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Stormwater Strategies for Arid and Semi-Arid Watersheds

Water supply and flood control have traditionally dominated watershed planning in arid and semi-arid climates. Until recent years, stormwater quality has simply not been much of a priority for water resource managers in the west. This situation is changing rapidly, as fast-growing communities are responding to both emerging water quality problems and new federal regulations. In particular, larger cities in the west have gradually been dealing with stormwater quality to meet the requirements of the first phase of EPA's municipal stormwater National Pollutant Discharge Elimination System (NPDES) program. Soon, thousands more smaller communities will need to develop stormwater quality programs when the second phase of this national stormwater regulatory program is rolled out later this year.

At first glance, it seems ludicrous to consider managing the quality of stormwater in arid regions where storms are such a rare and generally welcome event— sort of like selling combs at a bald convention. The urban water resources of the southwest, however, are strongly influenced by stormwater runoff and by the watershed development that increases it. Indeed, the flow of many urban streams in the southwest is generated almost entirely by human activity: by urban storm flow, irrigation return flow and wastewater effluent. Thus, the quality of both surface water and groundwater in urbanizing areas of arid and semi-arid regions of the southwest is strongly shaped by urbanization.

For purposes of this article, arid watersheds are defined as those that receive less than 15 inches of rain each year. Semi-arid watersheds get between 15 and 35 inches of rainfall, and have a distinct dry season where evaporation greatly exceeds rainfall. In contrast, humid watersheds are defined as those that get at least 35 inches of rain each year, and often much more. There are many arid and semi-arid watersheds, most of which are located in fast growing regions of the western United States (Figure 1). Low annual rainfall, extensive droughts, high intensity storms and high evaporation rates are characteristic of these watersheds, and present many challenges to the stormwater manager. [Note: in some arid and semi-arid watersheds, most precipitation falls as snow and evaporation rates are much lower. These watersheds are found in portions of Alaska and at higher elevations of the Rocky Mountains and Sierra Nevada. Guidance on stormwater strategies for these dry but cold watersheds can be found in Caraco and Claytor (1997)].

Figure 1: Distribution of Rainfall in the United States

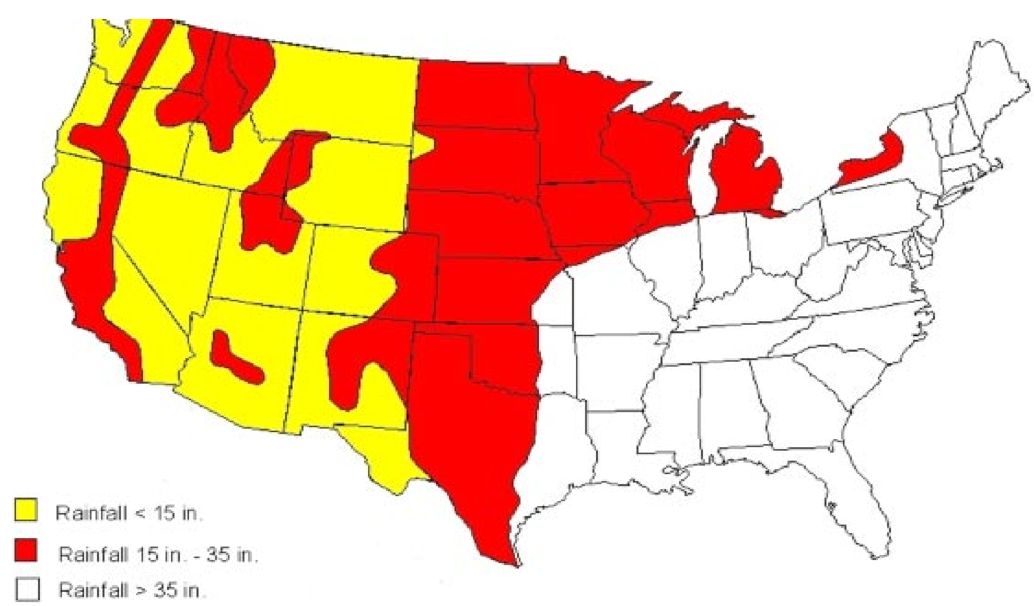


Table 1: The West Is Different - Key Considerations in Arid and Semi-Arid Watersheds
Aquatic resources and management objectives are fundamentally different.
Rainfall depths are much lower.
Evaporation rates are much higher.
Pollutant concentrations in stormwater are much greater.
Vegetative cover is sparse in the watershed.
Sediment movement is great.
Dry weather flow is rare, unless return flows are present.

This article reviews strategies for managing stormwater in regions of scarce water based on an extensive survey of 30 stormwater managers from arid and semi-arid regions. Next, the article explores how source control, better site design and stormwater practices can be adapted to meet the demanding conditions posed by arid and semi-arid climates. It begins by examining the environmental factors that make stormwater management in arid and semi-arid watersheds so unique and challenging. As a consequence, stormwater strategies for the west are often fundamentally different from those originally developed for more humid regions. Some of these differences are explored in the next section and are outlined in Table 1.

Aquatic Resources and Management Objectives Are Fundamentally Different

The rivers of arid regions are dramatically different from their humid counterparts. Some idea of these differences can be seen by comparing the dynamics of an arid river to a humid one (see below). The differences are even more profound for the smaller urban streams in arid watersheds. In fact, it is probably appropriate to refer to them as gullies or arroyos rather than streams, since they rarely have a perennial flow of water. Many of the physical, chemical and biological indicators used to define stream quality in humid watersheds simply do not apply to the ephemeral washes and arroyos that comprise the bulk of the drainage network of arid watersheds. Without such indicators, it is difficult to define the qualities that merit protection in ephemeral streams. Clearly, the goals and purposes of stream protection need to be reinterpreted for ephemeral stream channels, and cannot be imported from humid regions.

In humid watersheds, the first objective of stormwater management is the protection of perennial streams, with goals such as maintaining pre-development flow rates, habitat conditions, water quality and biological diversity. In contrast, the objectives for stormwater management in most arid watersheds are ultimately

An Arid River Runs Through It

Consider, for a moment, the characteristics of the South Platte River as it runs through Denver, Colorado, as chronicled by Harris *et al.* (1997). Flow in the South Platte River is extremely variable with a few thunderstorms and the spring snow melt causing a half dozen dramatic peaks in discharge. Normally, however, the river flows quite low, falling below the average daily flow level some 354 days a year. Much of the flow in the South Platte has been spoken for: it has been estimated that river water is used and returned back to the river from three to seven times before it leaves the state (primarily due to upstream water appropriations for irrigation). Most of the time, the river's flow is sustained by municipal wastewater effluent flows, which contribute about 90% of the river's daily flow during most of the year. Indeed, without wastewater and irrigation flows, the river would frequently run dry (as it had prior to settlement). The river continues to strongly interact with groundwater, and much of the flow moves underground. The South Platte is very warm, with summer surface water temperatures exceeding 30 degrees Celsius (and fluctuating by as much as 15 degrees each day).

From a water quality standpoint, the South Platte frequently suffers from oxygen depletion, and has high concentrations of dissolved salts and nitrogen. Prior to settlement, the South Platte River was not believed to have riparian forest corridors, but in recent years, introduced species have become well established along many parts of the river. The quality of river habitat is generally regarded as poor, due to low flows, sandy, shifting substrates, and a lack of channel structure and woody debris. The river's channel continually changes in response to extreme variations in both flow and sediment supply. These extremely variable conditions are not conducive to a diverse aquatic habitat for aquatic insects or fish. For example, fewer than a dozen fish species inhabit the South Platte River, as compared to 30 or more that might be found in a humid region.

Table 2: Rainfall Statistics for Eight U.S. Cities (all units in inches) (NOAA, 1997)						
City	Rainfall Statistics					
	Annual Rainfall	Days of Rain per Year	90% Rainfall Event	Annual Evaporation Rate	Two Year, 24 Hour Storm	Ten Year, 24 Hour Storm
Washington, DC	38	67	1.2	48	3.2	5.2
Dallas, TX	35	32	1.1	66	4.0	6.5
Austin, TX	33	49	1.4	80	4.1	7.5
Denver, CO	15	37	0.7	60	1.2	2.5
Los Angeles, CA	12	22	1.3	60	2.5	4.0
Boise, ID	11	48	0.5	53	1.2	1.8
Phoenix, AZ	7.7	29	0.8	82	1.4	2.4
Las Vegas, NV	4	10	0.7	120	1.0	2.0

driven either by flood control or the quality of a distant receiving water, such as a reservoir, estuary, ocean, or an underground aquifer.

Witness some of the recent water quality problems in arid and semi-arid watersheds for which stormwater is suspected to be primarily responsible: beach closures along the Southern California coast, trash and floatables washed into marinas in Santa Monica, nutrient enrichment in recreational reservoirs like Cherry Creek Reservoir in Denver and Town Lake in Austin, trace metals violations in the estuarine waters of San Francisco Bay, or concerns about the quality and quantity of groundwater recharge in aquifers of San Antonio. More local stormwater concerns include preventing the loss of capacity in irrigation channels or storage reservoirs caused by sedimentation.

Groundwater is particularly valued in arid and semi-arid watersheds. Many fast-growing western communities are highly reliant on groundwater resources, and it is becoming a limiting factor for some. On a national basis, groundwater provides 39% of the public water supply. In the arid and semi-arid southwest, however, groundwater sources comprise 55% of the water supply (Maddock and Hines, 1995). Consequently, these communities have a strong interest in both the recharge and protection of groundwater on which they depend.

Rainfall Depths Are Much Smaller

Table 2 compares a series of rainfall statistics for eight arid, semi-arid and humid cities, and documents the fact that it rarely rains in arid watersheds. For example, in the fast growing Las Vegas, Nevada region, rainfalls greater than a tenth of an inch occur, on average, less than 10 days a year. Not only does rain seldom fall, not much falls when it does. In arid watersheds, 90% of all rainfall events in a given year are usually less than 0.50 to 0.80 inches, compared to 1.0 to 1.5 inches in humid watersheds.

Consequently, if a "90% rule" is used in arid regions, the water quality storm is roughly half that of most semi-arid and humid watersheds, which greatly reduces the size, land consumption and cost of structural practices that need to be built. In many cases, the entire water quality storm can be disposed of on-site through better site design, without the need for structural practices. It should be noted that there are some significant exceptions to this rule. Los Angeles, for example, experiences higher rainfall depths due to intense coastal storms in the winter, especially in el Nino years.

While intense storms cause the flash flooding that is so characteristic of the west, it is also important to keep in mind that the depth of rainfall in these storms is smaller than that of semi-arid and humid watersheds (Table 2). For example, the rainfall depth associated with the two-year 24-hour storm in most arid watersheds ranges from 1.0 to 1.4 inches, which is roughly equal to the typical water quality storm for a humid watershed. Similarly, the rainfall depth for the 10-year 24-hour storm in most arid watersheds ranges from two to three inches, which is roughly equivalent to the depth of a two-year storm in a semi-arid or humid watershed. Consequently, stormwater managers in arid regions can fully treat the quality and quantity of stormwater with about a third to half of the storage needed in humid or semi-arid watersheds, with all other factors being equal.

Even though the rainfall depths in arid watersheds are lower, watershed development can greatly increase peak discharge rates during rare flood events. For example, Guay (1996) examined how development changed the frequency of floods in arid watersheds around Riverside, California. Over two decades, impervious cover increased from 9% to 22% in these fast-growing watersheds. As a direct result, Guay determined that peak flow rate at gauged stations for the two-year storm event had climbed by more than 100%, and that the average annual stormwater runoff volume had climbed by 115% to 130% over the same time span.

Evaporation Rates are Greater

High evaporation rates are a great challenge in arid and semi-arid watersheds. Low rainfall combined with high evaporation usually means that stored water will be lost water. In Las Vegas, for example, annual rainfall is a scant four inches, while pan evaporation exceeds 10 feet (See Table 2). Consequently, it is virtually impossible to maintain a pond or wetland in an arid watershed without a supplemental source of water (see Saunders and Gilroy, 1997; article 74*)*. Evaporation also greatly exceeds rainfall for many months of the year in semi-arid watersheds, and requires special pond design techniques.

Pollutant Concentrations in Stormwater Are Often Higher

The pollutant concentration of stormwater runoff from arid watersheds tends to be higher than that of humid watersheds. This is evident in Table 3, which compares event mean concentrations (EMCs) from five arid or semi-arid cities to the national average for several common stormwater pollutants. As can be seen, the concentration of suspended sediment, phosphorus, nitrogen, carbon and trace metals in stormwater runoff from arid and semi-arid watersheds consistently exceeds the national average, which is heavily biased toward humid watersheds. In addition, bacteria levels are often an order of magnitude higher in arid regions (Chang, 1999).

The higher pollutant concentrations in arid watersheds can be explained by several factors. First, since rain events are so rare, pollutants have more time to build up on impervious surfaces compared to humid regions. Second, pervious areas produce high sediment and organic carbon concentrations because the sparse vegetative cover does little to prevent soil erosion in uplands and along channels when it does rain. The

Table 3: Stormwater Pollutant Event Mean Concentrations in Arid and Semi-Arid Regions (Units: mg/l, except for metals which are in ug/l)

Pollutant	National	Phoenix, AZ	Boise, Idaho	Denver, Colorado	San Jose, California	Dallas, Texas
Source	(1)	(2)	(3)	(4)	(5)	(6)
Rainfall		7.1 inches	12 inches	13 inches	14 inches	28 inches
No. of Samples	**2-3000**	40	15	35	67	32
TSS	**78.4**	227	116 *	384	258	663
BOD	**14.1**	109	89	nd	12.3	12
COD	**52.8**	239	261	227	nd	106
Total N	**2.39**	3.26	4.13	4.80	nd	2.70
Total P	**0.32**	0.41	0.75	0.80	0.83 #	0.78
Soluble P	**0.13**	0.17	0.47	nd	nd	nd
Copper	**14**	47	34	60	58	40
Lead	**68**	72	46	250	105	330
Zinc	**162**	204	342	350	500	540

References: (1): Smullen and Cave, 1998, (2) Lopes et al, 1995 (3) Kjelstrom, 1995 (computed) (4) DRCOG, 1983, (5) WCC, 1992 (computed) (6) Brush et al, 1995.
Notes: nd= no data, # = small sample size * = outfall pipe samples

strong effect of upland and channel erosion can be detected when stormwater samples are taken from channels, but are less pronounced in stormwater outfall pipes.

Vegetative Cover Is Sparse in the Watershed

Native vegetative cover is relatively sparse in arid and semi-arid watersheds, and offers little protection against soil erosion. Irrigation is required to establish dense and vigorous cover, which may not be sensible or economical given scarce water resources. In addition, high flows released from storm drains frequently accelerate downstream erosion since channels are also sparsely vegetated. Finally, many stormwater practices require dense vegetative cover to perform properly (e.g., grass swales are often not practical in arid watersheds, given the difficulty of establishing and maintaining turf).

Sediment Movement Is Greater

Stream channels in arid and semi-arid watersheds move a lot of sediment when they flow. For example, Trimble (1997) found that stream channel erosion supplied more than two thirds of the annual sediment yield of an urban San Diego Creek. He concluded that the higher flows due to watershed urbanization had greatly accelerated the erosion of arroyos, over and above the increases caused by grazing, climate and riparian management. Channel erosion can be particularly severe along road ditches that experience higher stormwater flows, which not only increases sediment erosion but also creates chronic ditch maintenance problems.

Dry Weather Flows Are Rare, Unless Supplemented by Return Water

Most small streams in arid watersheds are gullies or arroyos that only flow during and shortly after infrequent storm events. As streams urbanize, however, dry weather flow can actually increase. Human sources of dry weather flow include return flows from lawn and landscape watering, car washing, and surface discharges of treated wastewater. For example, Mizell and French (1995) found that excess water from residential and commercial landscape irrigation and construction site dewatering greatly increased rate and duration of dry weather flow in a Las Vegas Creek, and was sufficiently reliable to be the primary irrigation source for a downstream golf course.

Stormwater Strategies for Arid and Semi-Arid Watersheds

Watershed managers need to carefully choose stormwater practices that can meet the demanding climatic conditions and water resource objectives of arid and semi-arid watersheds. Communities can employ three broad strategies: aggressive source control, better site design, and application of "western" stormwater practices. Some of the key trends in each of these areas are described below.

Aggressive Source Control

The term "source control" encompasses a series of practices to prevent pollutants from getting into the storm drain system in the first place. These practices include pollution prevention, street sweeping, and more frequent storm drain inlet clean-outs. Each practice acts to reduce the accumulation of pollutants on impervious surfaces or within the storm drain system during dry weather, thereby reducing the supply of pollutants that can wash off when it rains.

Pollution prevention. Pollution prevention seeks to change behaviors at residential, commercial and industrial sites to reduce exposure of pollutants to rainfall. Almost all arid stormwater managers consider pollution prevention measures to be an integral element of their stormwater management program, on par with the use of structural stormwater practices (Caraco, 1997). And certainly, many western communities have pioneered innovative pollution prevention programs. These programs focus on educating homeowners and businesses on how they can reduce or prevent pollutants from entering the storm drain system when it's not raining.

In recent years, western communities have been targeting their educational message to more specific groups and populations. For example, Los Angeles County has identified seven priority categories for intensive employee training in industrial pollution prevention— auto scrap yards, auto repair, metal fabrication, motor freight, chemical manufacturing, car dealers, and gas stations— on the basis of their hotspot potential and their numerical dominance (Swammikannu, 1998). In the Santa Clara Valley of California, the three key priorities for intensive commercial pollution prevention training are car repair, construction, and landscaping services. Targeting is also used to reach homeowners with specific water conservation, car washing, fertilization and pesticide messages.

Street sweeping. Street sweeping seeks to remove the buildup of pollutants that have been deposited along the street or curb, using vacuum assisted sweeper trucks. While researchers continue to debate whether street sweepers can achieve optimal performance under real-world street conditions, most concede that street sweeping should be more effective in areas that have distinct wet and dry seasons (CDM, 1993), which is a defining characteristic of arid and semi-arid watersheds.

Storm drain inlet clean-outs. One of the last lines of defense to prevent pollutants from entering the storm drain system is to remove them in the storm drain inlet. Mineart and Singh (1994) reported that monthly or even quarterly clean-outs of sediment in storm drain inlets could reduce stormwater pollutant loads to the San Francisco Bay by five to 10%. Currently, few communities clean out their storm drain inlets more than once a year, but a more aggressive effort to clean out storm drains prior to the onset of the wet season could be a viable strategy in some communities.

Better Site Design

Better site design clearly presents great opportunities to reduce impervious cover and stormwater impacts in the west, but it has not been widely implemented to date. Indeed, the "California" development style, with its wide streets, massive driveways, and huge cul-de-sacs has been copied in many western communities and arguably produces more impervious cover per home or business than any other part of the country (Figure 2). While the popularity of the California development style reflects the importance of the car in shaping communities, it is also a strong reaction against the arid and semi-arid landscape. The brown landscape is not green or pastoral, and many residents consider concrete and turf to be a more pleasing and functional land cover than the dirt and shrubs they replace.

While better site design techniques were extensively profiled in the last issue of *Techniques* (3:2), it is worth discussing how these techniques can be adapted for western developments. A key adaptation is to incorporate the concept of "stormwater harvesting" into residential and commercial development design (COT, 1996). Water harvesting is an ancient concept that involves capturing runoff from rooftops and other impervious surfaces and using it for drinking water or to irrigate plants (e.g., the cistern). In a more modern version, rooftop runoff is spread over landscaping areas or the yard, with the goal of completely disposing of runoff on the property for storm events up to the two-year storm (which ranges from one to two inches in most arid and semi-arid climates). For example, the City of Tucson recommends 55 gallons of storage per 300 to 600 square feet of rooftop for residential bioretention areas (COT, 1996). In higher density settings, it may be more practical to store water in a rain barrel or cistern for irrigation use during dry periods.

Figure 2: Many Western Developments Create Needless Impervious Cover

When water harvesting is aggressively pursued, stormwater runoff is produced only from the impervious surfaces that are directly connected to the roadway system. Denver has utilized a similar strategy program to disconnect impervious areas and reduce the amount of stormwater pollution (DUDFC, 1992). A useful guide on these techniques has also been produced for the San Francisco Bay area (BASMAA, 1997). Water harvesting may prove to be another useful stormwater retrofitting strategy, particularly in regions where water conservation is also a high priority.

Better site design techniques also need to be adapted for fire safety in Western communities adjacent to chaparral vegetation that are prone to periodic wildfires. In some case, vegetation setbacks must be increased in these habitats to protect developments from dangerous wildfires (CWP, 1998).

Developing Western Stormwater Practices

Given the many challenges and constraints that arid and semi-arid watersheds impose, managers need to adapt and modify stormwater practices that were originally developed in humid watersheds. In our stormwater managers survey, four recurring principles emerged on how to design "western" stormwater practices:

1. *Carefully select and adapt stormwater practices for arid watersheds.*
2. *Minimize irrigation needs for stormwater practices.*
3. *Protect groundwater resources and encourage recharge.*
4. *Reduce downstream channel erosion and protect from upland sediment.*

1. Carefully select and adapt stormwater practices for arid watersheds.

Some stormwater practices developed in humid watersheds are simply not applicable to arid watersheds, and most others require major modifications to be effective (Table 4). Even in semi-arid watersheds, design criteria for most stormwater practices need to be revised to meet performance and maintenance objectives. The following section highlights some of the major design and performance differences to consider for major stormwater practices.

Extended Detention (ED) Dry Ponds. The most widely utilized stormwater practices in arid and semi-arid watersheds were dry ponds, according to the Center's survey (Figure 3). Most were designed exclusively for flood control, but can be easily modified to provide greater treatment of stormwater quality. While dry ED ponds are not noted for their ability to remove soluble pollutants, they are reasonably effective in removing sediment and other pollutants associated with particulate matter (see article 64). In addition, ED ponds can play a key role in downstream channel protection, if the appropriate design storm is selected, and adequate upstream pretreatment is incorporated. Dry extended detention is the most feasible pond practice in arid watersheds, since they do not require a permanent pool of water.

Table 4. Design Modifications for Stormwater Practices in Arid and Semi-Arid Watersheds

Stormwater Practice	Arid Watersheds	Semi-Arid Watersheds
ED Dry Ponds	PREFERRED multiple storm ED stable pilot channels dry forebay	ACCEPTABLE dry or wet forebay needed
Wet Ponds	NOT RECOMMENDED evaporation rates are too high to maintain a normal pool without extensive use of scarce water	LIMITED USE liners to prevent water loss require water balance analysis design for a variable rather than permanent normal pool use water sources such as AC condensate for pool aeration unit to prevent stagnation
Stormwater Wetlands	NOT RECOMMENDED evaporation rates too great to maintain wetland plants	LIMITED USE require supplemental water submerged gravel wetlands can help reduce water loss
Sand Filters	PREFERRED requires greater pretreatment exclude pervious areas	PREFERRED refer to COA, 1994 for design criteria
Bioretention	MAJOR MODIFICATION no irrigation better pretreatment treat no pervious area xeriscape plants or no plants replace mulch with gravel	MAJOR MODIFICATION use runoff to supplement irrigation use xeriscaping plants avoid trees replace mulch with gravel
Rooftop Infiltration	PREFERRED dry well design for recharge of residential rooftops	PREFERRED recharge rooftop runoff on-site unless the land use is a hotspot
Infiltration	MAJOR MODIFICATION no recharge for hotspot land uses treat no pervious area multiple pretreatment soil limitations	MAJOR MODIFICATION no recharge for hotspot land uses treat no pervious area multiple pretreatment
Swales	NOT RECOMMENDED not recommended for pollutant removal, but rock berms and grade control needed for open channels to prevent channel erosion	LIMITED USE limited use unless irrigated rock berms and grade control essential to prevent erosion in open channels

Wet Ponds. Wet ponds are often impractical in arid watersheds since it is not possible to maintain a permanent pool without supplemental water, and the ponds become stagnant between storms. On the other hand, wet ponds are feasible in some semi-arid watersheds when carefully designed. Performance monitoring studies have demonstrated that wet ponds exhibit greater pollutant removal than other stormwater practices in Austin, Texas, at a lower cost per volume treated (COA, 1998, and article 75).

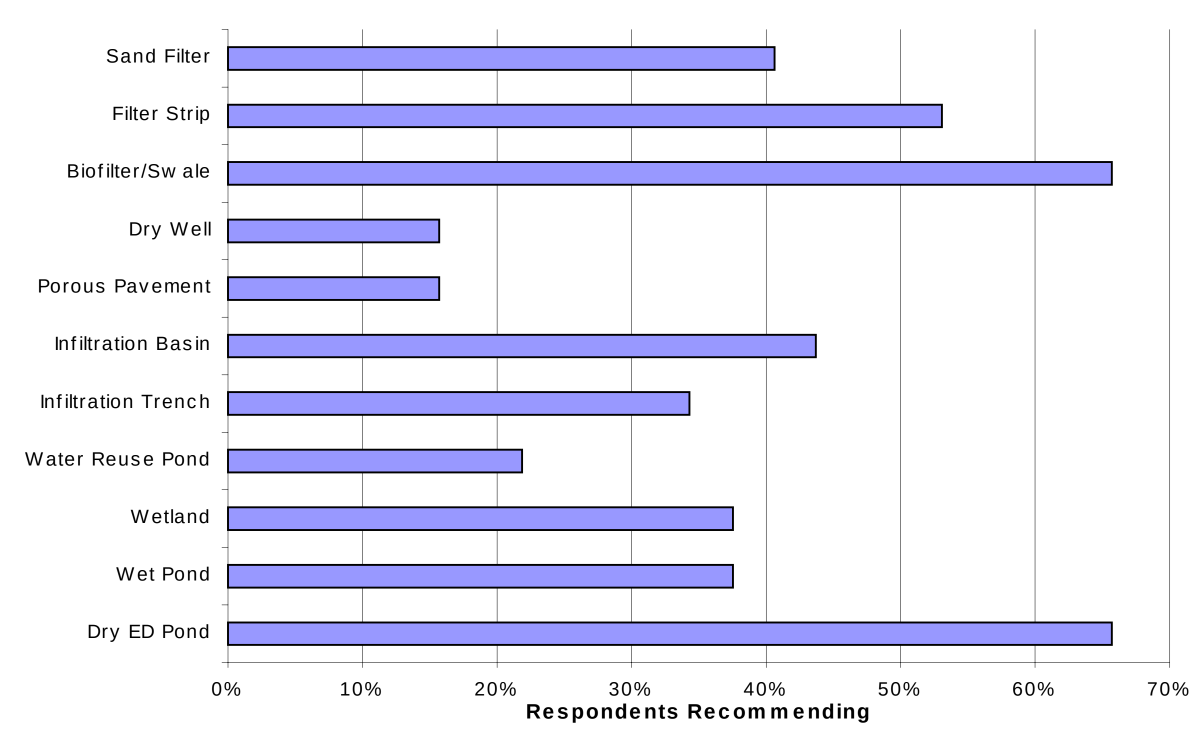
In arid and semi-arid climates, wet ponds can require supplemental water to maintain a stable pool elevation. Saunders and Gilroy (1997) reported that 2.6 acre-feet per year of supplemental water were needed to maintain a permanent pool of only 0.29 acre-feet. Generally speaking, stormwater designers working in semi-arid watersheds should design for a variable pool level that can have as much as a three-foot draw down during the dry season. The use of wetland plants along the pond's shoreline margin can help conceal the drop in water level, but managers will need to reconcile themselves to chronic algal blooms, high densities of aquatic plants and occasional odor problems. The City of Austin has prepared useful wet pond design criteria to address these issues (COA, 1997).

Stormwater Wetlands. Few communities recommend the use of stormwater wetlands in either arid or semi-arid watersheds. Once again, the draw down rates caused by evaporation make it difficult to impossible to maintain standing water that can sustain emergent wetland plants, unless copious subsidies of supplemental water are supplied. One interesting exception was a gravel-based wetland that treated parking lot runoff in Phoenix, Arizona (Wass and Fox, 1995). While the wetland did require some supplemental water, evaporation was reduced by the overlying gravel bed, and the wetland achieved relatively high removal rates of oil and grease.

Sand Filters. Sand filters continue to be one of the most common practices used to treat the quality of stormwater in both arid and semi-arid watersheds. Sand filters require no supplemental water and can be used with almost any soil type (Claytor and Schueler, 1997). Still, the basic sand filter design continues to evolve to counter the tough design conditions found in these regions.

For example, Urbonas (1997) evaluated sand filter performance in Denver, Colorado, and concluded that designs need to be modified to account for the greater sediment buildup in arid regions (see article 108). Urbonas found that the test sand filter quickly became clogged with sediment after just a few storms, and recommended that sand filters include a more frequent sediment clean out regime, an increase in the filter bed size, and upstream detention to provide greater sediment pretreatment. Some additional research on the performance and longevity of sand filters in the semi-arid climate of Austin, Texas can be found in article 106.

Figure 3: Stormwater Practice Preferences in Arid Climates (CWP, 1997)



Bioretention. The use of bioretention as a stormwater treatment practice is not very common in many western communities at the present time. Clearly, this practice will require extensive modification to work in arid watersheds. This might entail xeriscape plantings, use of gravel instead of mulch as ground cover, and better pretreatment. Sprinkler irrigation of bioretention areas should be avoided.

Infiltration Practices. While a number of communities allowed the use of infiltration in arid and semi-arid watersheds, few encouraged its use. Two concerns were frequently cited as the reason for lack of enthusiasm for structural infiltration. The first concern was that infiltration practices are too susceptible to rapid clogging, given the high erosion rates that are customary in arid and semi-arid watersheds. The second concern was that untreated stormwater could potentially contaminate the aquifers that are used for groundwater recharge.

Swales. The use of grass swales for stormwater treatment was rarely reported for arid watersheds, but was much more common in semi-arid conditions. Grass swales are widely used as a stormwater practice in residential developments in Boise, Idaho, but the dense turf can only be maintained in these arid conditions through the use of sprinkler irrigation systems. The pollutant removal performance of swales in arid and semi-arid watersheds appears to be mixed. Poor to negative pollutant removal performance was reported in a Denver swale that was not irrigated (Urbonas, 1999 -personal communication). In the semi-arid climate of Austin, Texas, Barret *et al.* (1998) reported excellent pollutant removal in two highway swales that were vegetated but not irrigated (Table 5). Similar performance was also noted in a non-irrigated swale monitored by the City of Austin (COA, 1997).

2. Minimize irrigation needs for stormwater practices

In arid climates, all sources of water, including stormwater runoff, need to be viewed as a resource. It seems senseless, therefore, to irrigate a practice with 50 inches of scarce water a year so that it can be ready to treat the stormwater runoff produced from 10 inches of rain a year. Still, irrigation of stormwater practices was very common in our survey of arid and semi-arid stormwater managers; in fact, 65% reported that irrigation was commonly used to establish and maintain vegetated cover for most stormwater practices.

Irrigation should be limited to practices that meet some other landscaping or recreational need in a community and would be irrigated anyway, such as landscaping islands in commercial areas and road rights of way. Irrigation may also be a useful strategy for dry ED ponds that are designed for dual use, such as facilities that serve as a ballfield or community park during the dry season. Even when irrigation is used, practices should be designed to “harvest” stormwater, and therefore reduce irrigation needs. Landscapers should also consider planting native drought resistant plant material to reduce water consumption.

3. Protect groundwater resources and encourage recharge.

In many arid communities, protection of groundwater resources is the primary driving force behind stormwater treatment. Ironically, early efforts to use

Table 5. Performance of Vegetated Swales in Semi-arid Climates (Barret *et al.*, 1997, and COA, 1998)

	Highway 183 Median	Walnut Creek	City of Austin Swale
Parameter	Mass Load Reduction (%)		
TSS	89	87	68
COD	68	69	33
TP	55	45	43
TKN	46	54	32
Nitrate	59	36	(-2)
Zinc	93	79	ns
Lead	52	31	ns

ns = not sampled. Fecal coliform and fecal strep removals were negative at the 183 and Walnut Creek sites.

stormwater to recharge groundwater have resulted in some groundwater quality concerns. In Arizona, for example, stormwater was traditionally injected into 10 to 40 foot deep dry wells to provide for groundwater recharge. Concerns were raised that deep injection could increase the risk of localized groundwater contamination, since untreated stormwater can be a source of pollutants, particularly if the proposed land use is classified as a stormwater hotspot.

Wilson *et al.* (1990) evaluated the risk of dry well stormwater contamination in Pima County, Arizona, and determined that dry wells had elevated pollutant concentrations in local groundwater. The build up of pollutant levels that had occurred over several decades tended to be localized, and did not exceed drinking water standards. Still, it is important to keep in mind that dry wells and other injection recharge methods should only be used to infiltrate relatively "clean" runoff, such as residential roofs. Other surface infiltration practices, such as trenches and basins, can also potentially contaminate groundwater unless they are carefully designed for runoff pretreatment, provide a significant soil separation distance to the aquifer, and are not used on "hot spot" runoff sites.

4. Design to reduce channel erosion

Above all, a western stormwater practice must be designed to reduce *downstream* erosion in ephemeral channels, while at the same time protecting itself from sediment deposition from *upstream* sources. This is a daunting challenge for any engineer, but the following ideas can help.

With respect to *downstream channel erosion*, designers will need to clamp down on the storm events that produce active erosion in channels. This might entail the design of ponds or basins that can provide 12 hours of extended detention for the one-year return interval storm event (which is usually no more than an inch or two in most arid and semi-arid watersheds). Local geomorphic assessment will probably be needed to set channel protection criteria, and these hydraulic studies are probably the most critical research priority in both arid and semi-arid watersheds today. Without ED channel protection, designers must rely on clumsy and localized engineering techniques to protect ditches and channels from eroding, such as grade control, rock berms, rip-rap, or even concrete lined channels. Bioengineering options to stabilize downstream channels in arid watersheds are limited, and often require erosion control blankets to retain moisture and seeds, as well as extensive irrigation.

Upstream erosion quickly reduces the capacity of any stormwater practice in an arid or semi-arid watershed, due to sparse vegetation cover and erosion from upstream gullies, ditches, or channels. Designers have several options to deal with this problem. The most effective option is to locate the practice so that it can only accept runoff from impervious areas, particularly for infiltration, sand filters and bioretention. Even then, the practice will still be subject to sediment transported by the wind.

All stormwater practices in arid and semi-arid watersheds <u>require greater pretreatment</u> than in humid watersheds. Seventy percent of the arid stormwater managers surveyed reported that sediment clogging and deposition problems were a major design and maintenance problem for nearly all of their stormwater practices.

Even though not all upstream erosion can be prevented, designers can compensate for sediment buildup within the stormwater practice itself. Pretreatment and over-sizing can prevent the loss of storage or clogging associated with sediment deposition. As noted in article 106, rock berms or vertical gravel filters are ideally suited as a pretreatment device.

Most stormwater managers surveyed indicated that sediment clean-outs need to be more frequent for stormwater practices in arid and semi-arid watersheds, with removal after major storms and at a minimum, once a year. Stormwater managers also consistently emphasized the need for better upland erosion control during construction. A full 65% of the managers reported that upstream erosion and sediment control were a major emphasis of their stormwater plan review.

Summary

It is clear that stormwater managers in arid and semi-arid climates cannot simply import the stormwater programs and practices that were originally developed for humid watersheds. Instead, they will need to develop stormwater solutions that combine aggressive source control, better site design and stormwater practices in a distinctly western context. Regulators, in turn, need to recognize that western climates, terrain and water resource objectives are different, and be flexible and willing to experiment with new approaches in municipal stormwater programs. Lastly, stormwater managers from arid and semi-arid watersheds must work more closely together to share experiences about the stormwater solutions that work and fail. It is only through this dialogue that western communities can gradually engineer stormwater practices that are rugged enough to withstand the demanding challenges of the arid and semi-arid west. ***- DSC***

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