.2.4 (top,) 2.2.5 (right): Narrow, curvilinear paved surfaces, and parcels sited with respect to contour allow for area on private parcels, increasing infiltration, and reducing runoff. Two examples of this effect in Tucson are Colonia Solana (right, City of Tucson Planning Department et al. 1994) built in the 1920s in which parcel size is large, and Sonora CoHousing Community, completed in 2000, in which parcel size is relatively small.



3. Special Zoning Overlays

Figures 2.2.6 (top right,) 2.2.7 (top left): Many special zoning overlay zones exist throughout metropolitan areas, and restrict building type and land use within them. In the example illustrated above, the Approach-Departure Corridor, also known as the "flight paddle" of Davis Monthan Air Force Base, prohibits residential, commercial, office, and active recreational/gathering area land use at the Kolb Road Basin, due to sound levels between 60-70 decibels, risk of a crash, and the potential for bird kill and resultant plane malfunction (Davis Monthan Air Force Base 2003). At right, though portions of the Guadalupe River Park lay within the flight paddle of San Jose International Airport, passive recreational use and hydroriparian habitat areas are allowed and enjoyed.

Key Questions for Design Decision

1. How is stormwater draining from secondary (not primary upstream wash) adjacent areas going to be controlled?
2. What are the views on site from neighboring developments and how can they be designed for positive perception?
3. Are the building exteriors and proximate landscape of neighboring developments formal/informal, vernacular or naturalistic?
4. How can the transition between the neighboring developments be best designed through the incorporation of contrast or smooth gradient design characteristics to improve positive perception of the designed riparian system?

Figure 2.2.8 (above): Reading areas of the Southeast Regional Library in Gilbert, AZ, overlook a recreational pond of the Riparian Preserve at Water Ranch (C.F. Shuler, Inc. 2010).

Figure 2.2.9 (right): A conference room in a business park adjacent to Granite Regional Park is enhanced by a window view of a water feature within a retention pond.

4. Views onto Site

5. Transition of Form

Figure 2.2.10: Skyscrapers holding Acer, T & C Productions, and Paolo's Restaurant in downtown San Jose, CA, are oriented towards the Guadalupe River Park, demonstrating an appealing transition between geometric and naturalistic form through the use of planting terraces, stairs, and recreational pathway.

Figure 2.2.11: At the Paradise Apartments along Greenway Wash in Phoenix, AZ, residents are treated to window views and a turfed seating and recreation area overlooking the riparian habitat below. Curbing on the left side of the concrete path conveys water to drains located at bump-outs to the left, which also serve as overlook points.

Permitting, Maintenance, & Monitoring

1. Where erosion rills from drainage problem areas threaten buildings, paths, or other infrastructure, their contributing watershed should be redesigned with diversion berms, swales, and/or basins to capture water upslope and concentrate flows into designed inlets.
2. Permit review of new adjacent developments should emphasize the preservation of sight-lines towards riparian visual amenities and on-site detention of increased runoff.
3. Revision of overlay zones, such as airport flight paddles, should consider the wildlife habitat value, and resultant waterfowl population, of sites within them.

Figure 2.2.12: Patrons at the Wolfgang Puck Restaurant at the Springs Preserve in Las Vegas, NV, enjoy an overlook of the formal landscape and riparian habitat below (Luchessi, Galati, Inc./Natural Systems International).

Additional Resources

City of Tucson Planning Department, Pima County, the University of Arizona. *Joesler & Murphey: An Architectural Legacy for Tucson.* City of Tucson Planning Department, Tucson, AZ, 1994.

Davis Monthan Air Force Base. Arizona Military Regional Compatibility Project. Davis-Monthan Air Force Base/Tucson Joint Land Use Study. Public Informational Meeting, September, 2003.

Pima County Regional Flood Control District, City of Tucson, 2008. DRAFT Ordinance No. 2008-FC____. An Ordinance of the Board of the Directors of the Pima County Flood Control District relating to Floodplain Management codifying the Pima County floodplain and erosion hazard management ordinance as Title 16 of the Pima County Code. Tucson, AZ.

C.F. Shuler, Inc. "Riparian Preserve at Water Ranch, Town of Gilbert, AZ." 2010

STREET-SIDE BASINS

STREET-SIDE BASINS

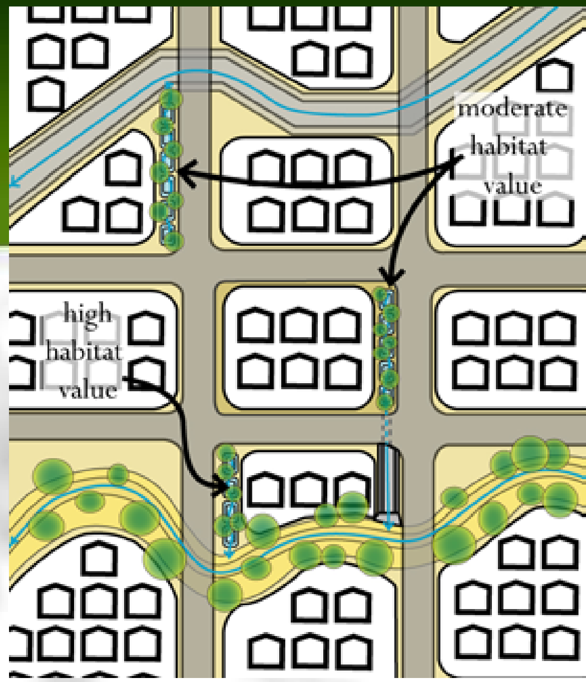
Figure 2.3.1: Street-side basins (in blue)

Street-side basin series can create a network of accessible, maintainable, riparian corridors of intermediate habitat value and beneficial community use, and should be designed according to the following guidelines:

Detention basins integrated within the matrix of a residential, commercial, or residential development primarily represent opportunities for the growth of native trees that can both create riparian corridors and improve the quality of life of residents or employees through the creation of shade, the lowering of ambient temperatures, and increasing aesthetic appeal. If riparian street-side basins are located in a continuous series connected to a tributary or regional watercourse, they can expand the regional ecological network by extending minor biological corridors from the core of the network into the matrix of the development. When disconnected from the regional ecological network by a road or other constructed barrier, the value of this habitat is lowered, though they still contribute to the ecological function of the region by serving as "stepping stones" for flying animals. (see figure 2.1.9). Therefore, while the human benefit of integrated mitigated habitat within detention basins is very valuable throughout a developed matrix, habitat value is lowered as the basin becomes more internal to the developed area.

Most existing developed areas within the developed areas of Pima County are bounded by streets with concrete curbs which contain stormwaters that have arrived into the street until it is conveyed to a storm sewer, or channel. If a site is to be redeveloped, detention requirements are often increased. If existing streets are planned for continued use, they can be retrofitted with cutting or removal of curbs. Curb cuts are openings cut into the concrete to the level of the street at points along the curb to allow for stormwater conveyed by the street to be directed into street-side basins. Completely new developments, however, can skip the expense of curbing, shifting conveyance, as well as detention, into linear series of basins adjacent to the both the street and developed parcels.

Because of their small size, street-side basins should concentrate woody plantings on slightly elevated extensions of side-slopes instead of internal planting islands.



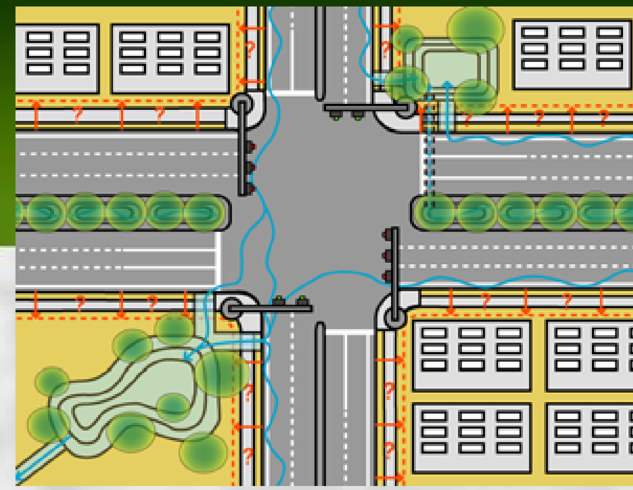


Figure 2.3.2 (left,) 2.3.3 (top): Basins abutting the pavement are only appropriate along small residential or rural roads, as depicted at left. Basin series extending from natural drainages are of higher habitat value than those separated by constructed barriers. Basins along arterial streets are more appropriate in medians or offset from the roads, which expand in size with increased traffic demand.

1. Street Scale

2. ROW Zonation

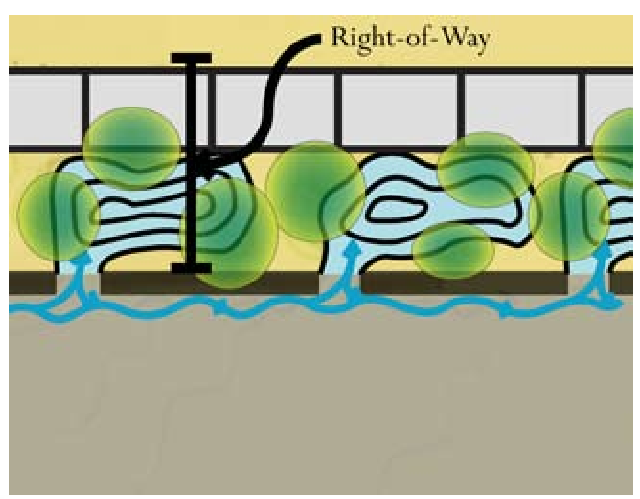


Figure 2.3.4: Urban street-side basins created by curb-cutting should be contained, along with a sidewalk or other pedestrian space, within the road right-of-way.

3a. No-curb Alternative (Street Even with Lot)

Figure 2.3.5: At the Confer private residence in the Colonia Solana neighborhood of Tucson, AZ, narrow streets (~24') drain into a series of slightly-depressed basins. When one of these fills to capacity, water bypasses it and flows into the next in the series.

Figure 2.3.6: In a rural, no-curb setting, a vegetation-free utility operational zone should be located between the road edge and street-side basins. When the road is down-cut from the surrounding grade, up-slope of the street-side basin, erosion control measures such as side-slope basins and slope-top diversion basin series can help prevent side slope erosion. (Design Collaborations, Ltd. 2009).

Key Questions for Design Decision

if a retrofit development:

1. Is it necessary to keep absolute stormwater control function of street? to keep curbs?
2. Are basin excavations compatible with existing underground and aboveground utility line location and maintenance zones?
3. Will placement of curb cuts degrade roadway pavement?

if a new development:

1. How is stormwater draining from secondary (not primary upstream wash) adjacent areas going to be controlled?
2. What are the views on site from neighboring developments and how can they be designed for positive perception?
3. What is the form of the landscape of neighboring developments?

Figure 2.3.7: Deep rectangular vegetated detention basin adjacent to impervious parking lot at Vernola Family Park, Riverside, CA.

Figure 2.3.8: Traffic circle: A parking area at the northern end of Columbus Boulevard in Tucson, AZ is designed around a concave, landscaped, pervious cul-de-sac that retains and infiltrates low-flows draining from the road, while providing a designed centerpiece of sculptural landscape.

3b. No-curb Alternative

4. Curbed Alternative

Figure 2.3.9: Curb-cut water-harvesting basins: By cutting away sections of an existing curb, low-flows are directed into shallow water-harvesting basins immediately adjacent to this residential street, and support hardy xeroriparian plants, at The Nature Conservancy water-harvesting demonstration site in Tucson, AZ (Watershed Management Group).

Figure 2.3.10: Basins in chicanes: In the Rincon Heights neighborhood of Tucson, AZ, water-harvesting basins are colocated within curb bumpouts, otherwise known as chicanes, which help slow the flow of traffic on streets of overdesigned width, and shade the street and sidewalk, reducing urban heat island effect (Silins, Joe. "Chicane." Watershed Management Group. 2010).

Permitting, Maintenance, & Monitoring

1. Ideally, individual basins within a series should all be easily approached by vehicle and of a consistent form in order for simplification of maintenance strategy.
2. Outlets and inlets should be kept clear of clogging by accumulated brush of rhizomatous vegetation such as cattail through manual removal (non-vehicular).
3. Maintenance responsibility lies with HOAs, facilities management staff, or municipal staff, depending on site location, but is never the responsibility of the individual homeowner of the private residential lot.

5. Detention Basin or Water Harvesting Basin?

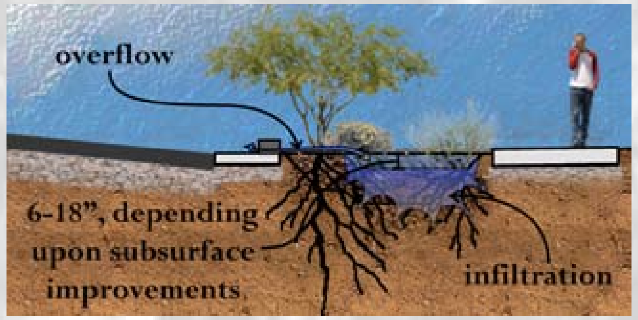


Figure 2.3.11: Street-side water harvesting/retention basins should be dug to a depth of 6-12," depending on subsurface improvements, to ensure adequate drainage.

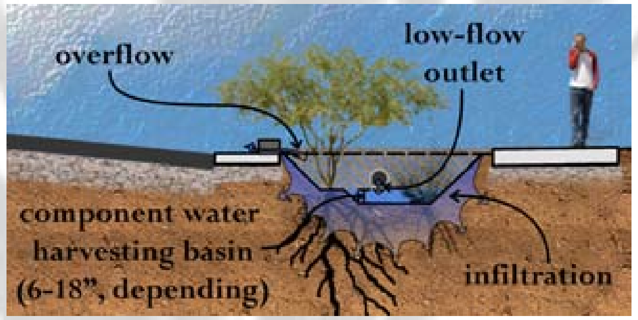


Figure 2.3.12: Street-side detention basins to varying depths can contain "nested" water harvesting/retention basins located below the bottom of the outlet pipe. Overflow occurs via the curb-cut inlet.

Additional Resources

City of Tucson. Department of Transportation. Stormwater Management Section, Water Harvesting Guidance Manual. Ann Audrey Phillips. Ordinance number 10210. 2005.

Design Collaborations, Ltd. from Street Edge Water Harvesting: Green Corridors for Our Community. 2009.

Lancaster, Brad. *Rainwater Harvesting for Drylands and Beyond; Vol. 2: Water-Harvesting Earthworks,* Tucson: Rainsource Press, 2008.

Waterfall, Patricia H. "Harvesting Rainwater for Landscape Use." University of Arizona Cooperative Extension. <<http://ag.arizona.edu/pubs/water/az1344.pdf>> last revised 2006.

Watershed Management Group. "Guidelines for working in the right-of-way." << http://www.watershedmg.org/sites/default/files/docs/wmg_public_right_of_way_handout.pdf>> last revised 2008.

LOT-BOTTOM BASINS

LOT-BOTTOM BASINS

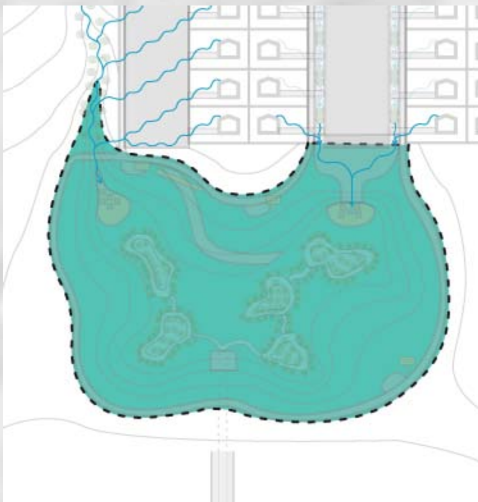


Figure 2.4.1: Lot-bottom basins (in blue)

Many basins detain runoff from large impermeable areas at the lowest point of a development or previously-developed region of the county. Basins of this size can take a variety of forms to support the growth of riparian habitat:

Basins located at the bottom of an intermediate-sized development or regional watershed catch excess runoff not detained and infiltrated within the matrix of the developed site. A benefit of locating riparian habitat within basins of this type is that they are generally located down-slope from impacted areas and are generally closer to tributary or regional watercourses that serve as major and minor biological corridors. Therefore, the creation of a riparian habitat mitigation area within one of these basins essentially contributes a connected node to an existing ecological network.

While all detention basins are inundated by storm-water runoff, other sources of water should be considered. Residential, public, and golf course landscape overwatering, commonly known as "urban drool," filtered or unfiltered, can be directed to planting areas. Other water sources that can irrigate plantings include reclaimed water from industrial processing or the treatment of effluent, or actively-harvested water stored in tanks.

Before designing a detention basin, the flow velocity and frequency of flow events through inlets should be modelled. High-velocity storm surges should be slowed by some combination of open-flow channels, drop structures, and energy dissipation structures should be designed in order to protect downstream microbasin planting areas from destruction. Low-flows should be directed through a series of shallow terraces or microbasins. As a rule of thumb, the shallower the terraces or microbasins, the more area within them can be covered in small events. The floor of microbasins closer to feeder inlets should be at or above the floor elevation of those microbasins further from feeder inlets to allow for successive overflow.

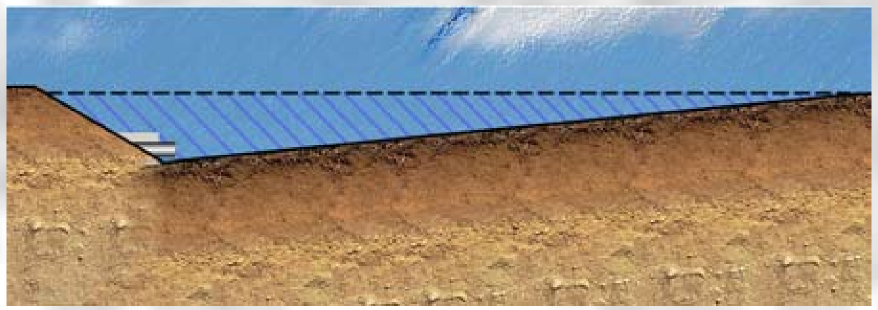


Figure 2.4.2 (top,) 2.4.3 (bottom): In order to achieve the same capacity, a detention basin's surface profile can vary from a steep drop and short, flat run, to an even-sloped, extended-run, which is more conducive to mitigated habitat.

1. Bottom-profile Basics

2. Agricultural Analogs

Figure 2.4.4: Partial flow diversion of flowing waters is the essence of diversion canal agriculture in both temperate/tropical areas, as seen here in South China, and arid and semi-arid regions such as the Sonoran Desert, the home of the early canal-based protohistoric Hohokam civilization. Linear Terrace: direct series of overflow terraces; develop graphic or use image of rice paddies on slope (China Forum 2010).

3. Natural Analogs

Figure 2.4.5: A pool and riffle arrangement mimics the *natural analog* wherein pooling areas overflow through intermediate riffles or cascades. These can be created by bedrock intrusions or cobble deposits, as seen here in the Tabletop Wilderness, AZ. Note the density of vegetation located to the sides of the sandy deposit areas.

Figure 2.4.6: In Clarkdale, AZ, the Verde River currently runs south of ruins of the Tuzigoot Sinagua civilization, during which time the river ran around the north. This old river channel has become Peck's Lake, a natural oxbow supplemented by waste water from an adjacent mining facility in town. Within it, Tavasci Marsh, a hydroriparian wetland and mesoriparian forest, provides ideal habitat for many bird species.

Key Questions for Design Decision

1. What do available annual storm series data tell you about the relative frequency of small and large storm events?
2. What capacity must the master detention basin contain to handle a 100-year event?
3. What is the project budget? Can the master-plan allow for construction of a first phase without sacrificing the function of future phases of development?
4. Are sensitive planting areas or recreational amenities to be included? Can the design of flow-diversion structures and offline systems protect these components?
5. Is the total detention basin to be visible and accessible? If not, is the design of an out-of-sight offline detention basin appropriate?

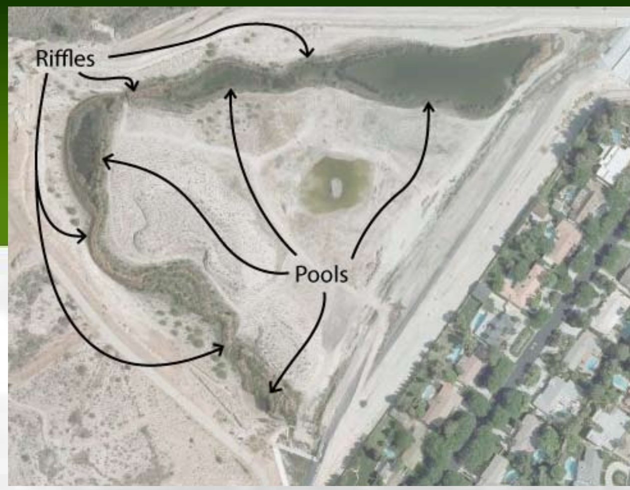


Figure 2.4.7: Pool and riffle: The Las Vegas Springs Preserve (Luchessi Galati, Inc./Natural Systems International) in Las Vegas, NV, concentrates hydroriparian plantings around successively lower perennial pooling areas consistently sloped towards their center, and riffle streams connecting them. In small storm events, vegetated overbank areas of both become inundated.

Figure 2.4.8: Curved Terrace, all flows: wide basins wrap around side slopes taking total volume of all storms, with no central/bypass negative space (overflow basin,) as in this multi-use master plan for Strathern Pit in Los Angeles (Natural Systems International).

4. Designed Flow Regimes

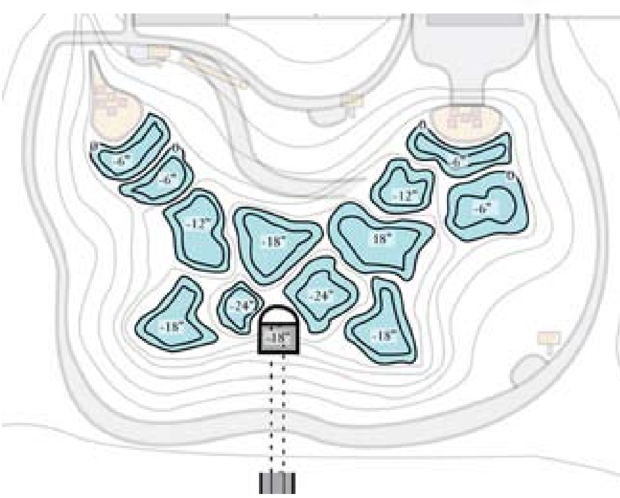


Figure 2.4.9: Subdivided terracing: Fine-scale grading of each microbasin should allow it to fill to capacity from low-flows emanating from its feeder inlet, then overflow to adjacent microbasins without "hogging" the full amount, in order to maximize the temporary pooling and saturation areas.

Figure 2.4.10: Low-flow channel, off-line component detention basins: At the Erie Lakes Detention Basin, CO, low flows (dark blue) are contained to a low-flow channel and water quality treatment pond, while, in large events, high-flows (light blue) back up at the outlet and overflow to an adjacent, off-line detention basin. This mimics the natural analog of a slough or oxbow lake in the overbank areas of a floodplain.

Permitting, Maintenance, & Monitoring

1. The maintenance of lot-bottom basins, as they are infrastructure internal to a development, lies with the neighborhood/home-owners association, or the facilities management staff.
2. Maintenance personnel, whether they are residents, facilities staff, or contracted crew, must be educated as to the proper functioning condition of the designed riparian habitat, which is vastly different than typical residential, commercial, or park landscapes. Education can occur via on-site signage, site maintenance manual, and/or direct education of crew by the groundskeeper.

Additional Resources

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INFLOW CHANNELS, DROP STRUCTURES

INFLOW CHANNELS, DROP STRUCTURES

INFLOW CHANNELS, DROP STRUCTURES

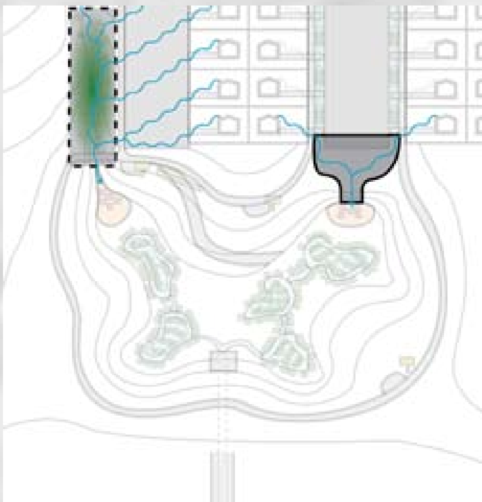


Figure 2.5.1: Inflow channels, drop structures

Inflow channels convey runoff to a detention basin, and, along with drop structures, can absorb energy, connect habitat, assist with sediment deposition, and create intriguing drama. In their design, the following should be considered:

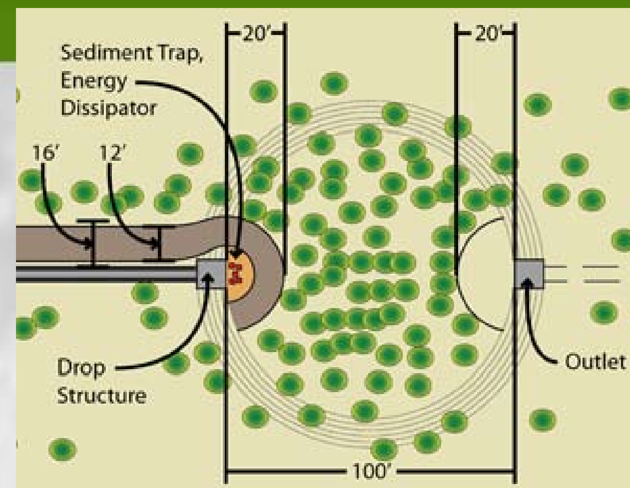
Inlets to detention/retention basins can be one or many. In order to minimize erosion, all contributing watersheds, even minor ones to the side of the basin, should be directed into designed inlets. The type of inlet designed is highly dependent upon the form of the master plan. The first two components of an inlet, in order of the direction of flow, are the inflow channel/spillway, and drop structure.

Generally, constructed infow channels should be kept free of vegetation to ensure proper conveyance. Open-channel inlet design begins with the concept that designed conveyance channels can serve secondary purposes, such as infiltration, recreation, and habitat, by slowing the passage of water through wider, easily accessible channels that contain vegetation. At Village Homes in Davis, CA, all residential lots drain to the rear of the property into open channels that are paralleled and crossed by walking paths, creating an interconnected network of common areas that are commonly used by home-owners and their children, fostering a sense of community (Francis 2003). The success of this has influenced other community designs in California, Colorado and Arizona, in which open channels parallel the front of lots and the road, or within the median of a road.

If the inflow channel continues upstream as a properly-functioning biological corridor, the spillway and drop structure should be designed in a way that encourages passage of terrestrial animals between the vegetated refugia of the channel above and the basin below. Additionally, as the upstream "tail" of the basin is lengthened, and the inflow channel within it is roughened with in-channel and overbank vegetation and either retained in original sinuous form or designed so, the energy of the incoming floodwaters is lessened and suspended sediment is given multiple opportunities to settle in low-energy areas of flow, requiring less of an engineered hardscape solution (Zeedyk and Clothier 2009).

Pima County Technical Policy 009 bounds the design of inflow channels by requiring "a 12' physical access corridor adjacent to the inflow channel and within the 16' access easement for maintenance purposes." Additionally, "no plantings, volunteer or otherwise, within 20' radius of basin inlet or outlet, as measured from the edge of the structure," are allowed in large basins, so that inlet or outlet structures that may require maintenance can be accessed by a utility truck or other heavy machinery (see figure 2.5.2). For smaller detention basins that can be maintained using smaller maintenance vehicles or by hand, landscaping may be allowed within a 20' radius from the basin inlet and/or outlet on a case-by-case basis, subject to District review and approval.

Figure 2.5.2: Basins above 1/5 acre in size or those with inlets separated from outlets by more than 100 feet are subject to policy TECH-009, which requires a 12' physical access corridor adjacent to the inflow channel and no woody plants around the inlet and outlet.



1. Maintenance Access

2. Culverts

Figure 2.5.3: Below-grade metal pipes and culverts can safely deliver incoming flows basins where above-ground conveyance is impossible, as shown here at Vista Hermosa Park, Los Angeles, CA (Mia Lehrer Associates,) and Regency Park, North Natomas/Sacramento, CA.

3. Constructed Channels

Figure 2.5.4: Flows from small drainage areas can be conveyed to the basin via narrow channels armored with concrete or rip-rap, as at Ladera Ranch, CA, and in suburban Pima County, AZ, at right.

4. Open Channels

Figure 2.5.5: The primary parkway of Ladera Ranch community in Orange County, CA, is flanked by a dual conveyance system, named the Sienna Botanica, that drains the entire development to a lot-bottom basin, provides an intermediate habitat-value biological corridor from the vegetated basin to wilderness located above the development, and improves water quality and infiltration along its length. These benefits, in sum, satisfy the development's habitat mitigation requirements.

Figure 2.5.6: The Los Angeles River Revitalization Master Plan, designed by Tetra Tech, Inc., Mia Lehrer Associates, Civitas, Inc. and Wenk Associates, calls for a stream profile that contains concrete step terracing for with access ramps leading to a low-flow environment containing emergent vegetation and pool and riffle flow (City of Los Angeles 2007).

Key Questions for Design Decision

1. Do inlet channels retain ecological integrity? If so, can spillways and drop structures be designed in a way that accomplishes long-term hydraulic function and wildlife passage?
2. Can the basin be used to improve the quality of life of the development? Can the arrival and hydraulic management of low-flows be sculpted into intriguing, eco-revelatory art?
3. Is sensitive use such as water quality treatment wetlands or lush mesoriparian woodlands designed within the immediate vicinity of the inlet? If so, can incoming hydraulic energy be absorbed by hardscape instream, or drop onto splash pads?

Figure 2.5.7: Runoff from an adjacent residential area arrives at the Greenway Wash through a concrete slip in low-flow conditions, swelling over a gabion walls in higher flows. The terrace created by these walls provides a xeroriparian planting area.

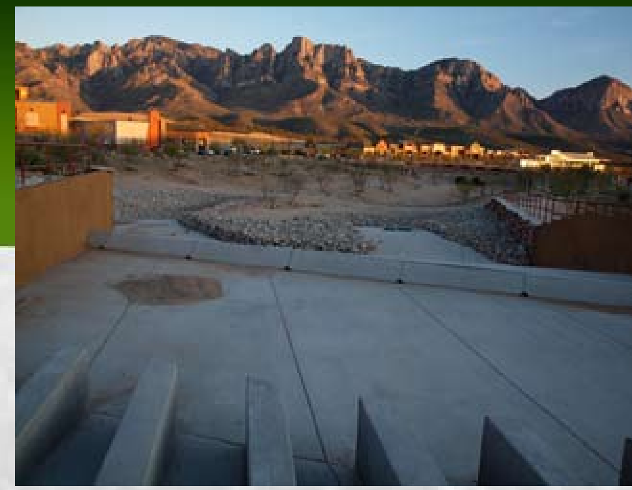


Figure 2.5.8: Inflows into a constructed wash that drains the Oro Valley Marketplace are dissipated by concrete blocks, a drop in elevation, and a rip-rapped isthmus of land that splits the flow.

5. Concrete Slip and Gabion

6. Combined

7. Naturalized Concrete Dams

Figure 2.5.9: Falls, boulders set in concrete dam: At the Erie Lakes Detention Basin in Erie, Colorado, boulders from a local quarry were set into concrete in order to create 18" vertical drops that, along with adjacent hydroriparian plant growth, absorb hydraulic energy while re-creating points of natural wonder along a neighborhood greenway (Belt Collins West).

Figure 2.5.10: Concrete dam + boulders: At Horseshoe Park in Denver, CO, hydraulic energy from an inlet channel is dissipated by instream vegetation, an approximately 2' dam, and boulders set above and below the dam (Wenk Associates).

Permitting, Maintenance, & Monitoring

1. Remove any volunteer plants from constructed inflow channels, but not from open flow channels or intentional planting areas.
2. Following major events, inspect drop structures for undercutting and the development of erosion channels other than the designed flow channel.
3. Following major events, remove coarse woody debris and large inorganic trash such as tires and appliances to ensure proper hydraulic function.

5. Naturalized Cascade

Figure 2.5.11: Cascade: Shop Creek outcrop soil cement slip into plunge pool, Off-set site soil-cement lifts: Curved, stratified drop structures created by site soil cement lifts enhance the appearance of water-quality wetlands and allow for natural observation along Shop Creek in Denver, CO (Wenk Associates).

Additional Resources

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SLOPE TOPS

SLOPE-TOPS

Figure 2.6.1: Slope-tops (in tan)

The form of a riparian detention basin's interior and edges is greatly influenced by the hydrological, biological, and developed nature of adjacent lands, and the transition to basin side slopes, which can take the following forms:

Minimally, the tops of detention basins must provide maintenance access and concentrate sheet flowing from minor adjacent watersheds into designed inlets. In order to accomplish the former, the tops all basins should preserve a 12' maintenance access corridor within a 16' maintenance easement (TECH-009).

The transition between the side slope, which drains towards the basin bottom, and the inside of the flat or back-graded top is an area where head-cut erosion will often occur, dependent upon the degree to which adjacent runoff is concentrated into inlets. Maintenance of these head-cuts, most commonly done by re-grading, can infringe upon functional areas along the top, including maintenance access/recreational pathways, safety barriers, and planting areas. In addition to erosion-prevention measures along the side slopes, the designer should also create a buffer space appropriately scaled to the height and slope of the side-slope for frequent re-grading between the steepest pitch of the side-slope and the beginning of slope-top improvements. In this area, designed elements should be restricted to small shrubs and other elements that can be easily removed or replaced without significantly impacting the design.

Maintenance access corridors along slope tops can double as recreational paths, and diversion swales and basins can enhance the ecological connectivity between the basin bottom and functionally-riparian inlet channels. Depending upon the size of the contributing watershed, waters flowing perpendicular or near perpendicular to the direction of the edge of the side slope should be diverted into a designed inlet structure through above-grade compacted berms, crown ditch swales, and/or a series of microbasins along this swale. Functionally-riparian inlet channels should be crossed over by bridging perpendicular roads and pathways in order to continue uninterrupted hydrologic processes and wildlife passage. Denuded inlet channels can be constructed more affordably to pass over top of the surface of the pathway.

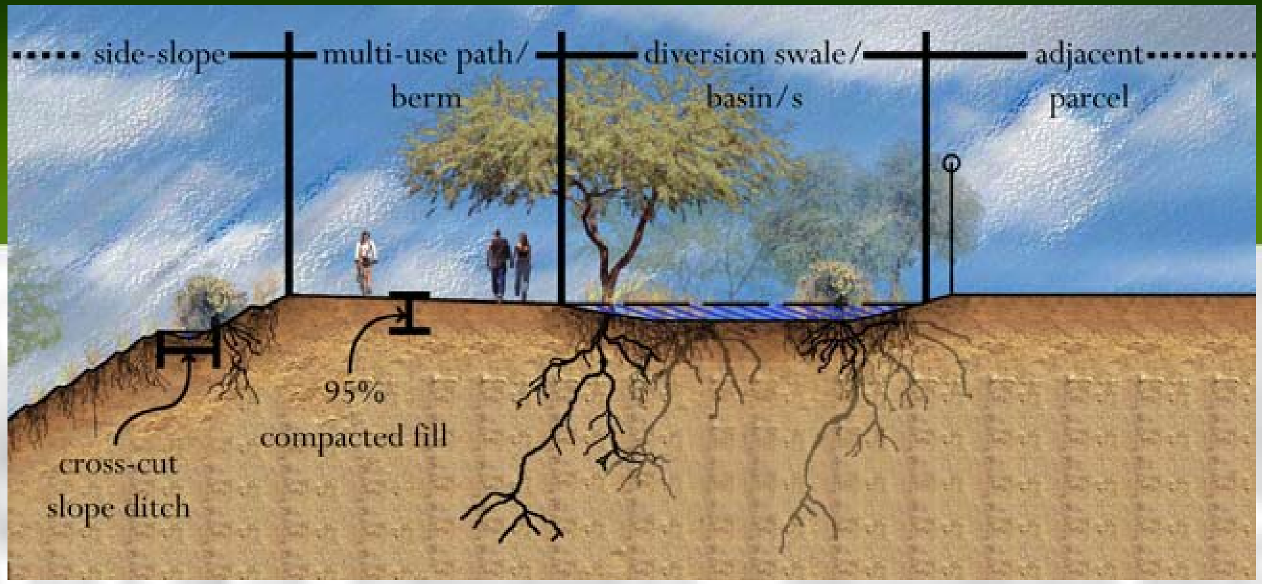

Figure 2.6.2: Runoff from adjacent parcels can be collected in diversion swales or basins parallel to the top of the slope of the basin, and safely conveyed to a designed inlet. Diversion areas can be contained by compacted berms or multi-use paths.

1. Berm and Basin

2. Crown Ditch

Figure 2.6.3: A crown ditch installed at the top of this Sonoran desert roadway cutbank diverts sheet flow from adjacent lands to the right, preventing rill erosion on the designed side-slopes. (Arizona Department of Transportation 2008).

3. Recreational Amenities

Figure 2.6.4: At Bluff Lake Nature Center in Denver, CO, a perimeter trail is punctuated by scenic overlooks such as this, which give a sense of place, and an opportunity to reflect upon the features below.

Figure 2.6.5: Shade, a safe walking surface, and areas for discovery and play are important features of slope-top recreational trails, as seen in this proposed image of The Los Angeles River Revitalization Master Plan, designed by Tetra Tech. Inc., Mia Lehrer Associates, Civitas, Inc., and Wenk Associates (City of Los Angeles 2007).

Key Questions for Design Decision

1. Is side-slope erosion from drainage problem areas in adjacent parcels likely without some sort of slope-top diversion?
2. Are the soils of the side-slope highly erosive? If so, does the soil of top-of-slope diversion structures need to be compacted to prevent undercutting?
3. Is the basin located along a river park, greenway, or other recreational path? If so, how can this path be sited along the slope-top to maximize field of view of the riparian amenities below and help concentrate runoff into designed inlets?
4. Can slope-top diversion areas also be infiltration and riparian habitat areas? Can trees growing among them help to shade existing paths?

Figure 2.6.6: This photo by the Arizona Wildlife Linkages Workgroup demonstrates the barrier to terrestrial animal passage posed by traditional culvert/scupper design, and the necessity for collaborative design between a project's civil engineering and landscape architectural designers (The Arizona Wildlife Linkages Workgroup 2006).

Figure 2.6.7: At the Star Valley Basin 4 park of the Star Valley Village subdivision in southwest Tucson, constructed inlet channels flow over the surface of perpendicular pathways through dips in the paving, an appropriate solution when the upstream channel does not retain ecological integrity (image courtesy of Novak Environmental, Inc. 2010).

4. Pathway / Inlet Channel Intersection

Figure 2.6.8: At Milagro Cohousing Community in unincorporated Pima County west of Tucson, tributary washes pass underneath pathway bridges, preserving hydrologic dynamism and the passage of small animals.

Figure 2.6.9: Following an assessment of elk-vehicle collisions on AZ-SR 260 along the Mogollon Rim, Arizona Department of Transportation installed riparian underpasses that preserves passage through the flow channel and dry banks of Christopher Creek (The Arizona Wildlife Linkages Workgroup 2006).

Permitting, Maintenance, & Monitoring

1. After major storm events, pathways may have been damaged at intersections with channels, or sediment deposits may have settled in undesirable places. Monitor at least once yearly, after the monsoon system, and make necessary repairs.
2. Paved and gravel pathways can erode and settle from sinkholes, and should be refilled and/or compacted with the base material when this occurs.
3. Maintain a vegetation free zone of 2' to each side of the 12' wide, slope-top, multi-use path. Clear overhanging branches if and only if they obstruct the necessary passage of maintenance vehicles at the time of maintenance.

Additional Resources

Arizona Department of Transportation. Guidelines for Highways on Bureau of Land Management and U.S. Forest Service Lands. Phoenix: Arizona Department of Transportation, 2008, http://www.azdot.gov/Highways/Roadway_Engineering/Roadside_Development/HwyBLM_USFS.asp (accessed 2010).

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SAFETY AND EDUCATION

SAFETY AND EDUCATION

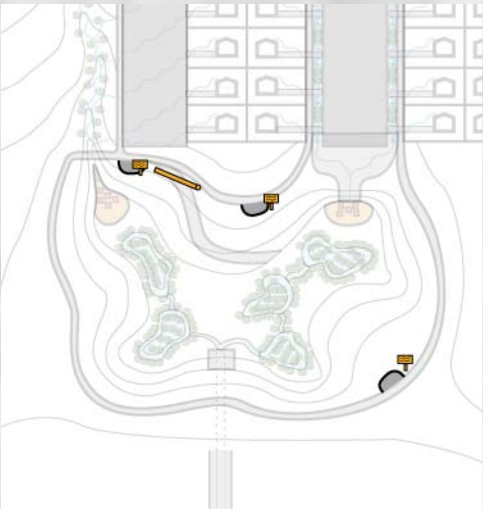

Figure 2.7.1: Safety and education

Acceptance, appreciation, and safe use of riparian basins by the public, maintenance staff, police and elected officials are essential for their successful function and maintenance, and can be promoted with the following techniques:

By its nature, recreational use within floodplains poses a risk of bodily harm. This is most pronounced in steep inflow channels, where flow velocities are greatest, and "walls" of water can arrive within instants, not providing a person enough time to escape from the nearest, sometimes far-away access point. For this reason, recreational use is not recommended within steep-walled inflow channels, and is instead focused to their slope-top banks.

Detention basins differ from inflow channels in that, at the arrival of these high velocity floodwaters to a detention basin, they are instantly spread across a great amount of area, and the hydraulic energy of these flows is quickly dissipated both through this spreading, re-orientation of direction of flow downward over drop structures, and energy dissipation structures below on which they can splash. For these reasons, high-flows of inflow channels should either be directed to bypass channels that are not programmed for recreational use, or directed into an area in which they can quickly be spread. In large storm events, slightly elevated berms of component microbasins will be the last soil within the basin bottom to become inundated, and are therefore ideal locations for walking trails. However, due to the vast area of the basin, inundation happens over a period of time in which visitors should be able to safely exit the basin. At worst, they may need to wade through water to reach an exit, but the time it takes to do so is minimal in comparison to the time it takes for the basin to fill to levels in which drowning would be likely.

Due to this potential harm and the resultant liability that the managers of the site take on, and the opportunity for public education, design of these basins should seek to inform the visitor of the risk and the ecology of the site through verbal and symbolic communication.

Landscape maintenance manuals should seek to educate the maintenance staff on the complex hydraulics and ecology of the site, as they are much different than traditional sites.

Figure 2.7.2: At the Anthem Hills multi-use basin in Henderson, NV, this sign, repeated around the basin's perimeter, informs users of the risk of drowning during rain storms, in both English and Spanish, and through symbolic figures.

1. Signage Alerting Risks

2. Signage Informing Purpose

Figure 2.7.3: Signage at a conservation area at the West Branch of the Santa Cruz River in Pima County informs the public of sensitive habitat value and use restrictions through text and images associated with riparian life (Burnham, Dave, Pima County Graphic Services, 2010).

3. Non-verbal Signage

Figure 2.7.4: Riparian biotic process can be communicated non-verbally through symbolic sculpture, as along a greenway in the North Natomas neighborhood of Sacramento, CA.

Figure 2.7.5: At the Gowan Basins, in Las Vegas, NV, a line of concrete along the side-slopes communicates depth of floodwaters during flood events and function of the basin throughout the rest of the year.

Key Questions for Design Decision

1. What are the risks to the visitor during storm events and how can they best be prevented?
2. What is the metropolitan's standard of legal liability of risk and recreational injury prevention for combined-use facilities? Is explicit signage the only acceptable form of communication per the law?
3. Can eco-revelatory art and/or non-verbal symbolism communicate risk and riparian process better than signage, which is often ignored?

Figure 2.7.6 (near right): Sculptural gestures of flow draw the eye to the function of a small contributing open channel at the Springs Preserve in Las Vegas, NM (Luchessi, Galati, Inc.).

Figure 2.7.7 (far right): This recirculating water feature at Vista Hermosa Park in Los Angeles makes a gesture of active riparian process throughout the year (Mia Lehrer Associates).

4. Symbols of Process

5. Fencing

Figure 2.7.8: Fencing separating the user from sensitive or dangerous environments should seek to enhance understanding of views below, as seen at this fishing pond at Gilbert, AZ's Water Ranch (C.F. Shuler, Inc.).

Figure 2.7.9: If the area is to be commonly used by visitors, investment in fencing types that contribute to the surrounding visual resources is most appropriate, as seen here in the form of a concrete seat wall, pipe and cable fence, and fencing composed of COR-10 t-bar posts, cable, and steel pipe railing (Luchessi, Galati, Inc.).

Permitting, Maintenance, & Monitoring

1. Fencing should be field-visited after major storm events, checked for damage from erosion, and repaired as necessary.
2. Signage should be cleaned or replaced when graffitied.
3. Remove flammable non-native vegetation (buffelgrass, fountain grass) to prevent wildfires in otherwise non-flammable riparian communities.
4. Shade and cover encourage inhabitation by people, including the homeless and teenagers. Discouragement of this type of use can occur through frequent community use and/or police presence if a crime has been committed, but removal of vegetation within interior habitat is not allowed.

Additional Resources

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SIDE-SLOPES

SIDE-SLOPES

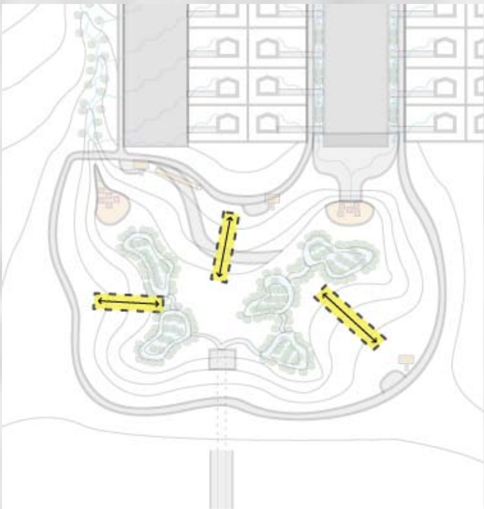

Figure 2.8.1: Side-slopes (in yellow)

Side-slopes of detention basins can be either separate or connect habitat and human use depending upon hydrologic routing, and the design of plantings and access paths. Primary considerations in the design of side slopes are:

Side slopes must serve at least two functions, maintenance access and drainage, and, preferably, a third function, habitat connectivity between functioning biological corridor above and habitat patch within the basin below. Traditionally, side-slopes and their component inlet drop structures have been designed as denuded hardscapes, that disconnect ecological networks and are susceptible to severe erosion (see figure 2.2.3). The form, function, and expense of detention basin side slopes are highly dependent upon the master plan type chosen (see "lot-bottom basins").

Often, in order to adequately dissipate incoming hydraulic energy, steep, rigid drop structures and coarse concrete energy dissipation structures are necessary at primary inlets (see section ""Hydraulic Structures.") However, portions of side-slopes that do not convey upstream drainage should not be built with steep slopes, as they do not need to dissipate hydraulic energy. In general, erosion is reduced and vegetation promoted when side slopes are less severe than a 4:1 ratio, avoiding costly erosion-protection measures (City of Chandler 2002). However, as slopes become less severe, more land area is needed to create the same basin capacity, increasing cost.

Side slopes are also the most common barrier to recreational access from adjacent residents, due to their severe slopes and unfriendly appearance. Multi-use pathways, terracing, fine-scale grading, and aesthetically-appealing vegetation improvements along side-slopes can transform these utilitarian spaces into recreational areas in which residents can interact with nature. These combined-use spaces can count as buffer-yard acreage as required by Pima County development code, and represent one of the best ways that developers can save money by reducing overall non-saleable acreage. (Pima County Development Services, Planning Division 1985).

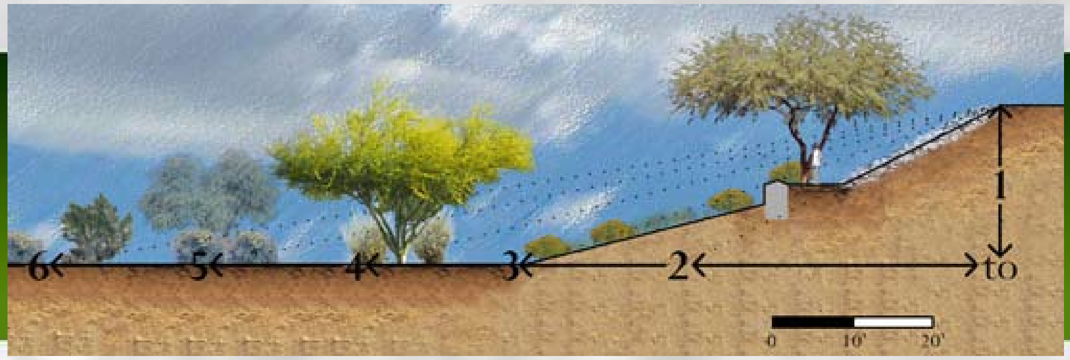

Figure 2.8.2: Basin side slopes of an overall ratio of 3 to 1 are difficult and expensive to vegetate and may require costly erosion control measures on steeper portions (rip-rap).

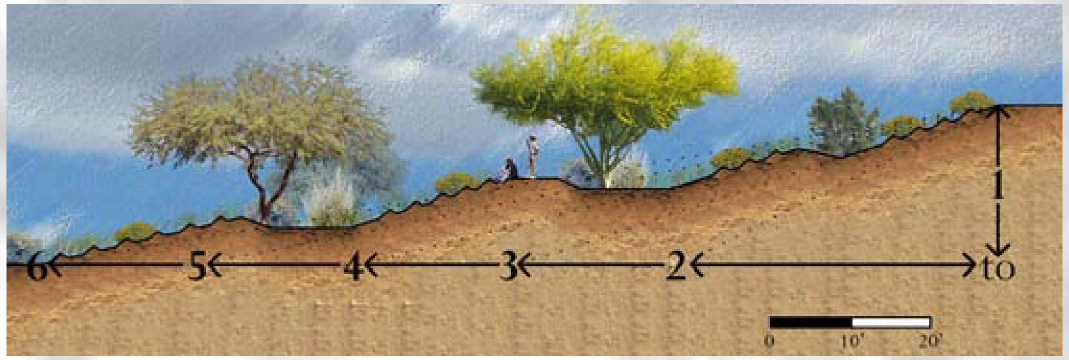

Figure 2.8.3: Basin side slopes of an overall ratio of 6 to 1 allow for relatively inexpensive micro-grading to support vegetation along them.

1. (Habitat) Connectivity

2. Access

Figure 2.8.4: Asphalt ramp, stairs trail: At the Bluff Lake Nature Center in Denver, Colorado, access down steep bluffs to an observational gazebo overlooking the natural riparian basin below can be accomplished either by descending a gently sloping asphalt ramp or a more steeply-graded trail of decomposed granite with wide steps retained by wooden beams.

Figure 2.8.5: Decomposed granite walking trails descend the side slopes of the Springs Preserve along switchbacks which are built overtop of a minor-contributing drainage composed of stretches of vegetated ditch, caliche block check dams, and culvert pipes (Natural Systems International, Luchessi, Galati, Inc.) .

3. Large-scale Drainage Features

Figure 2.8.6: On-contour berms: At the Arizona Cancer Center in Tucson, AZ, building and slope runoff is retained by mid-slope shallow water-harvesting basins contained by an on-contour berm. Within this environment, mesquite, creosote, and desert willow have been established. Exceeding the capacity of this basin, overflow is directed through a naturalized concrete ditch to the street-side storm drain. This feature, along with inorganic rock mulch, prevents erosion rills from forming (Ten Eyck).

Figure 2.8.7: Cross-cut slope ditch, unvegetated; mini-benching: At the recently-completed City of Chandler, AZ, Paseo Vista Park, rip-rapped ditches cross-cutting the steep side-slopes intercept small amounts of runoff from open slopes, which have temporarily been roughened with on-contour microberms to improve the success of hydroseeding. Larger flows from adjacent lands to the right of this picture are conveyed directly down the slope through rip-rapped channels perpendicular to the contour of the slope.

Key Questions for Design Decision

1. How much space is available in the development for detention? By overlapping bufferyard, recreational, and mitigated habitat acreage within the detention basin, can this area be increased to allow for shallower slopes?
2. Where are the primary and secondary inflow channels to be located along the side slope? Is it possible to redirect secondary channels or divert base flows from primary channels along the slope via a cross-cut channel to increase planting conditions?
3. How will the basin bottom be accessed by maintenance staff and visitors?
4. Can cross-cut channel berms also serve as a path?

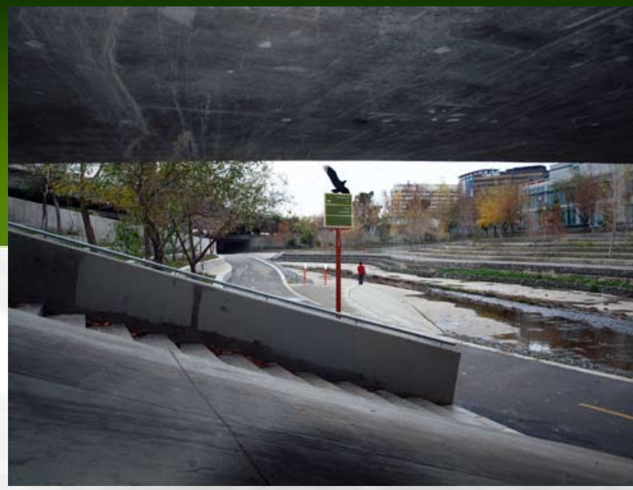

Figure 2.8.8: Retaining wall terraces: The Guadalupe River Park in San Jose, CA, designed by Hargreaves Associates, is an active channel that runs through the heart of the city's downtown. Base flows run through a naturalized central corridor. Peak event flows then inundate, a series of even-graded terraces contained by human-scaled retaining walls, which serve as easily-accessible, vegetated lunch-spots for local employees in base conditions.

Figure 2.8.9: By following the slope contour, large "bioswales" can intercept, roughen, slow the velocity, biologically treat, and infiltrate runoff from the upslope (State of Oregon DEQ 2003).

Permitting, Maintenance, & Monitoring

1. In order to slow the migration of soils from these side-slopes less steep than a 4:1 ratio, live plants, deadfall and litter from plants should be left in place. Prunings from recreational buffer zones or adjacent parcels can be placed on top of bare soil areas. Slopes steeper than a 4:1 ratio, though not recommended, should be stabilized by inorganic rip-rap.
2. In poorly-designed basins, rill erosion may create headcuts damaging or threatening to damage slope-top improvements or adjacent buildings. Deep rills should be re-graded and upstream drainage problem areas diverted to designed inlets.

4. Small-scale Drainage Features

Figure 2.8.10: On-contour microberms: At Del Paso Park in Sacramento, CA, a steeply-sloped area adjacent to a recreational vernal pool detention basin was graded to include human-scaled, back-graded berms parallel to the contour of the slope, and successfully vegetated with container plantings and volunteer growth (The HLA Group and Foothill Associates).

Figure 2.8.11: Pocket plantings/berms: Vernola Family Park in Riverside County, CA, uses small berms surrounding container plantings on side-slopes, preventing drip irrigation from escaping a "pocket" for the establishment of the tree's rooting system, but doing little to retard and infiltrate runoff flow into this rooting zone, making this an inferior method of side-slope grading..

Additional Resources

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<<http://www.sjparks.org/Trails/GRiver/index.asp>>

State of Oregon Department of Environmental Quality. "Biofilters (Bioswales, Vegetative Buffers, & Constructed Wetlands) For Storm Water Discharge and Pollution Removal." 2003.

HYDRAULIC STRUCTURES

HYDRAULIC STRUCTURES

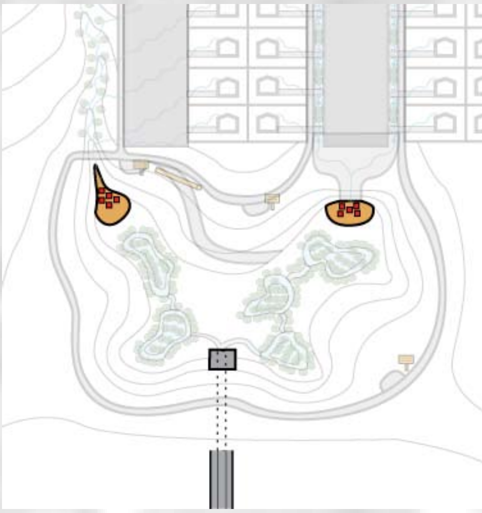

Figure 2.9.1: Hydraulic Structures

Hydraulic energy and sediment load of incoming stormwater flows have the potential to destroy the fine-scale grading and infiltration ability of microbasins. To mitigate these effects in an aesthetic manner, consider the following:

If the inlet channel continues upstream as a properly-functioning biological corridor, the spillway and drop structure should be designed in a way that encourages passage of terrestrial animals between the vegetated refugia of the channel above and the basin below (see figures 2.1.7, 2.8.31). Additionally, as the upstream "tail" of the basin is lengthened, and the inlet channel within it is roughened with in-channel and overbank vegetation and either retained in original sinuous form or designed so, the energy of the incoming floodwaters is absorbed and suspended sediment is given multiple opportunities to settle in low-energy areas of flow, requiring less of an engineered hardscape solution (Zeedyk and Clothier 2009).

Along with drop structures, energy dissipators are one of the best opportunities to design moments of drama and hydrologic interpretation, as points of change of hydraulic energy states that are on the visible edge of riparian basins.

As mentioned above, hydraulic energy and sediment load of stormwater flows entering a detention basin following a sudden drop in elevation is highly dependent on master plan configuration and upstream channel design. In general, the less the contributing watershed and inlet channel is engineered, the more hydraulic energy can be absorbed by it, and the less that needs to be addressed upon arriving at the basin.

As mentioned above, Pima County Policy TECH-009 requires a 20' access buffer surrounding the drop structure. Energy dissipators and sediment traps can be located within the first 10', with an additional 10' allowed for vehicle access. As discussed in the section below entitled "Microbasins," sedimentation leading to the formation of an impermeable surficial clay layer is a condition that greatly decreases the rate of soil infiltration and the ability of riparian vegetation to take root. A sediment trap prevents these fine sediments from reaching them, and is therefore an important component of a functional riparian detention basin.

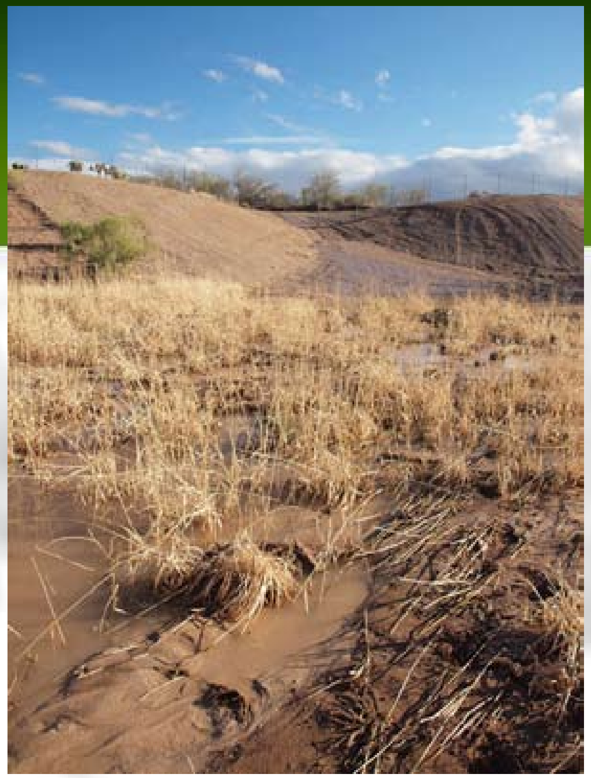

Figure 2.9.2 (left): The function of a sediment trap can be improved by the growth of non-woody annual vegetation that can assist in the process of aggradation, is nearly impossible to prevent or control, and poses no obstruction to vehicular maintenance, as seen here at the Kolb Road Basin, in Pima County, AZ. This exception to TECH-009 does not apply to woody vegetation, which can obstruct access.

Figure 2.9.3 (top): In a community setting, weedy plant growth can be controlled by "destructive" active use, as seen here in the form of a childrens' BMX play-space at the Anthem Hills Park, in Henderson, NV.

1. Sediment Traps

Figure 2.9.4: At the Oro Valley Marketplace in Oro Valley, AZ, incoming floodwaters from an arterial street above are dissipated of energy through a series of blocks, a rip-rap lined flow bifurcator, and a slight plunge pool in which sediment is trapped. In the flow energy shadow between the gully, xeroriparian trees have been planted.

Figure 2.9.5: This view of the sediment trap of the Erie Lakes Detention Basin, also depicted at left, demonstrates how moderate amounts of grass growing within the pooled water of the concrete catch-basin can help roughen flow, catch incoming sediments, biofilter the water, and mitigate the industrial nature of the structure, within easy access of a multi-use path. The water quality treatment pond below provides as a naturalistic view from the neighboring RV park (Belt Collins West).

2. Inflow Channel Energy Dissipators

Figure 2.9.6: Channel bend, formalized: The hydraulic energy of inflows along this portion of Westerly Creek at Lowry Parks is absorbed by concrete walls along a severe bend of the creek. As shown, these walls slope down along with the direction of flow, allowing recreational access and appreciation of emergent wetland vegetation, which is planted within low-energy "shadows" of the ends of the wall sections (Wenk Associates).

Figure 2.9.7: Channel bend, naturalistic: At the Rillito River/Swan Wetlands Restoration Project in Tucson, AZ, hydraulic energy of a tributary inflow channel is dissipated at severe bends of flow by stretches of soil-cemented bank terraces. Note that this terrace continues upstream, losing the soil cement, and adding riparian planting areas (RECON Environmental).

Key Questions for Design Decision

1. What is the flow velocity within primary and secondary inflow channels? Can it be slowed within the inflow channel through natural cutbanks or designed energy dissipators?
2. Are there designed planting areas within the immediate vicinity of the arrival of inflows that can be damage by their velocity? If so, as flows arrive at these points, can they be slowed through drop structures and/or energy dissipators that enhance the naturalistic or formal design of the basin and slope-top improvements?
3. Is incoming water laden with sediment? Can energy dissipators encourage settlement at downstream sediment traps?

Figure 2.9.8: Along daylighted Westerly Creek in the Stapleton neighborhood of Denver, CO, low-flows draining from an adjacent parcel are diverted into a water-quality treatment pond, while large-event flows bypass directly into the creek (EDAW).

Figure 2.9.9: Storm surges arriving at Anthem Hills Park in Henderson, NV, a combined-use active recreational detention basin, are split and slowed by a single terraced rise, at right, mirroring the wide stair-step form of the rest of the drop structure, at left, which doubles as stairs to an open greenway channel internal to the neighborhood located upstream.

3. Flow Diverters

4. Energy Dissipation Structures

Figure 2.9.10: Below pipe: As large amounts of runoff flow in from an upstream housing development along Shop Creek, in Denver, CO, through a road box culvert, cubic blocks of concrete capture the eye and roughen the pipe flows arriving at a series of water quality treatment wetlands filled with cattails and surrounded by cottonwood and riparian scrub (Wenk Associates).

Figure 2.9.11: Below open channel: Along Goldsmith Gulch, at George Wallace Park, this formal drop and energy dissipation structure absorbs significant hydraulic energy among large colored-concrete blocks that serve as a playful amphitheater of seating within an inspirational, sculpturally abstract environment. Base flows spill out of a rectangular concrete channel, creating an elegant falls (Wenk Associates).

Permitting, Maintenance, & Monitoring

1. Woody vegetation in basins above 1/5 acre in size or those in which the distance between inlet and outlet is 100' or greater is prohibited per TECH 009 policy (see figure X.X)
2. Though the Sonoran desert biome is vegetated mostly of small-statured plants, coarse woody debris and trash may accumulate in energy dissipation structures with narrow interstitial space. These should be removed periodically; organic matter can be placed within interior habitat areas in the basins below, provided that the process of moving them there does not disturb them.

Figure 2.9.12: Further up Goldsmith Gulch, this combination drop/energy dissipation structure contains rough-hewn boulders set in an invisible concrete base, creating a naturalistic cascade along the riparian stream (Wenk Associates, "GoldsmithGulch.DropStructure." 2009).

Additional Resources

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Haan, C.T. B.J. Barfield, an J.C. Hayes. Design Hydrology and Sedimentology for Small Catchments. Academic Press, Inc., San Diego, 1994.

Pima County Department of Transportation and Flood Control District, and City of Tucson. Stormwater Detention/Retention Manual. Pima County Department of Transportation and Flood Control District, Tucson, AZ, 1987.

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INTERNAL CHANNELS, OUTLETS

INTERNAL CHANNELS, OUTLETS

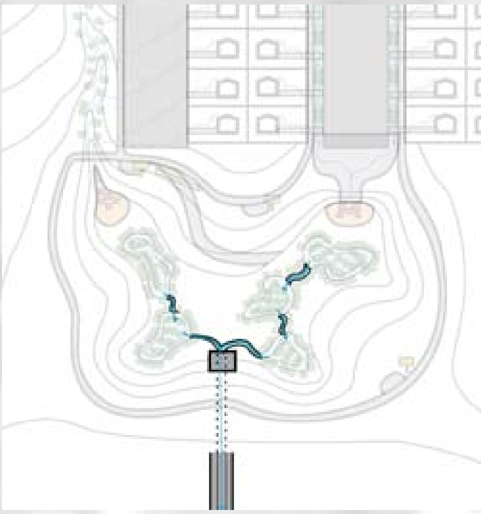


Figure 2.10.1: Internal channels, outlets

Channels internal to a detention basin either convey water between microbasins, or away from habitat areas that could be damaged by the hydraulic energy of high flows. Characteristic types are:

Channels within detention basins are necessary design components only when the master plan is of a type that requires them. Generally, small street-side basins only require channels between them, and design should follow open-channel or pipe recommendations outlined in the Pima County sections 3.1.6, Inlet Standards. As discussed above, vegetation in constructed conveyance channels is prohibited by TECH-009 since these channels are designed with the assumption of smooth sides.

Often times a master-plan requires the divergence of base or low-flows from storm surge or high-flows. High flow channels within detention basins, in essence, are conveyance channels whose disrupted function and subsequent flooding may imperil adjacent parcels. In addition, high velocity flows within these channels can rip out any established vegetation within them. As such, mitigated riparian vegetation should not be planted within these channels, either.

Low-flow channels within detention basins, on the other hand, while important for distributing incoming floodwaters between vegetated micro-basins, do not carry an inherent risk to adjacent parcels outside of the floodplain, and therefore may contain vegetation. While the amount of flow passing between off-line, low-flow microbasins may be slight, the passage of water between them can cause erosion. Spillways between basins should be constructed from the top of a higher microbasin to the bottom of the next basin in the series. These may need to be constructed and lined with rock to manage prevent erosion headcutting from sacrificing the storage capacity of the higher microbasin (City of Tucson 2005).

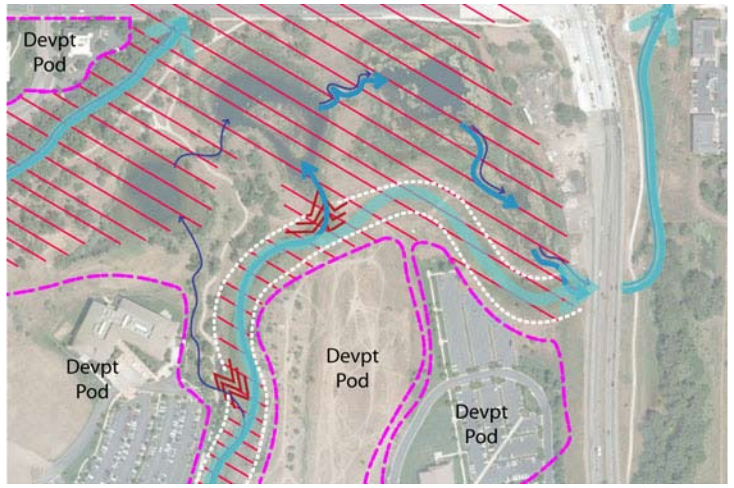
Figure 2.10.2: At the Las Vegas Springs Preserve in Las Vegas, NV, urban drool and low-flows from small events are filtered and diverted into a series of permanent and ephemeral pools.

1. Separation of High and Low Flows

Figure 2.10.3: The grading design (Luchessi Galati, Inc./Natural Systems, International,) ensures that the delicately-designed riparian habitat in the microbasins and its complementary passive recreational features will not be destroyed by high flows from large events by diverting these flows near the entry of the basin into a high-flow channel embanked by a large berm (in white).

Figure 2.10.4: An intermediate flow (3-8 cfs) inlet diverts flows from small storm events into the second pond of the system, creating a pastoral scene (diverter at right).

1. Separation of High and Low Flows, cont.



Figures 2.10.5: Incoming flows at the University of Colorado-Boulder Research Park wetland detention basin are subdivided into base (0-3 cfs, in dark blue) intermediate (3-8 cfs, in true blue) and high flows (8+ cfs, in light blue) with the use of flow diverters (in maroon) and large berms (in white.) 100-year storm event flows back up at the outlet and inundate 23 acres (in red hatching,) avoiding developments (in purple).

Key Questions for Design Decision

1. If the master-plan of the lot-bottom basin necessitates separation of flow, can a high-flow bypass channel be contained by a high earthen berm?
2. Is there a series of microbasins or water quality treatment ponds? How much drop in grade is there between them? In order to prevent channels between them from headcutting into the relatively upper pooling area, how much horizontal distance is needed to create a slope of less than 2%?
3. Are there trails in the basin? How can these cross channels without damaging them?
4. How can the outlet be positioned so that it is accessible, free of vegetation, and out of sight?

Figure 2.10.6 (above): When channel water is of poor quality or supports habitat of high quality, barriers to entry may be appropriate (Kino Ecological Research Project, Tucson, AZ).

Figure 2.10.7 (right): Pedestrian bridge over hydroriparian low-flow channel, Las Vegas Springs Preserve (Natural Systems International).

2. Low-flow Channel

3. Outlets

Figure 2.10.8: At Regency Park in North Natomas, Sacramento, CA, the outlet of a water-quality treatment pond and detention basin is hidden from view by concrete walls and kept free of vegetation with deep water.

Figure 2.10.9: Outlets can be disguised from view by hedge screening if they do not contribute to the aesthetic appeal of the system (Ladera Ranch, CA).

Permitting, Maintenance, & Monitoring

1. Repair channels between pooling areas by regrading or installing rigid hardscape if they headcut into upper pooling areas, causing them to fully drain.
2. Improve the strength of berms/levees of high-flow bypass channels with rip-rap or soil cement where their structural strength appears compromised.
3. Grub out vegetation and remove coarse debris within a 20 foot radius of large basins (>1/5 acre) and proportionally smaller radius for smaller basins to allow for proper drainage.
4. Re-grout portions of concrete-lined channels that appear to be breaking up.

4. Recirculating Stream

Figure 2.10.10: Where water resources are available, the incorporation of an above-ground stream can bring drama and a full array of riparian biotic communities to the side-slopes of a site. These designed watercourses should drain only a minimal watershed, as their built features and emergent streambank growth can be destroyed by large events. At the Riparian Preserve at Water Ranch in Gilbert, AZ, this channel lined with cobbles set in concrete connects a desert overlook with a fishing pond below (C.F. Shuler, Inc.).

Additional Resources

City of Tucson. Department of Transportation. Stormwater Management Section, Water Harvesting Guidance Manual. Ann Audrey Phillips. Ordinance number 10210. 2005.

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University of Colorado-Boulder. UC-Boulder Research Park Master Site Development Plan and Flood Mitigation Plan. prepared by Downing, Thorpe and James. << http://fm.colorado.edu/planning/projects/ResearchPark/documents/MasterSiteDevelopmentPlan.pdf>> 1987.

MICRO-BASINS

MICRO-BASINS

Figure 2.11.1: Microbasins (in blue)

The goal of microbasin design is to create multiple microclimates for diverse riparian growth without creating long-term pooling. Fine-scale grading and soil profiles should therefore be guided by the following site components:

Microbasins are nested, shallow basins (often referred to as water harvesting basins,) within a larger master detention basin, that drain down through soil infiltration, but not out through a controlled-flow outlet, in order to increase the time of soil saturation optimal for riparian growth. In order to ensure drainage from these pooling areas within a 24-72 hour period, the minimum time needed for the life cycle of a mosquito, two primary factors, depth and sub-surface porosity, can be altered. Depth between the surface of the microbasin bottom and the elevation of the surrounding grade or basin berm should generally not exceed approximately 6”. However, when the soil profile below the surface of the basin has been improved by manual soil-loosening/aeration/scarification, the addition of French drains or dry wells, and/or deep-mulching, the soil infiltration rate is increased, allowing for rapid drainage from a basin depth greater than 6”. Such cases are allowable on a case-by-case basis, subject to District review and approval.

As discussed above, clay sealing through repeated deposition events is a common problem in basins that causes water to pool without infiltration for long periods of time. Though sediment traps can help prevent sediments from reaching microbasins, some fine sediment will make its way to the microbasins over time, particularly during large inundation events in which the master detention basin is filled. Basin-bottom mulching primarily improves the condition of the growing areas when sediment does reach them, providing a decomposing, highly variable three-dimensional matrix in which they can deposit. Organic mulching also lowers the temperature and raises the carbon and other nutrient content within the soil, mirroring the organic catchment of natural drainages and making for a preferable growing medium for riparian plants. Once plants establish, their root structure further perforates and aerates the surficial crust, so that infiltration will increase over time as riparian communities establish.

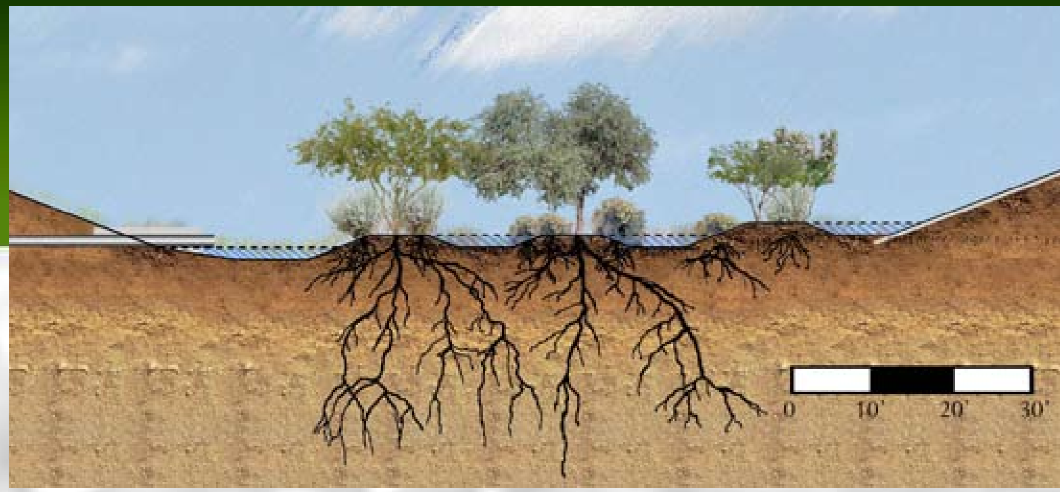

Figure 2.11.2: In wrap-around terracing, low-flow channel, or subdivided terracing, each microbasin should be offset 6 or more inches below of or at grade with upstream microbasins in order to ensure timely drainage.

1. Relative Depths

Mitigated micro-basin areas, since they restore native habitat, can be counted as landscape bufferyard per Pima County code (Pima County Development Services 1985). They can also be counted as water-harvesting catchment areas to gain points towards certification as a Pima County Regional Residential Green Building (Pima County Green Building Program 2009).

Figure 2.11.3: Micropooling areas at the Kolb Road Detention Basin in southeast Tucson receive fine sediments and saturate the lower trunks of the vegetation growing within them, precluding woody growth. Woody vegetation thrives in adjacent areas that are slightly elevated and drain relatively quickly, allowing the shoots to trunks to stay dry and the roots to access moister soils.

2. Planting Islands

Figure 2.11.4: In the middle of an open channel at Oro Valley Marketplace in the Town of Oro Valley, AZ, slightly elevated planting islands serve as point bars within the wash where instream vegetation is allowed to grow, buffered from hydraulic energy by the upstream earth of the island.

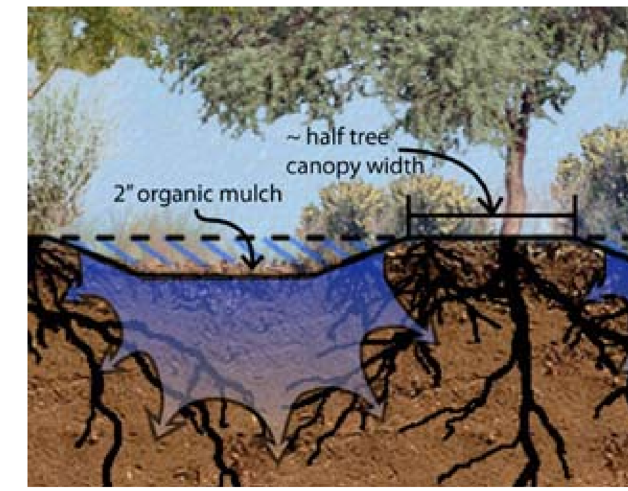

Figure 2.11.5: Slightly elevated planting islands within microbasins should be wide enough to accommodate a full-statured woody tree and understory shrubs surrounding it, but narrow enough to allow for these root systems to reach adjacent, slightly deeper pooling areas. In order to prevent trunk rot, the base of the tree's trunk is out of the pooling area, which is mulched to prevent clay sealing.

Key Questions for Design Decision

1. How wide is the canopy of my target tree plantings?
2. How wide is my detention basin?
3. In what manner of master plan will the low-flows be subdivided into microbasins?
4. How many planting islands across will my microbasins be?
5. Is a sediment trap or other deposition area located upstream? Will the microbasins receive much sediment?
6. What is porosity of the site soil? Will it infiltrate and percolate too fast to support riparian vegetation? to slow to prevent mosquito breeding? If so, can soil and subsurface treatments generate appropriate soil infiltration conditions within budget?

3. Soil and Subsurface Treatments

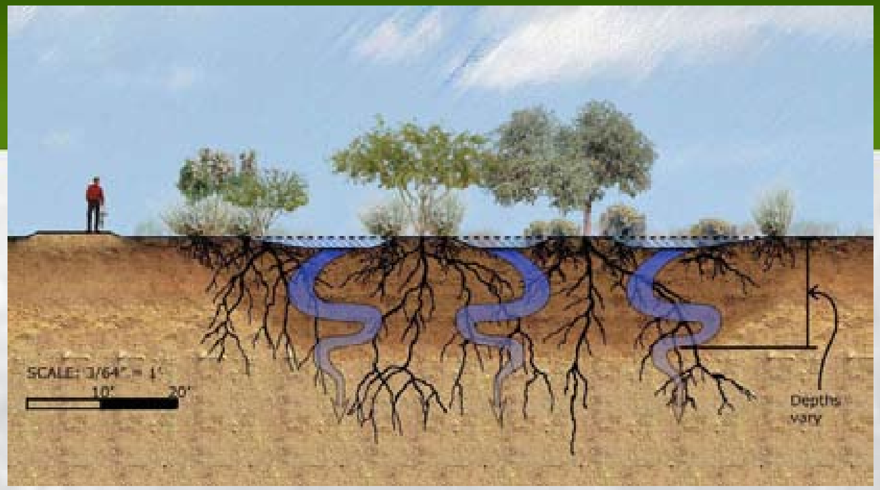

Figure 2.11.6: Following grubbing of a riparian area to be disturbed, topsoils to a depth of 4 to 6 inches can be salvaged, temporarily stockpiled, and used to create an upper organic soil horizon in microbasins, giving the basin a "kick-start" of fertility, native seeds, and beneficial soil organisms.

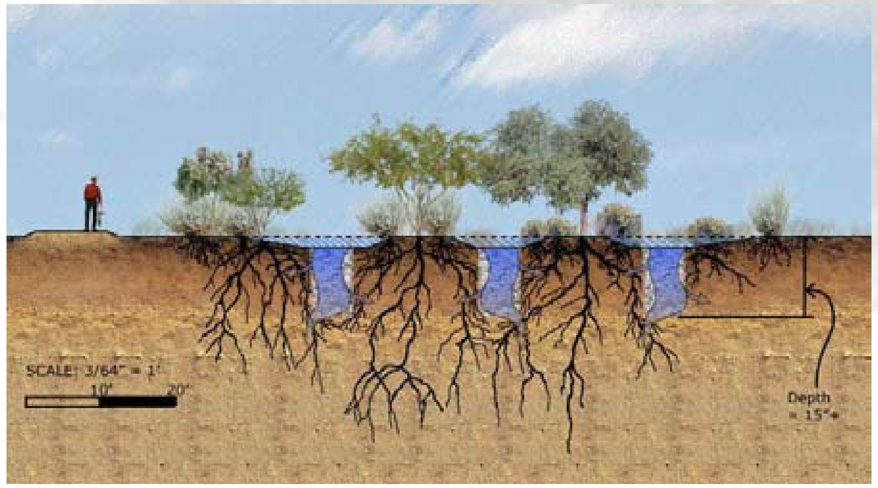

Figure 2.11.7: French drains increase the storage capacity of the proximate soil profile by using coarse-grained, rough-edged, evenly-sized riprap in order to create maximum pore space. Infiltration rate and total capacity of microbasins is improved with this method, causing adjacent soils to be saturated for longer periods of time, benefiting deep-rooted woody growth.

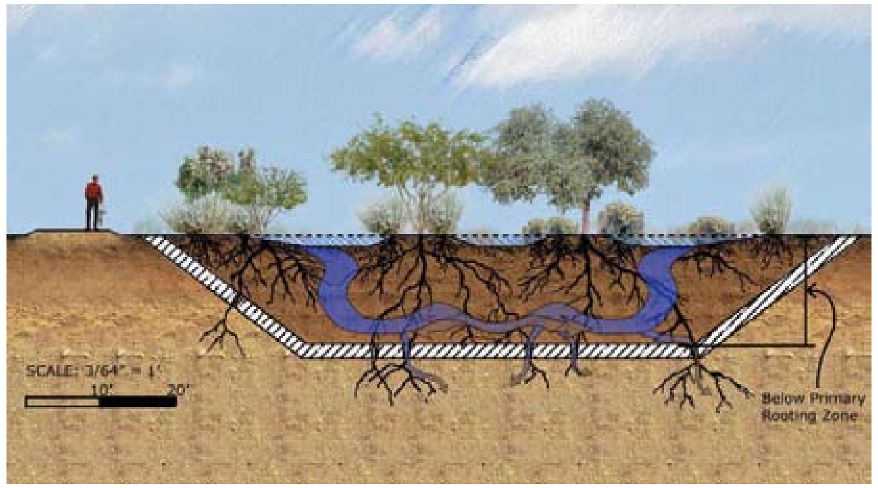

Figure 2.11.8: Impermeable liners located just below the targeted rooting zone can increase the time of soil saturation when site soil conditions are too permeable, without creating problem pooling above the surface. These can be made from bentonite clay and geomembrane plastics, and should be designed to allow for inevitable root penetration. A disadvantage of liners is that roots are contained for the most part within the lined volume, and can be susceptible to root rot.

Permitting, Maintenance, & Monitoring

1. "Bust the crust:" If microbasin bottoms become sealed with clay and silt, increase the pore space of the top soil by blading, using hand tools, and/or placing prunings and brush on top in order to promote proper soil infiltration.
2. Pooling areas will contain smaller interior strand species, and are necessary for the success of trees on adjacent planting islands. Both areas should be counted as riparian habitat acreage.
3. Remove invasive weeds (see figure 2.12.6).
4. For the most part, microbasins should be left to go wild. These are the areas of interior habitat, and the more structural diversity, the better!

Figure 2.11.9: Organic mulch placed on top of site soil to a depth of approximately four inches, such as seen at this demonstration site on the NE corner of Country Club and Broadway in Tucson, will reduce evaporation and extend the period of soil saturation. As it decomposes, soil fertility will be enhanced until such time that established vegetation contributes leaf litter and deadfall.

Additional Resources

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PLANTING RECOMMENDATIONS

PLANTING RECOMMENDATIONS

Figure 2.12.1: Plantings

Mitigated riparian plantings, once established, must sustain without supplemental irrigation. The following species lists and planting techniques should guide the planting design of these habitats:

As discussed in the section above entitled "Riparian Ecology," a process of regional, local, and site analysis of ecophysiological conditions should be undertaken in order to identify one or more target biotic communities to be designed within the detention basin, with the recognition that hydrologic processes and dynamic successional growth can alter the relative percentages of these related communities over time. In most cases, designed biotic community type should be the same as that which has been disturbed.

The plant list of a site should include canopy trees, understory shrubs, and annual grasses and forbs, and should be further subdivided into planting zones. "Deep rooted" nursery stock are preferred for canopy tree container plants. Using this technique, desert leguminous tree seeds/seedlings are grown in approximately 2' long, narrow, soil-filled tubes, perforated on the bottom to allow for drainage and aeration. The benefit of this type in comparison to traditional, "bucket" plantings is that the root growth of the developing plant is focused upon the extension of a deep tap root, mirroring the manner in which these plants would grow in field conditions, improving the chances of survival once it is planted at a habitat mitigation site with minimal establishment irrigation (localized drip, subsurface mat irrigation, or other approved method near the rootball of container plantings for the first few growing seasons (1-2 years)).

The "shotgun" approach to plant seeding, where a seed mix with a wide variety of species affiliated with the target biotic community are broadcast over areas in which container plants have not been dug, and some species successfully establish while others don't, takes much of the guess work out of site analysis and plant selection. Following seeding, broadcast sprinkler irrigation should be avoided in order to prevent the rapid growth of weedy plants that can "crowd out" the growth of species within the seed mix that are appropriate for the site conditions, by completely exhausting available solar, soil, and water resources, (and the seeds' limited viability).

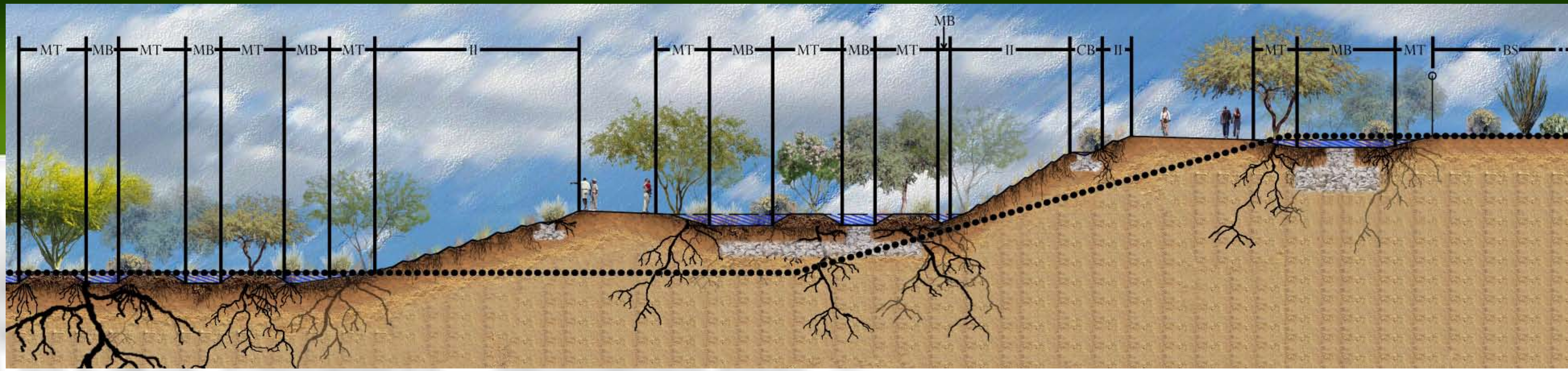

Figure 2.12.2: Planting zone codes: The zones of a detention basin are characterized by frequency of inundation, and can, in this way, be compared to a natural floodplain analog. Plant species can withstand varying periods of inundation, and have been categorized by the following zonation:

1. Planting Zones

- Microbasin Bottom (MB): analogous to naturally-occurring depressions, these areas are subject to long periods of inundation and fine sediment deposits; generally, species in this group are non-woody and annual.
- Microbasin Terrace (MT) and Channel Bank (CB): analogous to the margins of depression and streams, these areas are inundated only in times of moderate to large storm events. Plant species within them can withstand temporary inundation, and depend up increased water availability in the soils of adjacent zones for root growth.
- Infrequent Inundation (II): analogous to upland areas that experience rare inundation (sheet flow in flats, furthest extent of 100-year floodplains, etc.), the species within this zone must be able to withstand rare inundation from the master detention basin in large events, and are either non-woody, succulent, or woody. Sonoran desert species common to dry hillsides are excluded from this group.
- Back of Slope (BS): analagous to steep upland areas that are never inundated by either pooling water, channel flow, or sheet flow, the species of this zone are not riparian, and include xeric cacti, shrubs, trees, and annuals.

2. Tall Pots

Figure 2.12.3 (top left,) 2.12.4 (top center): Long pots, such as these provided by Stuewe and Sons, allow for desert leguminous tree seedlings to grow to saplings much as they do in natural conditions, extending a deep tap root to reach available groundwater, as demonstrated by the three-month seedling at right. Traditional bucket pots, as deep as they are across, promote shallow roots that can become bound too tightly for optimal field planting.

3. Hydroseeding

Figure 2.12.5 (top right): Within water harvesting basins located on a riparian terrace of the Rillito River/Swan Wetlands Ecosystem Restoration Project, hydroseeded saltbush (*Atriplex*,) following broadcast sprinkler irrigation, has established thick mono-typic stands, though, overall, species evenness is low.

Key Questions for Design Decision

1. Which zones of the site will experience high-velocity flow, preventing plant growth?
2. In which areas must maintenance vehicles be able to pass?
3. Which zones of the site will experience frequent inundation? infrequent inundation? no inundation?
4. Based upon site soil conditions, subsurface improvements, and volume of inflow, how long will the rooting zone remain saturated over the course of the year? What is the target plant community based upon these conditions?
5. Are there invasive plant species in the contributing watershed?

In the unique soil and microclimate conditions of riparian areas of the southwestern U.S., a diverse flora much different than adjacent xeric habitats can be found. Perhaps the most noticeable, by biomass and canopy cover, is the *Leguminoseae*, or leguminous trees, which include the mesquites, acacias, palo verdes, and ironwood. These trees and shrubs serve as the botanical skeleton of these ecosystems, highly important both for their provision of food and shelter for animals, and coarse woody debris for proper hydrologic stream or wash function. Other species, including those of the common families *Asteraceae* (sunflower,) Cyperaceae (sedge,) and Poaceae (grass) families, annually regrow to provide lush forage for insects, birds, and grazing/browsing animals (Baker et al. 2004, 132).

When considering plant species to include in a riparian mitigation area design, it is important to consider not only what plants are native to nearby streams and washes, but also which of these species are suited to survive in the unique microclimate afforded by a detention basin. Therefore, in order to determine a list of species appropriate for container planting and seeding, five primary characteristics were analyzed: commercial availability, transplant hardiness, ecosystem function (as determined by habitat function, relative abundance, and ability to self-replicate), nativity, and ability to withstand both total inundation and long periods of drought.

Multiple sources of information were considered to develop a list of candidate species, and analyze them in respect to these characteristics. First and foremost, plants common to riparian habitat within Pima County, both listed in the Pima County Riparian Ordinance, and from field observations of the preparer of this research, were compiled. This list, in turn, was compared to plants encountered in case study review (online research, site visits, and interviews with designers and regulators) of riparian habitat projects throughout the southwestern U.S., including, most importantly, those within Pima County. Additionally, frequent consultation with University of Arizona Professor of Landscape Architecture Margaret Livingston, Novak Environmental, Inc. Landscape Architect Karen Cesare, and Pima County Regional Flood Control District hydrologists Marisa Rice and Carla Danforth, and less frequent consultation with University of Arizona Professor of Soil, Water, and Environmental Sciences Ed Glenn, University of Arizona Campus Planner Grant McCormick, Bureau of Land Management Arizona State Botanist John Anderson, private consultant Anne Audrey, Civil Engineer David Confer, The Nature Conservancy Tucson Office, classmates in the University of Arizona Department of Landscape Architecture, and colleagues within the Arizona Riparian Council helped inform and refine this list.

This list was then cross-checked with descriptions of the plant species habitats found in plant guides (see: Additional Resources), the dichotomous key to Arizona (Kearney and Peebles' *Arizona Flora*), and various online sources (see: Additional Resources); and availability at three major sources of seed and container plants (Mountain States Nursery, Desert Survivors, and Native Seed Search). Finally, in order to determine the specific Google-Map referenced location and location description of known herbarium specimens for particular species, SEINET (Southwest Environmental Information Network), an online resource in which most of the major herbarium collections for this region are electronically compiled, was queried.

This list was further categorized by planting zone (see figure 2.12.2). The most important condition of detention basins that must be considered in this respect is the period of inundation. Unlike most naturally-occuring riparian areas, detention basins, by nature, detain water and infiltrate soil for long periods of time. Many species found in or directly adjacent to riparian areas are susceptible to rotting diseases, including Texas root rot, that can take hold in poorly drained soils. Therefore, in microbasin bottoms (MB,) too much water can prevent the successful establishment of certain species.

In contrast, other microclimates of a detention basin, including the infrequent inundation areas (II) on the interior of the basin side slopes, and the never-inundated backs of these slopes (BS,) receive so little annual rainfall and soil infiltration, that they can not support typically riparian species. Instead, they must be planted with more xeric species, that, within the basin (II,) must be able to withstand temporary inundation.

Therefore, the following list of suggested container plants native to xeroriparian and mesoriparian areas of the Lower Sonoran and Upper Sonoran zones of Pima County have been categorized by their ability to survive in the five basic microclimates, which range from poorly-drained soils to highly xeric soils. In order to determine which native species can withstand temporary periods of inundation, we must look to existing detention basins, and natural depressions or sinks. Some native riparian plants on this list have been included, though their ability to withstand periods of temporary inundation is unknown. These microclimates for which success is unknown for a particular riparian species have been further marked by an asterisk (*). Those species more typical of a higher elevation life zone not typical to metropolitan Pima County have been further marked with a cross (†).

When selecting plants from this list, it is important to note the elevation and solar aspect of the site and only select those species that can tolerate site-specific heat, frost, and sun conditions. In general, the selection should include a moderate number of species from the larger size/growth classes (trees, shrubs, cacti and succulents, and some species of perennial forbs/sub-shrubs and grasses.) Once container-planted and irrigated to establishment, these can form a skeleton of structural diversity across the transition zone between the most lush riparian zones (microbasin bottoms, MB) and the most arid upland zone (back of slope, BS). While species on this list are more appropriate for planting by container, they may also be grown from a broadcast seed mix on-site, and should be included as such when deemed appropriate.

Additionally, this list has been selected based upon the transplant hardiness, commercial availability, and likelihood of on-site self-replication of the species. Additional native species approved for use within riparian mitigation areas that do not meet these criteria are listed in Pima County publication 'Regulated Riparian Habitat Mitigation Standards and Implementation Guidelines,' section B-2: Approved Plant List.

Permitting, Maintenance, & Monitoring

1. Remove invasive non-natives against which there is a fighting chance. Focus on buffelgrass, fountain grass, arundo, and tamarisk through manual (hand-tools, skid-steer loader,) and herbicidal removal (Basal bark, foliar, and/or cut stump application.) The rhizomal nature of Bermuda grass and Johnson grass makes them nearly impossible to remove in a basin setting.
2. While deep-rooted trees can cause failure in constructed soils through root growth, they reduce slope erosion through the retention of soil by root networks and coarse litter. On excavated basin side-slopes, let them grow and leave the downfall!

4. Container Plant List

Trees:

- *Acacia constricta*: whitethorn acacia (MT, CB)
- *Acacia greggii*: catclaw acacia (MT, CB, II)
- *Celtis laevigata (*aka *Celtis reticulata)*: netleaf/canyon hackberry (MT, CB)
- *Chilopsis linearis*: desert willow (MT, CB)
- *Olneya tesota*: ironwood (MT, CB)
- *Prosopis velutina*: velvet mesquite (MT, CB, II, BS)
- *Parkinsonia florida*: blue palo verde (MT, CB)
- *Parkinsonia microphylla*: foothills palo verde (II, BS)
- *Sambucus nigra ssp. Cerulea*: Mexican elderberry (MT*, only lusher sites)
- *Sapindus saponaria var. drummondii*: western soapberry (MT*, CB*, only lusher sites)

Shrubs:

- *Aloysia wrightii*: beebush (CB*, II*)
- *Anisacanthus thurberi*: desert honeysuckle, chuparosa (MT, CB)
- *Asclepias subulata*: desert milkweed (MT, CB)
- *Atriplex canescens*: fourwing saltbush (MB, MT, CB, II)
- *Baccharis salicifolia*: seepwillow (MT, CB)
- *Barkleyanthus salicifolius* (*Senecio salignus*): senecio, willow ragwort (MB, MT, CB)
- *Calliandra eriophylla*: fairy duster (CB*, II*, BS)
- *Celtis ehrenbergiana/pallida*: desert hackberry (MT, CB, only lusher sites)
- *Condalia globosa*: bitter condalia (MT*, CB*)
- *Condalia warnockii*: Warnock condalia (MT*, CB*; only lusher sites)
- *Coursetia glandulosa*: baby-bonnets (MT*, CB*)
- *Dalea Pulchra*: dalea (II*, BS)
- *Dodonaea viscosa*: hopbush (CB*, II*, BS)
- *Ericameria laricifolia (Haplopappus laricifolius)*: turpentine bush (II*, BS)
- *Gossypium thurberi (Thurberia thespesioides)*: desert cotton (MT, CB, †)
- *Hyptis emoryi*: desert lavender (MT*, CB*, †)
- *Justicia candicans*: Red justicia (MT*, CB*, †)
- *Larrea tridentata*: creosote bush (II*, BS)
- *Lycium andersonii* var. *andersonii*: Anderson wolfberry, waterjacket (MT, CB)
- *Lycium fremontii*: Fremont wolfberry (MT, CB)
- *Mahonia haematocarpa* (*Berberis haematocarpa*): red barberry (MT*, CB*, †)
- *Parthenium incanum*: mariola (II*, BS)
- *Rhus microphylla*: littleleaf sumac (MT*, CB*, II*, BS; only lusher sites)
- *Rhus trilobata*: three-leafed sumac, skunkbush sumac (BS, only lusher sites)
- *Simmondsia chinensis*: jojoba (BS)
- *Tecoma stans*: yellow bells (MT*, CB*, †)
- *Trixis californica*: trixis (CB*, II*, BS)
- *Vauquelinia californica* ssp.*californica/sonorensis*: Arizona rosewood (MT*, CB*; generally a slope plant in higher elevations)
- *Ziziphus obtusifolia*: gray thorn (MT, CB)

Perennial forbs/sub-shrubs:

- *Ambrosia ambrosiodes*: canyon ragweed (MB, MT, CB)
- *Ambrosia deltoidea*: triangle-leaf bursage (II*, BS)
- *Baileya multiradiata*: desert marigold (II*, BS)
- *Epilobium canum* ssp. *latifolium* (*Zauschneria californica*): Hummingbird trumpet (MT*, CB*)
- *Zinnia acerosa (Zinnia pumila)*: desert zinnia (II*, BS)

Graminoids:

- *Bouteloua curtipendula*: sideoats grama (MB, MT, CB)
- *Muhlenbergia rigens*: deergrass (MT, CB, †)
- *Muhlenbergia rigens*: deergrass (MT, CB, †)
- *Sporobolus airoides*: alkali sacaton (MB)
- *Sporobolus wrightii*: big sacaton (MB)

Cacti and succulents:

- *Agave deserti* ssp. *simplex*: desert agave (II, BS)
- *Agave palmeri*: Palmer agave (II, BS)
- *Agave parryi*: Parry agave (II, BS)
- *Agave schottii*: shin dagger (BS)
- *Carnegia gigantea*: saguaro (BS)
- *Cylindropuntia arbuscula* (*Opuntia arbuscula*): Arizona pencil cholla (MT, CB, II, BS)
- *Cylindropuntia leptocaulis* (*Opuntia leptocaulis*): christmas cactus, desert christmas cholla (BS)
- *Cylindropuntia fulgida*: jumping cholla (BS)
- *Cylindropuntia versicolor*: staghorn cholla (BS)
- *Dasylirion wheeleri*: sotol, desert spoon (BS)
- *Echinocereus engelmannii*: Strawberry hedgehog (BS)
- *Escobaria vivipara*: beehive cactus (BS)
- *Ferocactus wislizeni* (*Echinocactus wislizeni*): fishhook barrel (BS)
- *Fouqueria splendens*: ocotillo (BS)
- *Jatropha cardiophylla*: limberbush (MT, CB, II, BS)
- *Nolina bigelovii*: Bigelow nolina (II*, BS)
- *Nolina microcarpa*: beargrass (BS)
- *Mammilaria grahamii*: fishhook pincushion (BS)
- *Opuntia engelmannii*: Englemann prickly pear (II*, BS)
- *Opuntia phaeacantha*: sprawling prickly pear (II*, BS)
- *Opuntia violaceae* var. *santa-rita*: santa rita prickly pear (II*, BS)
- *Yucca arizonica*: Arizona yucca (BS)
- *Yucca baccata*: banana yucca (BS)
- *Yucca elata*: soaptree yucca (BS)

5. Seed Mix List

A seed mix for a particular site should be selected based upon the chance of successful establishment of given species. Broadcast seeding a site, by planting zone, with a wide diversity of species (aka the "shotgun" approach) takes some of the guess work out of vegetating a site, as seeds will only germinate where the microclimate and soils are appropriate. Additionally, the perennial and annual growth resulting from seeding helps to stabilize the recently-disturbed soils of the site, and can kick-start the process of rebuilding healthy top-soil. Often, seeding a site can be a significantly cheaper method than container planting for establishment of tree, shrub, and some perennial forb/sub-shrub and grass biomass over the life of the project. Most annual wildflowers and graminoids should only be seeded and not container-planted, due to their short life span and small size.

The following list of suggested species native to Pima County riparian areas appropriate for a seed mix has been selected based upon the commercial availability, seeding success ratio, ecosystem function (as determined by habitat function, relative abundance, and ability to self-replicate), nativity, and ability to withstand both total inundation and long periods of drought. While many species on this list are commonly available from commercial sources, some are not at this time. For additional native species that do not meet these criteria, please refer to the Pima County publication 'Regulated Riparian Habitat Mitigation Standards and Implementation Guidelines,' section B-3: Approved Class H Seed Mix, and section B-4, Approved Xeroriparian Seed Mix.

Trees:

- *Acacia constricta*: whitethorn acacia (MT, CB)
- *Acacia greggii*: catclaw acacia (MT, CB, II)
- *Celtis laevigata (*aka *Celtis reticulata)*: netleaf/canyon hackberry (MT, CB)
- *Chilopsis linearis*: desert willow (MT, CB)
- *Olneya tesota*: ironwood (MT, CB)
- *Prosopis velutina*: velvet mesquite (MT, CB, II, BS)
- *Parkinsonia florida*: blue palo verde (MT, CB)
- *Parkinsonia microphylla*: foothills palo verde (II, BS)

Shrubs:

- *Anisacanthus thurberi*: desert honeysuckle, chuparosa (MT, CB)
- *Atriplex canescens*: fourwing saltbush (MB, MT, CB, II, BS)
- *Baccharis salicifolia*: seepwillow (MT, CB)
- *Calliandra eriophylla*: fairy duster (CB*, II*, BS)
- *Encelia farinosa*: brittlebush (UI, BS)
- *Ericameria laricifolia (Haplopappus laricifolius)*: turpentine bush (II*, BS)
- *Eriogonum fasciculatum* var. *Foliolosum/polifolium*: flattop buckwheat (II*, BS)
- *Gossypium thurberi (Thurberia thespesioides)*: desert cotton (MT, CB, †)
- *Hymenoclea monogyra*: burrobrush (MB, MT, CB)
- *Larrea tridentata*: creosote bush (II*, BS)

Vines:

- *Clematis drummondii*: old man's beard, Virgin's bower, Drummond's clematis (MT*, †)
- *Cucurbita digitata*: fingerleaf gourd (MB, MT)
- *Ipomoea hederifolia* (*Ipomoea coccinea* var. *hederifolia*): scarlet creeper (MB, †)
- *Maurandya antirrhiniflora*: snapdragon vine (MT, CB, †)

Perennial Forbs/Sub-shrubs:

- *Allionia incarnata*: trailing four-o-clock (MT*, CB*, II*, BS)
- *Ambrosia ambrosiodes*: canyon ragweed (MB, MT, CB)
- *Ambrosia deltoidea*: triangle-leaf bursage (II*, BS)
- *Baileya multiradiata*: desert marigold (II*, BS)
- *Brickellia coulteri*: brickelbush (MT, CB, II)
- *Bebbia juncea*: sweetbush/chuckwalla's delight (II, BS)
- *Cassia covesii*: desert senna (II, BS)
- *Dichelostemma capitatum (Dichelostemma pulchellum)*: blue dicks (MB, MT, CB)
- *Dicliptera resupinata*: Arizona foldwing (MT)
- *Dyssodia pentachaeta*: dogweed (MB, MT, CB, II)
- *Epilobium canum* ssp. *latifolium* (*Zauschneria californica*): Hummingbird trumpet (MT*, CB*)
- *Glandularia gooddingii*: Goodding's verbena (MB, MT, CB)
- *Machaeracantha tanacetifolia*: tansyleaf spine aster (MB, CB, II)
- *Penstemon parryi*: Parry's penstemon, beardtongue (MT*, CB*)
- *Penstemon pseudospectabilis*: desert penstemon, desert beard-tongue (MT*, CB*)
- *Psilostrophe tagetina*: Cooper's paperflower (II)
- *Rumex hymenosepalus*: canaigre dock (MB, MT, CB)
- *Senna hirsuta* var. *glaberima (Cassia leptocarpa* var. *glaberrima)*: (MB,* MT*, CB*)
- *Sphaeralcea ambigua* ssp. *ambigua*: desert globemallow (MT*, CB*, II*)
- *Xanthium strumarium*: rough cocklebur (MB, CB)
- *Zinnia acerosa (Zinnia pumila)*: desert zinnia (II*, BS)

Annual Wildflowers:

- *Bowlesia incana*: hoary bowlesia (MT*, CB*)
- *Datura wrightii*: sacred datura (MB, MT, CB)
- *Eriastrum diffusum*: miniature woolystar (II*, BS)
- *Eschscholzia californica ssp. Mexicana*: Mexican gold poppy, California poppy (MT*, CB* II, BS)
- *Kallstroemia grandiflora*: Arizona poppy (MT*, II, BS)
- *Lesquerella gordonii* var. *gordonii*: Gordon's bladderpod (MT*, CB*, II, BS)
- *Lupinus sparsiflorus* ssp. *mohavensis*: Coulter's lupine (II*, BS)
- *Nama demissum* var. *demissum*: purplemat (CB*, II*, BS)
- *Phacelia distans*: blue-eyed scorpion weed, distant phacelia (CB*, II*, BS)
- *Platystemon californicus*: creamcups (MT, CB, †)
- *Polansia dodecandra:* western clammyweed (MB, MT, CB)
- *Salvia columbariae* var. *columbariage*: chia (MB, CB, II, BS)

Graminoids:

- *Aristida ternipes*: spidergrass (II, BS)
- *Bothriochloa barbinodis*: cane beardgrass (MB, MT, CB, II, BS)
- *Bouteloua aristidoides*: needle grama (MB, MT, CB, II, BS)
- *Bouteloua curtipendula*: sideoats grama (MB, MT, CB)
- *Bouteloua rothrockii*: rothrock grama (II, BS)
- *Cyperus odoratus*: fragrant flatsedge (MB)
- *Dasyochloa pulchella (Erioneuronpulchellum, Tridens pulchellus)*: fluffgrass, low woolly grass (MT, II, BS)
- *Distichlis stricta*: desert salt grass (MB)
- *Hilaria belangeri* var. *belangeri* (*Anthephora belangeri*): curly mesquite (MT, CB, II, BS)
- *Hilaria mutica*: tobosa grass (MB, MT, CB, II, BS)
- *Hilaria rigida*: big galleta (MB, MT, CB)
- *Leptochloa dubia*: green sprangletop (MT, CB, II, BS)
- *Muhlenbergia emersleyi*: bullgrass (MT, CB, II, †)
- *Muhlenbergia porteri*: bush muhly (MT, CB)
- *Muhlenbergia rigens*: deergrass (MT, CB, †)
- *Panicum obtusum*: vine mesquite (MB, MT, †)
- *Paspalum distichum*: knotgrass (MB, MT, CB)
- *Setaria macrostachya*: plains bristlegrass (MB, MT, CB)
- *Sporobolus airoides*: alkali sacaton (MB)
- *Sporobolus cryptandrus*: sand dropseed (MB)
- *Sporobolus contractus*: spike dropseed (II, BS)
- *Sporobolus wrightii*: big sacaton (MB)
- *Vulpia octoflora* (*Festuca octoflora*): sixweeks fuscue (MB, MT, CB)

6. Invasive Species

As in a natural system, seeds in developed watersheds travel by wind, animal carrier, or, mostly, by water flow. Therefore, it is essential that the contributing watershed of basins which are designed for mitigated riparian habitat, including adjacent parcels, must not be planted with invasive non-native plants.

While many invasive species are present throughout Pima County, a select few are hardy enough to establish significant stands within riparian basins. These are:

- Buffelgrass (*Pennisetum ciliare*)
- Fountain grass (*Pennisetum setaceum*)
- Giant Cane (*Arundo donax*)
- Johnson Grass (*Sorghum halapense*)
- Salt Cedar (*Tamarix ramosissima*)
- Bermuda grass (*Cynodon dactylon)*

Figure 2.12.6: Four of the most common and invasive exotic plant species in Pima County that should be controlled within riparian habitat areas include (from right, clockwise,) arundo, salt cedar/tamarisk, and fountain grass, and buffelgrass. Arundo outcompetes native emergent plants, while the latter three can grow into profuse monotypic stands with limited water resources.

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