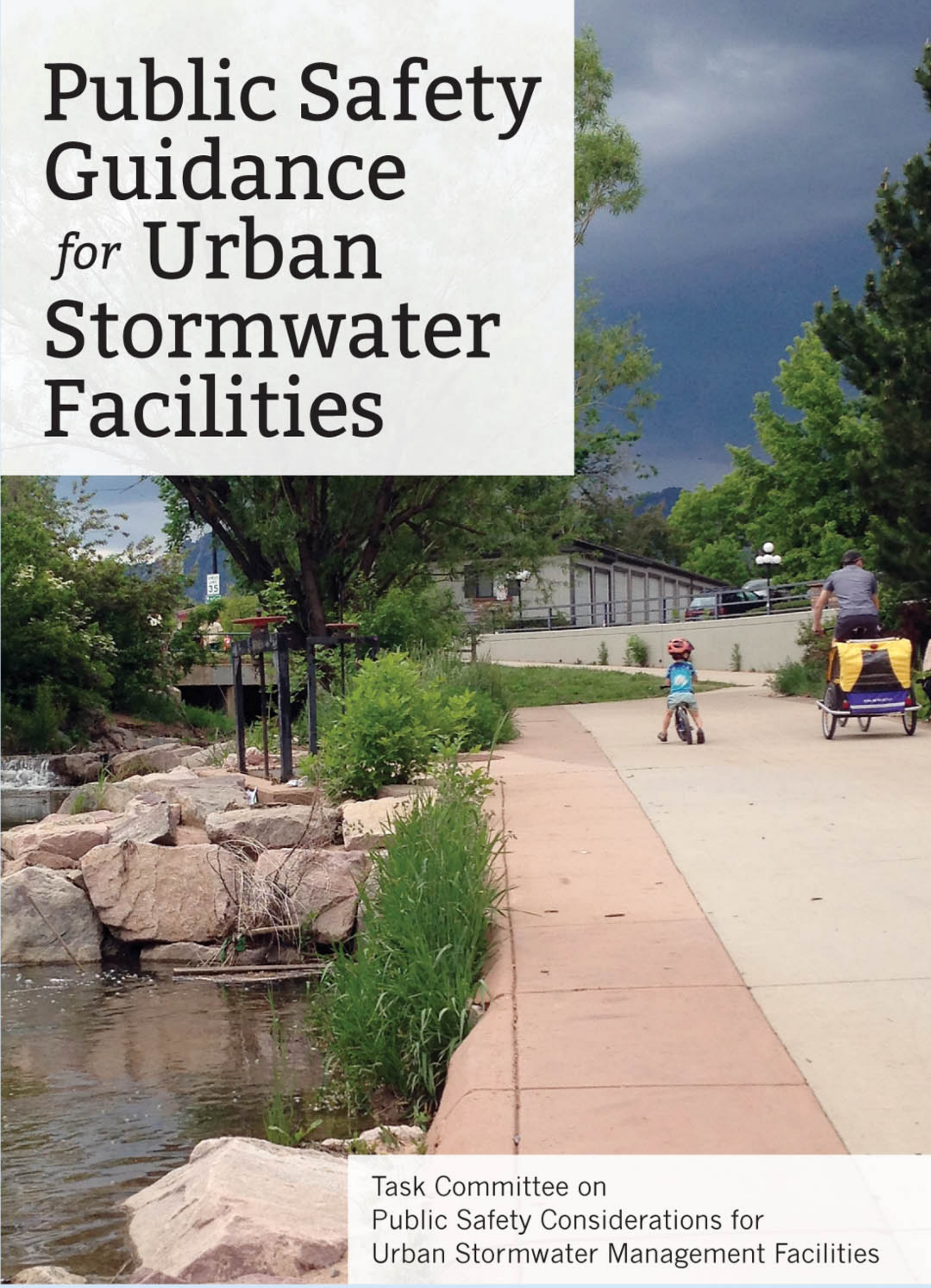
Public Safety Guidance *for* Urban Stormwater Facilities



Task Committee on
Public Safety Considerations for
Urban Stormwater Management Facilities

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INSTITUTE

Public Safety Guidance for Urban Stormwater Facilities

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for Urban Stormwater Management Facilities

Sponsored by

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Contents

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Preface

The purpose of this document is to provide guidance for protecting public safety at urban stormwater management facilities, such as ponds, channels, water quality control measures (also widely referred to as best management practices, or BMPs) and low-impact development (LID) features, to engineers, landscape architects, land planners and other stormwater professionals. This guidance applies to the planning, design and operation/maintenance (including inspections) of such facilities. This guidance is conceptual and provides general observations and recommendations.

Unless site-specific circumstances clearly indicate otherwise, stormwater professionals should assume that members of the public will visit and interact with stormwater facilities in urban areas. People like to be around water, to be involved with it and to become stewards of it. Surveys have shown that properties adjacent to attractive, well-maintained water bodies hold a premium value. The hazards posed to the public by such facilities should be anticipated, discussed with relevant public and private parties, evaluated and mitigated as appropriate. Public education on the purpose of stormwater facilities and their potential dangers (including mitigation) is essential.

The cosponsors of this document recognize that it is impractical, if not impossible, to provide zero risk at stormwater management facilities. As with any other type of public works infrastructure, there are inherent risks associated with conveying, storing, treating and otherwise managing stormwater, and there are practical constraints related to budgets, appearance, access and other factors that preclude complete public protection. Also to be considered is that there are inherent risks associated with natural water bodies. However, failure to consider public safety is not consistent with the standard of care that professional engineers, landscape architects, planners and other stormwater and public works professionals are entrusted to uphold. Similarly, regular inspection and maintenance are essential to ensure that stormwater management facilities function safely and perform as designed. The American Society of Civil Engineers/Environmental & Water Resources Institute/Urban Water Resources Research Council (ASCE/EWRI/ UWRRC), the National Association of Flood & Stormwater Management Agencies (NAFSMA), the American Public Works Association (APWA), the Water Environment Federation (WEF), the American Water Resources Association (AWRA), the American Planning Association (APA) and the American Society of Landscape Architects (ASLA) recommend that protecting public safety should be a key objective when planning, designing, inspecting, operating and maintaining urban stormwater management facilities.

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Chapter 1
Purpose and Overall Perspective

The purpose of this document is to provide guidance for protecting public safety at urban stormwater management facilities, such as ponds, channels, water quality control measures (best management practices, or BMPs) and low-impact development (LID) features, to engineers, landscape architects, land planners and other stormwater and public works professionals. This guidance applies to the planning, design and operation/maintenance (including inspections) of such facilities. This guidance is conceptual and provides general observations and recommendations.

The cosponsors of this document represent a broad coalition of public and private sector engineers, planners, landscape architects, regulators, public works staff and others who regularly practice in the areas of urban stormwater management, flood control and water quality protection. The cosponsors have previously published literature that provides suggestions for enhancing public safety. Representative excerpts are provided in Appendix A. Many general engineering, planning and landscape architecture references discuss public safety; examples are found in Appendix B. Appendix C contains photographs of both safe and unsafe stormwater facilities, while Appendix D contains example conceptual design drawings related to public safety.

As shown in Figures 1 and 2, potential hazards to the public can be apparent (such as overly steep side slopes, lack of escape route and maintenance access and high-velocity discharges onto a steep drop into a detention basin), but hazards can also be far more subtle. By contrast, Figure 3 provides an example of a facility that was designed with safety in mind; this stormwater retention pond has safety provisions, including mild, well-vegetated side slopes and a gentle drop-off below the water level, and it has trails safe for public use, receives regular maintenance, and is attractive, which promotes regular public use and thus improves safety and contributes to economic, environmental and community benefits.

This guidance addresses a wide range of safety issues and considerations. Safety considerations are site specific in nature and should be evaluated on a case-by-case basis.

Figure 1. Dry Detention Basin with Safety Concerns Due to Steep Side Slopes and No Egress or Escape Route

Source: James Lenhart, P.E., D.WRE; reproduced with permission.

Figure 2. Dry Detention Basin, Culvert and Rundown with Safety Concerns Due to Steep Side Slopes and No Egress or Escape Route

Source: Robert Pitt, Ph.D., P.E., BCEE, D. WRE; reproduced with permission.

Figure 3. Stormwater Retention Pond with Safety Features

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Chapter 2
Background and Scope of Guidance

2.1 Representative Facilities Addressed

Representative urban stormwater management facilities that this guidance document addresses include:

- Open channels and waterways, including both manmade and modified natural channels.
- Structures within or immediately adjacent to open channels, such as grade control/drop structures, low-head dams, weirs, low water crossings, trails and pedestrian bridges.
- Closed conduits such as storm drains, culverts, long underground pipes, inverted siphons and related facilities such as inlets, outlets and energy dissipaters.
- Impoundments with a permanent water surface (commonly called "retention ponds" or "wet ponds") and without a permanent water surface (commonly called "detention basins" or "dry ponds") and features such as dam embankments, spillways, inlet and outlet structures, energy dissipaters, surrounding slopes, forebays, micropools, railings, debris barriers (trash racks) and related facilities.
- Other water quality control measures (BMPs) such as wetlands, infiltration basins, swales, filter strips and techniques collectively referred to as "low impact development" (LID), such as rain gardens and bioretention facilities.
- Public trails and bridges adjacent to channels, ponds and other features.

2.2 Scope of Guidance

This guidance applies both to larger, regional facilities that typically serve multiple properties and to small onsite facilities that serve individual properties. The focus is on post-construction facilities of all types, including best management practices (rather than construction BMPs), and on separate storm sewer systems (rather than combined sewer systems) although some recommendations are transferable. Many of the design guidelines primarily apply to new or reconstructed (retrofitted) facilities; however, many recommendations also apply to existing facilities.

The authors of this document have generally not provided hard and fast design criteria, such as keeping the product of depth and velocity less than a prescribed factor. Such a quantity could have unintended consequences, such as discouraging the use of open channels with the many associated benefits that such facilities often provide to communities. Instead, the cosponsors urge that safety considerations be evaluated on a site-specific basis.

Public safety risks associated with structural or geologic/geotechnical failures are not addressed in detail herein, nor are requirements related to flood control facilities such as levees and large dams (small earthen embankments are discussed in Section 4.7). Urban stormwater runoff often has pollutants that can adversely affect public health, such as bacteria, viruses and trash (diapers, hypodermic needles, hazardous material containers, etc.), and this aspect of safety is only briefly reviewed.

Facilities may involve safety risks extending beyond those inherently associated with stormwater and associated control structures or practices. For example, additional safety risks may arise from facility placement in locations that are secluded (due to lack of visibility) or otherwise attractive to criminal elements. Numerous physical risks may be inherently associated with any facilities, arising from sharp edges, confined spaces, soft or unreliable footing, slippery surfaces, uneven ground, abrasive or hard surfaces, and so on. Such risks are not addressed in detail in this document.

This document is intended for use by those with professional competencies sufficient to enable its proper interpretation and application within the current state of professional practice regarding stormwater facilities. It is not intended to be useful to, or used by, those without such qualifications.

Contributors to this guidance document from the American Planning Association and American Society of Landscape Architects emphasize that many of the public safety measures described herein are consistent with good urban design and can promote the following objectives (Hopper 2006):

- Enhancing the local economy
- Connecting the community physically and socially
- Providing a diversity of options and experiences
- Creating an equitable, comfortable and welcoming environment
- Retaining the character of the community and creating a sense of place
- Making the community sustainable, enduring and resilient
- Making the community safe and suited to the needs of everyone, including disabled and elderly people
- Making the community walkable and bikeable
- Providing for custodianship, management and maintenance over time
- Preserving historic facilities

Legal considerations are not discussed in detail, although there are references to this topic (including "attractive nuisances"), especially in Appendices A and B. Legal/liability issues vary significantly from locality to locality. Litigation is, by definition, case specific, and dependent on facts unique to the incident in question. Stormwater facility owners, planners/designers and those charged with inspection and maintenance should be cognizant of potential liability if their actions are found to not meet a reasonable standard of care and should utilize risk management practices (anticipating risks and managing them).

2.3 Examples of Safety Hazards

Examples of potential causes of failures, accidents and threats to public safety (and in some cases to maintenance workers) include the following. This list is not complete, but it attempts to illustrate the range of issues that may be encountered.

- Pond and channel side slopes that are overly steep and prevent reasonable access and egress (escape), and which are hazardous for maintenance staff who may be using heavy equipment such as lawn mowers.
- Ponds that lack safety benches and which have underwater slopes that “drop off” rapidly.
- Inadequate or inappropriate use of fencing and railings, or poor maintenance that compromises their function.
- High-velocity and rapidly rising flow in channels that are publicly accessible and that include bicycling and walking trails in close proximity. Static and dynamic forces that can act upon a person in a stormwater facility can be overwhelming and are generally not recognized by the public. Appendix B contains guidance on how to calculate such forces, as do various other references cited herein.
- Low water crossings along roadways, usually in rural areas. When these crossings are inundated with flood flows, flow can readily move a car and possibly undermine the roadway, posing great danger to the vehicle’s occupants.
- Localized flooding or standing water or ice, which interferes with foot, bicycle or vehicle traffic.
- Flowing water across grassy areas (causing erosion and rilling) where pedestrian traffic can reasonably be anticipated.
- Water accumulation/ponding due to poor hydraulic design of storm drainage facilities at roadway underpasses, low water crossings and other “sag” locations.
- Unprotected culvert and pond inlets and pond outlet structures (lacking trash racks), including long conduits, particularly where pipe inlets are inundated frequently and for prolonged periods.
- Roadside ditches with high, steep banks and inadequate guardrails, signage and/or lighting.
- Below grade roadway conduits that double as pedestrian access and that are subject to inundation.

- Low head dams, weirs and grade control structures that have unsafe hydraulic conditions (and that create “keepers” [reverse rollers] from which escape can be very difficult).
- Standing water (for more than 3 days) that is conducive to mosquitoes and the diseases they transmit. Mosquito infestations can be aggravated by trash that accumulates.
- Ponds or channels that have synthetic or clay liners that either are not covered with a material that enables solid footing or become covered with algae and silt and are slippery.
- Inverted siphons in irrigation or drainage canals that receive runoff and that are not properly signed, roped off, etc., and that lack safety racks.
- Facility inflow and outflow pipes that are directly across from and in close proximity to each other, creating a zone of high forces.
- Structural or geotechnical problems at detention/retention pond dams or at highway culverts that can cause embankment failure.

Table 1 provides representative news headlines pertaining to safety incidents at urban stormwater management facilities. Although news coverage of episodes such as those referred to in Table 1 increases public awareness of the hazards of stormwater facilities, this heightened awareness is usually limited to the local area and short-lived; in general, the public does not have a proper appreciation for the hazards posed by these facilities and by natural water bodies.

Table 1
Representative News Headlines
Regarding Public Safety Incidents at Stormwater Facilities and Urban Waterways

Headline	Source and Date
Third Victim Found Dead as Flood Warnings Remain in Sodden San Antonio	NBC News. May 28, 2013
Crews Recover Teen's Body from Big Sioux River	KOTA News (Sioux Falls, South Dakota) March 15, 2013
Five-year-old Renton Girl Nearly Drowns in Detention Pond; Is Fence the Answer?	pnwlocalnews.com (Renton, Washington) June 28, 2012
A Harrowing Journey	*Stormwater Magazine* Editorial June 26, 2012
Missing Leesburg Man Drowns in Drainage Pond	*Loudoun* (Virginia) *Times.com* May 22, 2012
2 Walnut Creek Teens Drowned in Treacherous Stream	*San Francisco Chronicle* February 23, 2011
Lawrenceville Mother Pleads for Help before Drowning in Her Car	*Atlanta Journal Constitution* September 23, 2009
Vigilance Only Line of Defense at Retention Ponds	*Columbus Dispatch* May 10, 2007
Suction in Texas Decorative Pool Apparently Pulled Four to Bottom	*USA Today* June 18, 2004
Boy Found in Retention Pond Dies	TheDenverChannel.com May 13, 2003
Drowning Sparks Protest of Pond	*St. Petersburg Times* June 17, 2001
City Worker Dies after Being Sucked into Drain	*New York Times* March 3, 2001
Teen Friends Drown in Culvert, Storm Runoff Trapped Boys under Water	*Cincinnati Enquirer* September 25, 2000
Denver firefighter dies in flood after saving trapped woman	*Deseret News* August 18, 2000
Tragedy of Girl Drowned in Drain Pipe	*The Oxford* (England) *Mai* May 4, 1998
Parents Pray Son's Death a Message	*The Cincinnati Post* August 21, 1997
Body of Boy Found in Drainage Ditch, Raging Waters Fill Area Culverts during Storm	*Colorado Springs Gazette* August 6, 1997
Man Drowns after Being Swept over Dam	*Springfield* (MO) *News-Leader* (undated)

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Chapter 3
Recommendations for Integrating Public Safety into Stormwater Facility Planning, Design, Operation and Maintenance

3.1 Factors Affecting Approach to Public Safety Protection

Circumstances involving public safety are site-specific in nature and depend on factors such as:

- What level (or levels) of risk will a particular structure pose?
- Does the proposed design envision areas where access is encouraged (such as wading zones), discouraged (where fencing or other measures might be employed) or prohibited (such as inlets to siphons)?
- Is access to the site controlled or not?
- Land use setting. Is regular public access and use of the facility likely because it is in a residential neighborhood or near a school, trail, playground, park or library?
- New facilities vs. retrofitting vs. simply maintaining existing facilities.
- Local standards, criteria, recommendations and design guidelines in literature (see Appendices A and B for examples of safety recommendations from the engineering, planning and landscape architecture literature).
- State or federal laws and regulations that may apply directly or indirectly, such as the Americans with Disabilities Act (ADA) or regulations promulgated by state/federal highway departments and agencies.
- Public comment during planning, design and after the facility is in operation. Public works departments can learn of safety issues from public comments.
- Intent of original designer—is facility being operated and maintained in accordance with original design drawings and associated documentation, including goals and objectives?
- History of public interaction with existing facilities; for example, are children known to play in an existing channel or pond that is being modified? Have accidents occurred at the location of interest?
- Topographic, geologic and hydrologic characteristics (including rainfall characteristics) of tributary drainage area.
- Legal considerations, including local legal precedents that may be pertinent.
- Capital and operation and maintenance costs, and available funding (and funding constraints).

When planning, designing, inspecting and operating/maintaining stormwater facilities, site-specific factors of this kind should be carefully considered and accounted for. In addition, the close interdependency among public safety practices, including emergency access, frequency of inspections/maintenance and facility appearance should be recognized. In general, safe facilities are regularly inspected and maintained and are visually appealing (or at least are not eyesores). By contrast, facilities that fall into disrepair and are unsightly often pose public safety concerns. The photographs in Appendix C provide examples of this.

3.2 Practices for Protecting Public Safety at Urban Stormwater Management Facilities

Experience has shown that a wide variety of general practices can be adopted to reduce public safety risks at urban stormwater facilities. Examples are provided in Table 2; however, this table is not intended as a checklist for all projects. The use of the listed items needs to be considered in light of local conditions, the intent of the facility, its design features and multiple other factors, as not all items on the list are appropriate for all facilities. Section 3.3 provides guidelines for specific kinds of facilities, such as ponds and channels. Specific issues such as mosquito management and appropriate use of fencing are addressed in Section 4. Appendix C provides photographs related to public safety, while Appendix D provides conceptual design drawings for various facilities.

In general, land planners, landscape architects and engineers are encouraged to plan and design attractive, multiple purpose facilities that appeal to the public and are regularly used. Facilities of this kind are generally well maintained, regularly observed, viewed as amenities and less likely to be vandalized, all of which promote public safety.

Table 2
General Practices for Protecting Public Safety at Urban Stormwater Management Facilities[1, 2]
(See Appendices C and D for examples.)

	Applicability		
Practice	*Project Planning and Design[3]*	*Structural Measures[4]*	*Facility Inspection, Operation and Maintenance[5]*
Promote public education regarding drainage and flooding safety risks, and respond to public input during planning and design (see Sections 4.5 and 4.6).	✓		✓
Train maintenance staff to evaluate facilities for hazards to both the maintenance staff themselves (for example, suction forces when plugged pipes are cleaned) and to the public. Provide regular inspection and maintenance. Include public safety concerns as a checklist item on facility inspection forms.	✓		✓
Train emergency response staff regarding special situations that may arise. Design operations manual should include section for hazard training and include design information that would be helpful for those charged with rescue operations (such as local fire department), including any specialized equipment necessary.	✓		✓
Plan facilities that are visible and accessible through appropriate development plans, grading plans and by assuring adequate access and egress.	✓	✓	
Use graphic warning signs.	✓		✓
Utilize railings and fencing that are visually appealing and which match the historic character of the area for barriers.	✓	✓	✓
Plant dense vegetation (as barrier).	✓	✓	✓
Provide mild slopes leading to edge of channels, ponds and other facilities, including for earthen embankments.	✓	✓	
Provide flat bench above the design water level around perimeter of channels, ponds and other facilities that store or convey stormwater.	✓	✓	
Utilize mild slopes within channels, ponds and other basins (below design water surface elevation).	✓	✓	

	Applicability		
Practice	*Project Planning and Design*[3]	*Structural Measures*[4]	*Facility Inspection, Operation and Maintenance*[5]
Integrate flat bench ("safety bench") below design water surface elevation in ponds and other impoundments.	✓	✓	
Utilize setbacks from ponds, channels and other facilities for trails, playgrounds, picnic tables and other multiuse structures.	✓	✓	
Adopt conservative trail design criteria near stormwater facilities for visibility requirements, maximum allowable grades, minimum sight distances, and minimum distance above normal water surface elevation and specified flood elevation.	✓	✓	
Consider risks related to slipping/insecure footing when planning, designing and maintaining areas adjacent to and within channels, ponds and other facilities.	✓	✓	✓
Provide mild ramps (for access and egress), ladders, safety ropes or similar practices for ponds, channels and other facilities, especially those subject to rapid rise.	✓	✓	✓
Implement effective and timely flood warning and a well-planned and rehearsed response plan or multi-hazard mitigation plan, as discussed in many documents prepared by FEMA.	✓		
Facility owners can include protection of public safety in contract documents and project agreements.	✓		
Local governments can provide design criteria related to public safety.	✓		
Properly maintain safety features such as racks, railings, fences and vegetation barriers, remove trash, control algae and otherwise keep facility functional, attractive and safe.			✓
Have periodic meetings where local engineers, planners and landscape architects interact and share ideas to promote public safety. Include attorneys who can address professional liability considerations.	✓		✓
Facility design team members (owner, contractor, engineer, site planner, landscape architect, local government and others) meet to review potential safety practices.	✓		

	Applicability		
Practice	*Project Planning and Design*[3]	*Structural Measures*[4]	*Facility Inspection, Operation and Maintenance*[5]
For below-grade crossings, attempt to use bridges for sight distance and egress, which also facilitates maintenance.	✓	✓	
Train maintenance staff to recognize increased hazards caused by vandalism, such as the removal of safety racks, plugging outlet pipes and others.			✓

1. This is a list of representative examples; it is not comprehensive and is not intended as a checklist. Use of measures is highly site specific.
2. Regular inspection and maintenance are recommended for all urban stormwater facilities.
3. Practice that can be considered for use during project planning and design, for both new (proposed) structures and existing ones.
4. Physical facilities or features that contribute to safety such as racks at pipe inlets and mild side slopes.
5. Practices that would typically occur during facility inspection, operation and maintenance.

3.3 Additional Practices for Protecting Public Safety for Specific Categories of Urban Stormwater Facilities

This list of representative examples is not comprehensive and is not intended as a checklist. Use of the measures is highly site specific. Consider using this list on a site-specific basis and use in conjunction with the general recommendations from Table 2; see Appendices C and D for examples. Regular inspection and maintenance are recommended for all urban stormwater facilities.

Stormwater Retention and Detention Ponds

- Flat or mildly sloping bench around pond perimeter and above the normal water surface (maximum 6 horizontal [H] to 1 vertical [V]; 6H:1V). Vary the side slopes around the pond to present a more natural and aesthetic appearance if terrain and right-of-way restrictions permit.
- Mild side slopes from pond edge below water to safety bench (no steeper than 3H:1V and milder if feasible; many references suggest maximum slope of 4H:1V).
- Safety bench around pond perimeter, typically 0.5 to 2 ft below normal water surface elevation and 4 to 8 ft wide.
- If clay, synthetic or plastic liners are used to minimize seepage, cover with gravel, roadbase or other material to provide footing and/or utilize other measures to enable egress.
- Design outlet structures to minimize risk of a person being pushed, pinned or sucked into outlet pipe. Trash/safety racks should be considered on a case-by-case basis. Hinged racks facilitate cleaning.
- Use caution with locating inflow and outflow drain pipes. Avoid situations where pond outflow pipe is directly across from and a short distance away from a storm drain that discharges into pond.
- Where appropriate, plant aggressive, thick and thorny vegetation along pond perimeter to discourage access to particular areas, such as where side slopes are steep or near the outlet structure. (Note: Vegetation to discourage access must be balanced against the need to provide egress from the pond if someone falls or wades in.)
- To accommodate ponds within site constraints, it may be necessary to use retaining walls, which should be designed with public safety in mind. For example, stepping a wall down with intervening terraces may be preferable to a single relatively high wall.
- Discourage public use of dry basins subject to rapid water level rises during floods and provide warning signs.
- Adopt measures to reduce mosquito risk (see Section 4.4).
- Address standard dam safety requirements where applicable related to (for example) spillway adequacy, outlet structure integrity and operation, embankment stability, seepage control, etc. See Section 4.7 for additional information.

- With pond design and operation, it can be beneficial to identify a redundant overflow path if the outlet structure becomes clogged with debris or vegetation. In some instances, even though a rainfall event may be less than the design storm, the pond can fill to a higher elevation than the design level. If there are structures adjacent to the pond that have a minimum opening elevation only slightly above the maximum design elevation and if the outlet clogs, they could be flooded. An effective redundant system would be to establish the minimum opening elevations to be higher than the embankment overtopping elevation, with freeboard.
- Educating homeowners and maintenance personnel on mowing and vegetation maintenance around ponds can be helpful. Debris or clippings that are of a certain size, if left, increase the risk of clogging the outlets. Also, some homeowners along a pond discard their tree and brush clippings into or next to the pond, and this can exacerbate flood risks and increase safety hazards.
- In retention ponds, local residents sometimes “extend” the riser to create a higher permanent pool. Maintenance staff should check for this, because it can decrease the capacity of the pond and increase flooding and safety hazards.
- Remember that one of the benefits of providing storage is that, if properly designed, storage can reduce “flashiness” of urban streams (particularly in smaller drainage areas), thereby enhancing the potential for escape.

Open Channels

- Avoid supercritical flow, if feasible. Utilize maximum allowable channel velocities and depths for specified return frequency flows (see Appendix B for guidance on calculating forces for different flow depths and velocities). Note: It is essential to recognize that during runoff events, many channels will have combinations of depths and velocities that are greater than a person can withstand. This situation obviously cannot be avoided, but many practices can be adopted (as defined in this document) to reduce the risk of a person being in a major drainageway during flooding conditions in the first place.
- Use mild side slopes, no steeper than 3H:1V, but preferably milder (many references recommend 4H:1V or flatter). If mild side slopes are not an option, such as with a channel with vertical walls, utilize alternative safety measures.
- Assure adequate access/egress and sound footing for pedestrians and access for maintenance equipment.
- Because many open channels are adjacent or proximate to public trails, use proper trail design criteria, discussed below.
- Mitigate hazards posed by low dams (including “collapsible” dams operated by air bladders), weirs and other hydraulic structures; see discussion below for recommendations.
- Carefully analyze channel hydraulics and minimize hydraulic jumps, standing waves, eddies, reverse rollers (downstream of low-head dams) and other flow conditions that can be hazardous, especially where contact with the waterway is encouraged.

- Where appropriate, use warning signs along channel banks. Warn public of rapidly rising flood waters in floodways and floodplains that are normally dry, particularly in locations such as “washes” in arid/semiarid areas where the public would have no indication of risk.
- Where recreational boating is anticipated, address boating safety issues during design, construction and maintenance. For example, grade control structures and drop structures should be designed to accommodate boating; low chord bridge elevations must be high enough to enable boater passage; and adequate depths need to be provided to accommodate the kinds of boats that are anticipated. Boaters must be able to get out of the channel rapidly if the waterway is subject to quick rise.
- Some open channels have reaches that transition into closed conduits—see discussion below regarding culverts and long underground pipes.
- Fencing/railings frequently are used along open channels, such as at the top of steep banks, concrete retaining walls or at significant channel transitions.
- Near schools, libraries, parks and other locations where children are likely to be present, provide good visibility to the extent feasible (recognizing that many communities require natural buffer zones that have trees and other vegetation that cannot be removed, except for footpaths).
- Complex channel geometries with multiple terraces and a narrower and farther removed thalweg (channel bottom) can be safer than wide uniform channels where a sudden flood wave would be uniformly experienced and may not be easily escapable. Slow flowing pools can provide refuge for someone who falls in.
- Design, construct and maintain channels to provide positive flow and to minimize stagnant pools that are conducive to mosquito growth, sediment deposition, algae and other aesthetic problems. Also utilize design approaches to facilitate access for debris, trash and sediment removal. Velocities should be adequate to minimize accumulations of sediment and algae, where feasible.
- Discourage homeowners from encroaching on the channel right-of-way, as this can destabilize banks, with associated safety concerns.
- In wide open channels, provide sloped ramps to the channel bottom to facilitate easier and safer maintenance operations for removal of large debris, such as trees and for sediment removal. The ramps should provide access/egress to the channel in the downstream direction so water cannot flow up the ramp and possibly flow out of the channel.
- Long reaches of channel with vertical walls or steep banks may require stairs, ladders, escape ramps and/or other means of egress.
- Restoring channels to a more natural condition, including (for example) the integration of a “slow flow” channel for base flows (often with meanders), creation of wetlands, plantings adjacent to the channel and in the riparian zone and utilization of “natural” approaches for bank stabilization generally provide many benefits and are conducive to reducing public safety risks.

- Evaluate the overflow path(s) for the channel under various assumed scenarios; that is, when the capacity of the channel is exceeded, what path(s) will the overflow take?

Culverts and Long Underground Pipes

These guidelines are adapted, with edits and additional discussion, from the *Urban Storm Drainage Criteria Manual* (2001b Volume 2; 2010 Volume 3), published by the Urban Drainage and Flood Control District, Denver, Colorado.

- The use of trash/safety racks at inlets to culverts (typically of relatively short length, equivalent to roadway or other embankment width) and long underground pipes (referring to pipes that are relatively long and that a person would be trapped in for minutes, and almost certainly killed, if swept in) should be considered on a case-by-case basis. While there is a sound argument for use of racks for safety reasons, field experience has shown that when the culvert is needed the most, that is, during the heavy runoff, trash racks can become clogged and the culvert is rendered ineffective. Hinged racks offer maintenance advantages.
- A general rule of thumb is that a trash/safety rack will not be needed if one can clearly "see daylight" from one side of the culvert to the other, if the culvert is of sufficient size to pass a 48-inch diameter object and if the outlet is not likely to trap or injure a person. By contrast, at entrances to longer culverts, long underground pipes and inverted siphons and for culverts not meeting the above-stated tests, a trash/safety rack is necessary.
- Consider depth and velocity of upstream flow, the local currents in the vicinity of the culvert entrance, the general character of the neighborhood and whether it has a residential population nearby, the length and size of the culvert, and other factors affecting safety and culvert capacity. Furthermore, in the event that someone was carried to the culvert with the storm runoff, the exposure hazard may in some cases be even greater if the person is pinned to the grating by the hydraulic pressures of the water rather than being carried through the culvert. Larger, oversized racks positioned well in front of the culvert entrance can reduce the risk of pinning. Guo *et al.* (2010) have prepared guidance on calculating pinning forces involving ponds and outlet structures.
- Where debris potential or public safety indicates that a rack is required, if the pipe diameter is more than 24 inches, the rack's open surface should be at least 4 times larger (some practitioners suggest factors larger than 4, with values up to 10 recommended). For smaller pipes, the factor increases significantly as suggested by Figure 4.
- For culverts larger than 24 inches (i.e., in the smallest dimension), in addition to the trash rack having an open area larger than 4 times (or more) the culvert entrance, the average velocities at the face of the rack should be less than 2 feet per second at every stage of flow entering the culvert.
- The rack should be sloped no steeper than 3H:1V (the flatter, the better) and have a clear opening at the bottom of 9 to 12 inches to permit debris at lower flows to go through. The sloping rack allows debris to "ride" to the top of the rack and

facilitate removal. The bars of the face of the rack should generally parallel the flow and be spaced to provide 4.5- to 5-inch clear openings between them. Transverse support bars and beams may be needed to keep the rack from collapsing under full hydrostatic loads.

- There are frequently recommendations against the installation of trash racks at culvert *outlets,* because debris or a person carried into the culvert will impinge against the rack, preventing escape by the person and leading to pressured conditions within the culvert, virtually destroying its flow capacity and creating a greater hazard than not having one.
- Inverted siphons in urban areas pose particular risks, and all reasonable steps (with redundancy) are recommended to reduce the risk of someone entering a siphon. Recommended steps include warning signs, fences, a rack upstream from the pipe entrance and ladders in the channel upstream. Public education can also be valuable in surrounding areas.
- Monitor embankment and upstream and downstream channel conditions at culverts, as recommended in culvert design and maintenance manuals published by the Federal Highway Administration, American Association of State Highway Transportation Safety Officials (AASHTO) and state highway departments.

Low-Head Dams/Weirs

Low-head dams are widely recognized to pose safety concerns if their hydraulic characteristics are not properly designed over a range of flows. However, there are also many examples of cascading pools and step-pool designs which have 1- to 2-foot drops and which were properly designed with public safety in mind.

The following five guidelines are adapted from the article "Hidden Dangers and Public Safety at Low-head Dams" by Bruce Tschantz and Kenneth Wright, which appeared in the *Journal of Dam Safety*, Volume 9, Issue 1, 2011, with edits and additions by the authors and reviewers of this Guidance.

As the number of people attracted to water recreational opportunities increases, water-related accidents and deaths are inevitable, but engineers, state and federal officials, boating safety organizations and recreational watercraft organizations need to work together to reduce or eliminate the environmental hazards at low-head dams. A five-step approach is proposed to reduce the risk to the public from dangerous conditions at low-head dams.

1. Public awareness programs that promote safety education and cognizance of the potential dangers at low-head dams. These programs would require the cooperation of several communities: the boating public, including national canoeing, rafting, kayaking and boating organizations; local clubs; design engineers; dam owners; public officials, including legislators and local, state and federal regulators; and boating safety and boating law administrator organizations to better educate swimmers and watercraft users.
2. Warning markers and appropriate warning signs and buoys, escape, portage, safety and other devices at low-head dams. It is essential from a public safety standpoint that dams be marked to warn the public of their existence and the potential hazard, especially as a result of changing flow conditions.

3. Structural modification of low-head dams. The physical hazard to boaters, fishermen and swimmers around and below low-head dams needs to be reduced or eliminated whenever practical. Practical alternatives include full or partial dam removal; use of engineered structures like stepped spillways, gabion baskets, flat slopes, cascading pools or dumped rock to dissipate energy and elimination of the "keepers" (reverse rollers); chutes to accommodate boaters; and portage ways for boaters to safely bypass a dam.
4. Rescue training programs to help state and local water rescue professionals understand and respond to the special hazards created at low-head dams.
5. Develop comprehensive national guidelines for public safety at dams for identifying potential hazards and evaluating risks; changing operating practices; installing hazardous warning systems, signage and safety controls; developing site-specific safety plans and inspection and maintenance programs; and developing a continual review and improvement process for dam owners and operators, design engineers, and other stakeholders.

Low head dams and vertical drop structures are best avoided, whenever feasible. They look pleasant and innocuous to the public, but can be very dangerous. Retrofitting with a sloping downstream face is often feasible. There are examples of safe cascading pools and step pool designs in current literature (such as conference proceedings of the cosponsors of this document). When inspecting low head dams, check for abutment erosion ("flanking"), as this is frequently observed and poses various safety risks. Providing good access to these dams for trained safety/ emergency staff is valuable.

Small Earthen Dams

See Section 4.7 for considerations.

Water Quality Control Measures (BMPs), Including Low-Impact Development

These guidelines are adapted from the WEF/ASCE 2012 Manual of Practice *Design of Urban Stormwater Controls,* with additional discussion and edits provided by the authors and reviewers of this Guidance.

- <u>Cisterns</u>: Consideration must be given to selecting rain barrels and cisterns that are vector proof and childproof. If a cistern is provided with an operable valve and water is stored inside for long periods, the cistern must be covered to prevent mosquitoes from breeding. Large cisterns should have the same safety precautions of any potable water storage tank.
- <u>Forebays</u>: The size of the forebay and the lateral sill or spillway between the forebay and the primary control should be designed using accepted engineering practices to prevent the forebay from overflowing onto adjacent property and to protect the basin's embankment. Side slopes of 4H:1V or flatter will facilitate maintenance such as mowing and reduce public risk of slipping and falling into the water. In addition, a littoral zone should be established around the perimeter of the forebay to promote the growth of emergent vegetation along the shoreline and deter individuals from wading.

- Vaults and other underground facilities: Vaults are often used on sites with constrained rights-of-way. They are below-grade structures that require relatively small footprints, and can be safer for children and pedestrians than open controls such as wet basins, provided that access is restricted and that they are well maintained and do not create mosquito habitat. Special safety needs for underground facilities need to be recognized and clearly marked. The presence of toxic gases or lack of oxygen requires special closed entry protocols (confined space entry) for maintenance personnel and warning signs to the public at all the entrances describing such hazards if entry is attempted. In addition, deep and dangerous drops into them through access entry points need to be identified.
- Oil and water separator: Similar to vaults, oil/water separators are below-grade structures that require relatively small footprints, and are safer for children and pedestrians than open controls such as wet basins.
- Swales: Properly designed swales present few safety hazards given the shallow water depths at the treatment design capacity. Greater depths can occur if there is no bypass for large runoff events but nonetheless will normally have lesser depths and velocities than found in traditional road ditch design. Rock treatments may be used at inlets where sediments may accumulate and/or erosion may occur. The design should include some means of reducing energy of the flow as it enters the upper end of the swale, and spreading the flow across the swale width. Swale design and maintenance practices should minimize standing water that is conducive to mosquitoes, and where swales adjoin sidewalks and curbs, proper footing must be provided.
- Vegetated filter strips (grass buffers): Properly designed vegetated strips present few safety hazards as they should support very shallow water depths at design capacity. As with swales, strips should be designed to blend into the landscape.
- Surface sand filter: Materials collected by surface sand filters will build up on the surface, creating unsightly conditions if not routinely maintained. This can become a safety issue if there is prolonged ponding that is conducive to mosquitoes. Filter facilities should have mild side slopes to minimize the risk of falls, or be fenced to limit entry.
- Subsurface sand filter: Subsurface sand filters are generally not visible and thus present few safety concerns if routinely maintained. Poor maintenance may cause the filter to clog, restricting release rates and potentially causing flooding or bypassing without adequate treatment. Often, entrance into the subsurface sand filters, for maintenance or inspection, is considered a confined space issue, and therefore proper personnel training and equipment are necessary.
- Bioretention/bioinfiltration/rain gardens: Sites with large sediment loads collected by bioretention control measures can build up on the surface when sediment loads are higher than what the surface mantle can assimilate. The buildup may clog the surface if not corrected. Systems should be periodically inspected for ponded conditions several days after rain events to avoid unsightly conditions and possible mosquito breeding. Sites that are not readily

visible require scheduled inspection. Maintenance should include removing sediment at entrances and vegetation removal. Shallow bioretention systems usually do not involve large ponding depths (6 – 18 inches); therefore, the associated risk is reduced. Large facilities need to consider public safety if the ponded depth is significant.

- Landscaped (green) roofs: Extensive landscaped roof systems are not typically designed for public access and thus present few safety concerns. Intensive roof designs require more maintenance, largely to support their aesthetic and recreational uses. Roofing materials and drainage principles appropriate for any roofing system also apply to landscaped roofs to prevent leakage.
- Drain inlet inserts: Clogged filter inserts provide little pollution removal and may result in flooding unless a bypass or overflow is provided.
- Manufactured filters: Manufactured filters are generally installed underground in chambers and present few safety concerns if they are designed to completely drain and are routinely maintained.
- Subsurface gravel wetlands: Subsurface gravel wetlands are similar in context to bioretention systems and thus present few aesthetic and safety concerns if routinely maintained. Poor maintenance may cause the gravel/stone to clog, restricting release rates and potentially causing flooding, bypassing without adequate treatment or mosquito problems. The subsurface gravel wetland is not limited by cold weather and freezing of the stone.

Public Trails

Trails next to a drainageway

- The low elevation of trails should be placed above a prescribed water surface elevation, often in the range of the 5- to 10-year flood, but strongly influenced by local criteria and site-specific hydrology. When establishing trail elevations, and as described in detail in Appendix B, be cognizant of forces that would act upon a person under flood conditions. A generalized "rule of thumb" is that if the product of depth × velocity is greater than a factor of 6 to 8 (depending on the source) hazardous conditions can exist for a person.
- No section of a trail should be isolated during the design storm without a means of escape through publicly accessible space.
- Side slopes from a trail should be 4H:1V or flatter to a point above the 100-year floodplain; areas with steeper slopes should have terraced walled sections that are designed for rapid exit (escape) in the event of rapid water rise.
- Trails should have a hard surface, generally not exceed a 5-percent slope and adhere to requirements of the Americans with Disability Act, to the extent feasible. Slopes can be steeper for soft surface trails.
- Allow ample opportunity for bicyclists to make turns and to stop safely, particularly where children are likely to frequent the area. Provide good lines of sight and pay careful attention to horizontal and vertical curvature.
- Pervious (porous) pavements tend to not get black ice from refreezing; consequently, they should be considered for pedestrian paths.

Trails next to walled channels

When feasible, channels should not be walled in reaches next to trails, because during flood events, walled channels can quickly fill, becoming highly dangerous. However, sometimes right-of-way availability, project budgets or other factors dictate that a walled section will be utilized. In walled sections of channels, consider no more than 300 to 500 feet of trail without an exit route above the 100-year floodplain, and of particular importance is the provision of egress upstream and downstream from underpasses. Site-specific design criteria should also be developed for velocity, depth and drag forces for various return frequency flows. With walled channels, consideration should be given to aesthetics and crime prevention to ensure that they do not have real or perceived effects on public safety.

Pedestrian paths that function as a secondary outlet structure (such as culverts)

- Pedestrian paths that also provide flood conveyance can be difficult to design. Such designs are efficient in terms of budget and construction, but special consideration needs to be taken concerning risks to the public. When it is raining, pedestrians will seek shelter in secondary outlet structures.
- Where applicable, escape paths must be available at both the upstream and downstream entrances to the culvert.
- A pedestrian culvert must have a continuous sight line to allow pedestrians entering the culvert to see out the other side in case water is rising. Also, a continuous sight line allows pedestrians to see if bicyclists are speeding through the culvert or other dangerous situations exist within the culvert.

Signage (“Climb to safety” or “Do not enter if water on trail”) and public education are essential at these facilities. Because pedestrians seek shelter inside culverts of this kind, warning signs should be placed both inside on wall and outside the pipe.

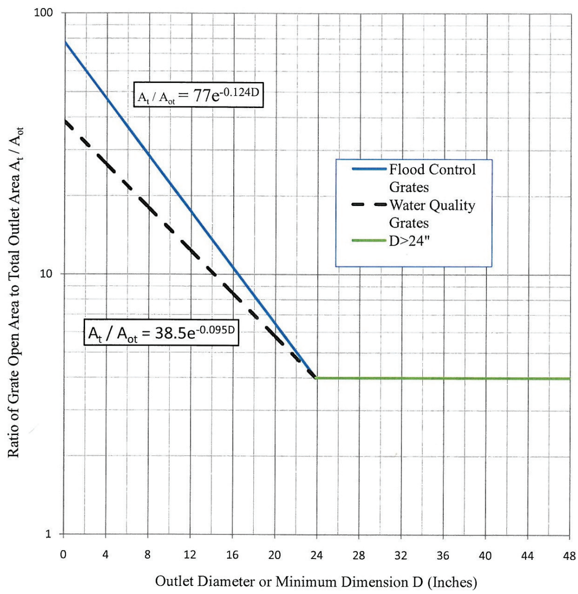

Figure 4. Trash Rack Sizing

Note: Figure 4 presents a minimum rack area to pipe cross sectional area ratio of 4, for pipes greater than 24 inches in diameter. This should be considered a minimum, and various references and reviewers of this guidance document suggest larger ratios, up to a factor of 10.

Source: Urban Drainage and Flood Control District (2010c); reproduced with permission.

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Chapter 4
Guidance for Specific Topics

4.1 Recommended Periodic Safety Evaluations and Comparing and Prioritizing Hazards

Storm drainage systems should be periodically reviewed and evaluated by facility owners for public safety and the safety of maintenance staff. There are clear differences between older stormwater facilities and facilities associated with new development or redevelopment. Over time, it can be expected that safety standards would be higher in the case of new development and redevelopment than they are with older stormwater facilities, due to the evolution of engineering and safety practice. This implies that older facilities may become obsolete (even substandard) from the perspective of public safety even though their performance is otherwise adequate. It follows that the factors that trigger a safety review are different from factors motivating a review of other aspects of functionality, and the schedule for a safety review may vary from the schedule for other reviews.

Safety should not be reviewed only when there is a detected degradation in facility performance or an accident occurs; rather, safety evaluations should be scheduled on a cycle that is driven by such factors as facility history, public reaction and the evolution of the standard of practice in this area. When facilities are identified that pose clear risk to the public (based on review of planning and engineering literature, state and local drainage criteria and standards [e.g., Northeastern Planning Commission 1990], case law, and professional judgment and experience, or when an accident occurs or a health or safety issue is identified), the responsible public and private entities need to make a record of the relevant facilities, compare and prioritize the relative risks, and proceed to mitigate the risks as feasible, given constraints related to funding, inspection and maintenance budget, staff availability and other factors.

This suggested and regular review of stormwater facilities is not peculiar or unprecedented. For example, in most states throughout the U.S., all dams (that meet certain criteria) are regularly inspected by the state engineer and their condition, recent improvements and recommendations for further improvements to assure dam safety are noted; see Section 4.6 for additional discussion.

4.2 Special Considerations for Children

Of particular concern are safety risks to children of all ages, including teenagers, which pose special considerations and challenges regarding (for example) maximum side slopes, shallow safety bench requirements, railing heights, pipe openings, etc. The intent is not to address infants or toddlers who are presumably under the control of a parent or guardian, but to consider the problem of children who are old enough to not be under continuous adult supervision and who might gain access to a facility in an unsafe way or might be swept toward a facility by rushing water.

Approaches that can be used to minimize risks to children during facility planning, design and operation/maintenance include, as examples:

- Evaluate the necessity of locating a stormwater facility close to a school, playground or other locations where children are likely to congregate.
- If it is necessary to establish a facility near a location that is likely to have children, or if an existing facility is being retrofitted in such a location, the design approach should integrate multiple layers of safety to the extent feasible.
- The site layout process is particularly important as it relates to children. As examples, children may not be able to make sudden turns on bicycles, children tend to underestimate the risks posed by steep slopes and children like to enter pipes that are unprotected (which lack racks), including during times that water is flowing into the pipe.
- When evaluating the need for racks at pipe inlets, recognize that children are small and can be pushed or sucked into and wedged into pipe openings as small as 15 inches in diameter.
- For retention and detention ponds and other facilities that involve basins, it is particularly important to utilize mild side slopes above and below the normal water surface and to integrate a safety bench.
- When stormwater facilities are located in residential communities, community education via neighborhood meetings, newsletters and signs is important.
- Consider design approaches that will reduce flow rates (thereby reducing channel depths and velocities) such as providing storage, encouraging infiltration, disconnecting directly connected impervious area and using wide, densely vegetated (slow flow) channels, when practical and consistent with other objectives.
- LID practices typically have fewer safety hazards than conventional approaches, and their use should be encouraged where children are anticipated and they are otherwise feasible.
- Smooth concrete trickle channels in pond bottoms can be attractive for skateboarders and roller-bladers, so designers should give consideration to roughening the surface or making other adjustments to discourage use.

4.3 Considerations Regarding Fencing

Although attractive, well designed and maintained fences, along with railings and guardrails, have their place in the repertoire of safety management practices, exclusive reliance on them as a safety measure is not recommended. Fences are not always compatible with public safety. To some children, scaling a fence is a challenge, and this can pose risks. Stockade fences can block vision and impede emergency access and escape and provide a safe haven for undesirable activity that is not in sight of security or police patrols.

In general, fencing may be appropriate in cases where access would be restricted, in areas that are out of sight or where unusual safety circumstances exist. The need for fences will often be readily apparent or they are required to comply with local and national building codes, such as at the top of retaining walls or culvert headwalls. In many cases, safety railings are an appropriate alternative to fences.

Legal considerations may drive requirements for fencing. Specifically, the issue of potentially creating a stormwater facility that becomes an “attractive nuisance” is an increasing professional liability. The use of fencing, plant materials and other obstacles to limit access to a stormwater facility can imply that the facility is a hazard and needs protection from public access. More realistically, the slope, access, barrier and edge of the stormwater facility need to be carefully planned and designed to either reasonably “encourage” public access or “discourage” public access. The photographs in Appendix C provide examples of appropriate fencing.

4.4 Mosquito Control

Mosquito control is an important aspect of public safety that is referenced in Section 3 of this Guidance. This section provides additional background. Illnesses such as West Nile virus, encephalitis and eastern equine encephalomyelitis, all carried by and transmitted through mosquitoes, indicate that integrating mosquito control measures into the planning, design and maintenance of stormwater facilities is necessary and may provide significant health benefits.

Some of the key facts on mosquito breeding include:

- A mosquito life cycle consists of four stages (egg, larva, pupa and adult). Mosquitoes must lay their eggs in stagnant water because the larvae and pupae must have standing water in order to survive.
- Although mosquitoes prefer shallow, stagnant water, they can breed within the top 6 to 8 inches of deeper pools.
- Mosquitoes need nutrients and prefer shelter from direct sunlight.
- Mosquitoes can go from egg to adult within 72 hours.

Considerations include the following:

1. To prevent (or limit) the production of mosquitoes, water should not be allowed to remain stagnant for more than 48 to 72 hours. Many local governments have regulations that require stormwater BMPs to fully drain within 48 to 72 hours (some even use 24 hours).
2. Integration of a “micropool” immediately upstream from the pond outlet structure (see design guidance in the 2010 *Urban Storm Drainage Criteria Manual,* Volume 3, published by the Urban Drainage and Flood Control District) can reduce mosquito problems.
3. Establish vegetation around the pond perimeter to provide and restore habitat for mosquito predators and take other steps to create an active biological community. Consider stocking ponds with native fish and macroinvertebrates,

which will feed on the larvae and prevent them from hatching. Another alternative for small retention ponds is for fountains to assure the water surface fluctuates, which can drown the larvae; however, the influence of fountains can be localized and they will not be effective for mosquito control in large ponds.

4. Minor increases in channel and pond bottom slope and the use of underdrains can improve drainage and reduce standing water.
5. Preserve natural drainageways, where mosquitoes have natural predators.
6. Attempt to avoid using underground structures where they are likely to remain wet due to a high groundwater table or the geometry of the installation.
7. Incorporate features such as properly designed trash racks to reduce the possibility of clogged discharge orifices.
8. Reduce reliance on barriers, diversions or flow spreaders that may retain shallow, quiescent water.
9. Pipes should be designed and constructed for a rate of flow that flushes the system of sediment and reduces water backup in the pipe, where feasible (sheltered environments inside storm drains can promote mosquito breeding).
10. For sumps, wet vaults and catch basin designs, consider appropriate pumping, piping, valves or other necessary equipment to allow for easy dewatering of the unit, when necessary. Certain proprietary larvaecides can be added to vaults to provide some control.
11. Provide for regular inspection of stormwater facilities to detect developing mosquito populations.
12. Consider integrating biological control, vegetation management and other physical practices into stormwater facility design for long-term management of mosquitoes.
13. Remove trash and debris such as cups and bottles that provide ideal breeding habitat.

In general, the key to reducing mosquitoes is diligent field monitoring and maintenance to reduce extended ponding of runoff. Field personnel should be trained accordingly.

There are other disease vectors such as rodents and problematic insects such as fire ants, etc., that pose a health and safety risk. Infestations or outbreaks need to be addressed through proper pest control methods, discussed in other literature.

4.5 Importance of Public Education and Communication

Educating the public on the benefits and potential hazards of stormwater and flood management facilities is essential. Education efforts should involve the public (with special emphasis on schoolchildren and their parents), facility owners, landscape architects, land planners, design engineers, other design professionals, governmental and regulatory staff, public and private sector maintenance professionals, neighborhood groups, elected officials and others. These education efforts can be conducted on a systemwide basis or focused on an individual facility or a group of facilities. In developing such education efforts, it is important to describe not only hazards, but also the necessity and benefits of the facilities, how the hazards are being mitigated and why the selected mitigation measures were chosen.

4.6 Public Education Regarding Flooding

The American Red Cross (2009) offers the following advice on floods:

- Listen to area radio and television stations and a NOAA Weather Radio for possible flood warnings and reports of flooding in progress or other critical information from the National Weather Service.
- Be prepared to evacuate at a moment's notice.
- When a flood or flash flood warning is issued for your area, head for higher ground and stay there.
- Stay away from floodwaters. If you come upon a flowing stream where water is above your ankles, stop, turn around and go another way. Six inches of swiftly moving water can sweep you off your feet.
- If you come upon a flooded road when you are driving, turn around and go another way. If you are caught on a flooded road and waters are rising rapidly around you, get out of the car quickly and move to higher ground. Most cars can be swept away by less than two feet of moving water.
- Keep children out of the water. They are curious and often lack judgment about running water or contaminated water.
- Be especially cautious at night when it is harder to recognize flood danger.
- Because standard homeowners insurance doesn't cover flooding, it's important to have protection from the floods associated with hurricanes, tropical storms, heavy rains and other conditions that impact the U.S.

4.7 Small Earthen Dams for Stormwater Impoundments

The design, construction, inspection and operation/maintenance of small earthen dams at stormwater impoundments such as retention and detention ponds, wetlands, infiltration basins or others, involves many facets of public safety. Representative examples include the risk posed by dam failure during overtopping under flood conditions, perhaps due to an undersized spillway; overly steep side slopes; tripping and falling hazards; hazardous hydraulic conditions; "dry weather" failure due to piping (water flowing through an earthen embankment outside of, rather than inside of, the outlet pipe); the possibility of a person becoming pinned against an outlet pipe that does not have a trash/safety rack at the inlet (Guo and Jones 2010); and geotechnical/structural deficiencies that can lead to failure. Dam designers, inspectors and maintenance staff should be familiar with these issues and address them in accordance with the extensive engineering literature available on dam safety published by federal and state governments and professional organizations, including, as examples:

- *Federal Guidelines for Dam Safety*. FEMA 93. Federal Emergency Management Agency. April 2004.
- *Dam Safety: An Owner's Guidance Manual*. FEMA 145. Federal Emergency Management Agency. 1987.
- *Safety Evaluation of Existing Dams (SEED): A Manual for the Safety Evaluation of Embankment and Concrete Dams.* A Water Resources Technical Publication. United States Department of the Interior Bureau of Reclamation. 1986.
- *Dam Condition Assessment Guidelines for Embankment Dams.* BLM Handbook H-9177-1. Bureau of Land Management. September 2006.
- *Dam Safety Public Protection Guidelines.* U.S. Department of the Interior, Bureau of Reclamation Dam Safety Office. August 2011.
- *Earth Dams and Reservoirs*. TR-60. United States Department of Agriculture Natural Resources Conservation Service – Conservation Engineering Division. July 2005.
- *General Design and Construction Considerations for Earth and Rock-Fill Dams*. Engineering Manual 1110-2-2300. Department of the Army – U.S. Army Corps of Engineers. July 2004.
- *Technical Manual for Dam Owners: Impacts of Plants and Animals on Earthen Dams*. FEMA 534. Federal Emergency Management Agency. September 2005.
- *Catalog of FEMA Dam Safety Resources*. Federal Emergency Management Agency. August 2006.
- *2011 ASDSO Publications Catalog*. Association of State Dam Safety Officials.
- *Design of Small Dams*. U.S. Department of the Interior, Bureau of Reclamation. 3rd Edition, 1987.

With regard to public safety issues associated with levees, there is extensive information available from FEMA and the U.S. Army Corps of Engineers, among many sources.

4.8 Miscellaneous Design and Maintenance Issues

Snow and Ice

Design and maintenance of facilities should account for safety issues related to snow and ice in relevant areas. Ice cover and snow can make ponds and waterways hazardous and public education and warnings are important; for example, signs have been used which state, "Ice is never safe." Anticipate areas of potential ice formation and minimize areas of ice to the extent feasible. Many of the recommendations herein such as mild side slopes and safety benches for ponds are valuable when there is ice cover. A frozen permanent pool in a pond may be mistaken for a parking area; bollards or other visible markers can be used. Pervious pavements are advantageous because they are not conducive to black ice formation.

Low Water Crossings and Underpasses

Conveyances that include roadway low water crossings or underpasses can pose great risk to the public, and clear warnings by signage or flashing warning light systems (or both) should be provided if the underlying problem cannot be addressed.

Stream Restoration Projects

Increasingly, degraded stream channels are being restored, and restoration of waterways needs to incorporate health and safety issues. Such projects have great value to the public, but it must be recognized that stream and river restoration projects inevitably "invite" the public to access the water, which emphasizes the need for the safety considerations described herein. Many features of restored streams (those in a more natural condition) are conducive to good public safety, such as multiple levels of benches and terraces, gradual side slopes, good flushing of fine sediment and algae (and thus better footing) and better habitat for mosquito predators, among other features.

Americans with Disabilities Act

Special design requirements may apply to accommodate those with disabilities (see Americans with Disabilities Act for background), and access by those with disabilities should be considered, as appropriate.

Pets and Other Animals

Many of the techniques described in this guidance can be valuable for reducing risks to pets and other animals, such as mild side slopes and racks at pipe inlets.

Ponds with Linings to Reduce Water Loss

At times, impoundments are lined to reduce/eliminate water loss. Pond lining design and installation should consider health and safety. Both synthetic and natural (clay) linings can be slippery and if they are used on steep side slopes without adequate stabilized cover, they can pose a significant public safety risk. Such situations may require retrofitting with a cover material that provides solid footing, such as gravel, larger rock, "geoweb" filled with rock or other, along with ladders and ropes with buoys, among others.

Graphic Signage

Warning signs are valuable if they are easy to understand and in the correct locations (see Figure 5). At highly hazardous locations such as siphon intakes and underpasses with trails, signs that are especially graphic, such as "Extreme Danger" or "High Risk of Drowning," are encouraged.

Figure 5. Warning Sign with Clear, Readily Understandable Text
Source: Jonathan Jones, P.E., D.WRE; reproduced with permission.

Maintenance of Low Impact Development Practices

Onsite facilities such as low impact development features are often maintained by the individual residential or commercial property owners. Local jurisdictions should provide targeted education and training on how to construct and maintain these facilities, including bioswales, rain gardens, green roofs, level spreaders, cisterns, porous pavement and underground gravel detention basins. Initial guidance on this subject is provided in Section 3 and Appendices A and B.

Chapter 5
Role and Responsibilities of Licensed Professional Engineers, Registered Land Planners and Landscape Architects, and Other Design Professionals

The cosponsoring professional societies of this Guidance document advocate that larger stormwater management facilities (those serving multiple lots up to regional facilities) be designed by licensed professional engineers and landscape architects. [Note: The cosponsors recognize that many onsite measures such as rain gardens, swales and filter strips will be designed by landscape contractors, home builders or property owners themselves, without the involvement of a licensed professional engineer or landscape architect.] In all 50 states, the paramount responsibility of licensed professional engineers is protection of public health, safety and welfare. A similar mandate applies to licensed/certified land planners and landscape architects. Licensed professionals should always be cognizant of this when they are planning, designing, overseeing the construction of, or assisting with the operation and maintenance of, stormwater facilities.

The cosponsors recognize that many other professionals such as ecologists, park/recreation specialists, soils and vegetation scientists, vector control specialists, government regulators and others often play significant roles in the planning, construction and maintenance of stormwater facilities. The applicable professional organizations are urged to inform their members of relevant public safety hazards and to provide guidance to reduce the related risks.

Many municipal government agencies, state governments and federal agencies have established safety standards/criteria for storm drainage facilities. All professionals involved with stormwater facilities should be familiar with such requirements (see Appendix B for examples), and should comply with them or provide the equivalent level of safety through alternative measures (if allowed).

Although many local governments (that ultimately have the authority for approving drainage facilities) do address stormwater facility safety, many others do not. In areas where no regulations/criteria apply, those involved with planning, designing, inspecting and maintaining stormwater facilities should nevertheless apply state-of-the-practice approaches that address public safety as they conduct their work.

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Chapter 6
Conclusion and Recommendations

This guidance document should be viewed as only a starting point for addressing public safety in the design and operation/maintenance of stormwater facilities. Stormwater professionals are expected to be conversant with the dimensions of safety not only as articulated herein but as represented by prevailing best professional practice.

Unless site-specific circumstances clearly indicate otherwise, stormwater professionals should assume that members of the public will visit and interact with stormwater facilities in urban areas. People like to be around water, to be involved with it and to become stewards of it. Surveys and academic research have shown that properties adjacent to attractive, well maintained water bodies hold a premium value. The hazards posed to the public by such facilities should be anticipated, discussed with relevant public and private parties, evaluated and mitigated as appropriate. Public education on the purpose of stormwater facilities and their potential dangers (including mitigation) is essential.

The cosponsors of this document recognize that it is impractical, if not impossible, to provide zero risk at stormwater management facilities. Like any other type of public works infrastructure, there are inherent risks associated with conveying, storing, treating and otherwise managing stormwater and there are practical constraints related to budget, access and other factors that preclude complete public protection. Also to be considered is that there are inherent risks associated with natural water bodies. However, failure to consider public safety is not consistent with the standard of care to which professional engineers, landscape architects and planners and other stormwater and public works professionals are entrusted to adhere. Similarly, regular inspection and maintenance are essential to assure that stormwater management facilities function as intended. The American Society of Civil Engineers/Environmental & Water Resources Institute/Urban Water Resources Research Council (ASCE/EWRI/UWRRC), the National Association of Flood & Stormwater Management Agencies (NAFSMA), the American Public Works Association (APWA), the Water Environment Federation (WEF), the American Water Resources Association (AWRA), the American Planning Association (APA) and the American Society of Landscape Architects (ASLA) recommend that protecting public safety should be a key objective when planning, designing, inspecting, operating and maintaining urban stormwater management facilities.

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Appendix A
Representative Quotations Regarding Safety from Previous Publications of Cosponsors

Quotations in this appendix are organized by the following topics:

1. General
2. Outlet Structures, Culverts and Trash/Safety Racks
3. Ponds, Dams, Embankments and Side Slopes
4. Stormwater BMPs, Including Low Impact Development
5. Open Channels

1. GENERAL

Urban Runoff Quality Management
WEF Manual of Practice No. 23
ASCE Manual and Report on Engineering Practice No. 87
Water Environment Federation
American Society of Civil Engineers
1998

> When the facility is in operation, safety concerns need to focus on flow velocities, water depths, and keeping the public from being exposed to high-hazard areas. During dry weather periods, safety is enhanced by reducing the use of high vertical walls and steep side slopes. Outlets and inflow structures and adjacent areas require special attention, and ASCE (1985) suggests the use of thorny shrubs and trash/safety racks at all outlet orifices, pipes, and weirs. (Page 220)

Stormwater Detention Outlet Control Structures
American Society of Civil Engineers
1985

> Public safety of the detention pond and outlet works, both in the passive condition and when functioning to control upstream stages and downstream discharges must be addressed in design. In addition, embankment stability and the consequences of embankment failure must be addressed. A hazardous detention pond may be worse than none at all. (Page 9)
>
> 1. Is the proposed detention facility located in a residential, commercial, industrial, or agricultural setting and what are the implications of the particular setting?
> 2. Is the pond readily accessible to the public? Is it safe?
> 3. Can the outlet works be simplified in any way to increase reliability and safety?
> 4. What is the risk if an event larger than the design flood overtops the embankment? (Pages 9 – 10)

Urban Stormwater Management
Special Report No. 49
American Public Works Association
1981

Although only two drownings at detention facilities were reported by the 325 respondents to the APWA survey in 1980, precautions always should be taken to minimize hazards. Embankment slopes, railings, fencing and other features are obvious considerations. The importance of designing and constructing outflow structures and dams with safety in mind should never be ignored. In general the approaches that can be used to promote safety are: (1) keep people off the detention facility site, (2) provide escape aids, (3) make the onset of the hazards gradual, and (4) eliminate the hazards. (Page 157)

Safety is another important consideration. Rooftop storage requires the design of a roof system to hold 7 to 10 cm (3 to 4 in.) of water for several hours without any structural damage. Parking lot storage has to be designed such that water will not cause any problems to pedestrians, vehicles, or buildings. In colder climates, precautions must be taken to minimize the hazards of ice on the surface of the pavement. Open ponds might have to be fenced, depending on their location, depth, and steepness of side slopes. The breeding of mosquitoes, growth of algae, and decay of aquatic vegetation also have to be considered as possible health concerns. (Page 155)

Manual of Practice: Design of Urban Storm Water Controls
Joint publication of WEF and ASCE/EWRI
McGraw-Hill
2012

Chapter 11 Maintenance
1.0 Introduction
1.2 Maintenance Requirements and Level of Effort
1.2.1 Maintenance Drivers
Three main drivers impact the degree and frequency of maintenance. These are:

- Protecting human health and safety;
- Maintaining facility functionality; and
- Maintaining facility aesthetics.

(Page 427)

2.0 General Maintenance Considerations
2.8 Vector and Pest Management
Many areas experience unique maintenance requirements related to wildlife, including beavers, muskrats, geese, gophers, and alligators. It was only a few years ago that widespread concern about the West Nile virus in the United States changed the way that agencies and the public viewed systems that maintain a permanent pool, such as wet ponds and underground vaults. Efforts are also

underway to determine if these controls are significant sources of mosquito problems. Reactions to real or potential threats vary and vigorous debate continues as to the nature and level of threat posed by wet basins and wetlands systems as breeding grounds for mosquitoes. (Page 435)

2. OUTLET STRUCTURES, CULVERTS, AND TRASH/SAFETY RACKS

Urban Runoff Quality Management
WEF Manual of Practice No. 23
ASCE Manual and Report on Engineering Practice No. 87
Water Environment Federation
American Society of Civil Engineers
1998

[Many references] reported many reasons for outlet problems, which include clogging by trash and debris, silting in of the outlet, damage by vandalism, children plugging an outlet, and other factors that modify its discharge characteristics. Each outlet has to be designed with clogging, vandalism, maintenance, aesthetics, and safety in mind. (Page 217)

Design and Construction of Urban Stormwater Management Systems
Water Environment Federation
American Society of Civil Engineers
1992

Outlet safety considerations include both the safety of the structure and safety to the public. The outlet works create a potential hazard when in operation due to the possibility of a person being carried into the opening. Gratings or trash racks are often used; however, with substantial pressure a person can be forced against the grate or trash rack which can, in some cases, be worse than being carried through the conduit. To mitigate this, low entrance velocities at the trash rack are recommended. Fencing or other effective measures also should be provided to exclude people from potentially hazardous areas. Such measures include site grading, planting of thorny shrubs, or grading to assure "safety ledges" along the pond perimeter. (Page 457)

Stormwater Detention Outlet Control Structures
American Society of Civil Engineers
1985

Outlet safety considerations include two aspects: safety of the structure and safety to the public at the facility. The outlet works create a potential hazard when in operation due to the possibility of a person being carried into the opening. Grating or trash racks are often used; however, a person can be forced against the grate or trash rack with substantial pressure which, in some cases, can be worse than being carried through the conduit. To mitigate this, low entrance velocities at the trash rack are recommended to reduce the potential pressure. Fencing or other effective measures should be provided to exclude people from potentially hazardous area. Alternative measures include site grading, planting of thorny shrubs, or grading to assure “safety ledges” along the pond perimeter.

Outlet works can be designed to reduce the hazard to the public where heavy recreational use is anticipated. For instance, a vertical riser of concrete, timber, or steel can have a series of openings of 12 inches or less from top to bottom with sufficient total area to cause low velocity at the entrances, if compatible with hydraulic requirements. The top of such risers can be grated, or even closed. In some instances the outlet works can be fenced. Fences are not universally recommended because of maintenance and operational needs, and because most fences do not fully prevent access. Appropriate signing is sometimes used to warn the public of the safety hazards involved at the outlet works. (Page 23)

Urban Stormwater Management
Special Report No. 49
American Public Works Association
1981

Outflow Structures. Water currents constitute a distinct hazard to persons who enter a detention pond or basin during periods when storm water is being discharged. The force of the currents may push a person into an outflow structure or may hold a victim under the water where a bottom discharge is used. (Page 157)

Standard Specifications and Design Criteria
American Public Works Association
Kansas City Metropolitan Chapter

Anti-Clogging Protection: Trash racks or other approved devices shall be installed where required to insure that the principal spillway(s) will remain functional. (Page 56-22)

3. PONDS, DAMS, EMBANKMENTS, AND SIDE SLOPES

Urban Stormwater Management
Special Report No. 49
American Public Works Association
1981

Privately owned detention ponds can become a threat to the health of local residents because of improper operation, forcing the municipality to take care of the problem. Detention basins can also become an unsightly nuisance to local residents. Without proper maintenance they can become overgrown with weeds, provide a breeding place for mosquitoes, and entrance and discharge facilities may become clogged with debris and silt. Protective fencing will also deteriorate without regular maintenance. Generally, unless basins are maintained by public agencies, long term adequate maintenance cannot be assured. (Page 131)

Safety

Detention facilities can present a safety hazard—particularly to children who will be naturally drawn to the site regardless of whether or not the site is intended for their use. Semipermanent grills and bars should be installed on all inlet and outlet pipes, particularly if they connect with an underground storm sewer system. Railings or fences should be placed around the top edge of inlet and outlet structures or other places where accidental falls may occur. Fences may be needed to enclose ponds under some circumstances; however, they also attract children who may be injured when climbing them.

Very mild bottom slopes should be used along the periphery of a detention pond extending out to a point where the depth exceeds a half meter (2 or 3 ft). If active recreation areas (for example, playgrounds or softball fields) are incorporated in a detention basin, they should be located away from busy streets and intersections. If a concrete (channel) is used to carry base flow through the detention facility, the lateral and longitudinal slopes should be very flat to help avoid falls and injury to children. Outflow structures should be designed to limit flow velocities at points where children could be drawn into the discharge stream. (Page 141)

Residential Storm Water Management: Objectives, Principles & Design Considerations
Urban Land Institute
American Society of Civil Engineers
National Association of Home Builders
1975

Design of permanent storage facilities should consider safety, appearance, recreational use and effective, economical maintenance operations, in addition to the primary storage function. (Page 19)

Permanent ponds and lakes have multiple benefits including short-term and long-term enhancement of property values and the landscape; possibilities for boating, ice skating, fishing and swimming; and habitat for resident and migratory wildlife. Proper maintenance and protection from health and safety hazards and positive control of visual appearance must be integral parts of storage basin design and planning. (Page 33)

Other Storage Considerations

In creating urban ponds or lakes, certain special considerations are worthy of mention.

- Access to and along shorelines may be effectively limited to desired locations by planting thorny decorative shrubs.
- Lake bottoms within ten feet of the shore should be so graded that water depth normally will not exceed eighteen inches, to simplify immediate rescue of small children.
- Extensive areas of shallow water, especially in upper reaches of the lake, should be avoided to prevent undesirable weed growth.
- Dense plantings of shrubs that will act as barriers to automobiles are appropriate where vehicles might otherwise run into the lake, especially at night.
- Paved walkways roughly paralleling the shoreline, low-level night lightings, fixed benches, floored rain shelters and sensitive landscaping can add considerably to the charm of a lake or pond setting, and to the desirability of the surrounding neighborhood. Massive plantings of seasonally colorful shrubs, such as azaleas, redbud, dogwood or Japanese maple, can help publicize an area and create particular pride of ownership throughout the neighborhood. (Page 36)

Urban Runoff Quality Management
WEF Manual of Practice No. 23
ASCE Manual and Report on Engineering Practice No. 87
Water Environment Federation
American Society of Civil Engineers
1998

Side Slopes along Shorelines and Vegetation. Side slopes along the shoreline of the retention pond should be 4H:1V or flatter to facilitate maintenance (such as mowing) and reduce public risk of slipping and falling into the water. In addition, a littoral zone should be established around the perimeter of the permanent pool to promote the growth of emergent vegetation along the shoreline and deter individuals from wading. (Page 227)

Basin Side Slopes. Basin side slopes need to be stable under saturated soil conditions. They also need to be sufficiently gentle to limit rill erosion, facilitate maintenance and address the safety issue of individuals falling in when the basin is full of water. Side slopes of 4:1 and flatter will provide well for these concerns. . . (Page 216)

When the facility is in operation, safety concerns need to focus on flow velocities, water depths and keeping the public from being exposed to high hazard areas.

During dry weather periods, safety is enhanced by reducing the use of high vertical walls and steep side slopes. (Page 220)

Practices in Detention of Urban Stormwater Runoff: An Investigation of Concepts, Techniques, Applications, Costs, Problems, Legislation, Legal Aspects and Opinions
Special Report No. 43
American Public Works Association
1974

Safety Features: Safety features of detention facilities include fencing, outlet guards and other measures and devices to protect the public from the hazards of the detained water. Although provision of such safety features does not remove the liability of the owner for accidents (in some areas of the country), such devices do minimize safety hazards and they should be checked regularly to make sure that they are in good operating condition. (Page 21)

Storm Drainage Systems and Facilities
American Public Works Association
2006

5608.5.F Public Safety Considerations in Structural Design and Operation of Stormwater Detention Facilities

The side slopes of all wet bottom basins and dry bottom basins shall be in accordance with the Kansas City, Missouri (KCMO) adopted APWA standards. If the side slopes exceed a maximum of 3:1, the design engineer shall justify the need for steeper slopes and shall provide a design to address safety measures, which are not limited to the following:

- Guardrail
- Security fence
- Safety ledges, access ladders or level steps (gradient terraces) with permanent pools of water deeper than 4 feet in depth
- Adequate egress provisions (e.g., ladders, steps, gradient terraces, etc.)
- A long perimeter between inflow-outflow structures for people to escape from the basin
- Posted and maintained signage of safety hazard and hazard area visible on all sides of the facility, also designating area as no-play or trespass area
- Other criteria are listed

(Page 56-51)

Manual of Practice: Design of Urban Storm Water Controls
Joint publication of WEF and ASCE/EWRI
McGraw Hill
2012

Chapter 5 Selection Criteria and Design Considerations
5.2.4 Social
5.2.4.2 Health and Safety
Open-water basins pose significant threats, especially when located near a park, playground, trail, or other recreational spaces. There are many elements in the stormwater management system of a site that could pose safety threats. (Page 179)

Mosquitoes can be controlled by natural predators such as dragonflies and mosquitofish. Properly operating infiltrators and filters drain in 12 to 48 hours and offer little opportunity for mosquito breeding, which typically requires at least 72 hours. (Page 181)

Not only is trash buildup an aesthetic problem, but it is a source of mosquito habitat that can affect every type of stormwater control because most are designed to remove floatables along with other pollutants. The key to managing trash is regular maintenance. (Page 183)

Chapter 6 Basins
4.0 Forebays
4.4 Aesthetic and Safety Considerations
The size of the forebay and the lateral sill or spillway between the forebay and the primary control should be designed using accepted engineering practices to prevent the forebay from overflowing to adjacent property and to protect the basin's embankment. Side slopes of 4H:1V or flatter will facilitate maintenance such as mowing and reduce risk to the public of slipping and falling into the water. In addition, a littoral zone should be established around the perimeter of the forebay to promote the growth of emergent vegetation along the shoreline and deter individuals from wading. (Page 203)

7.0 Dry Basins
7.4 Aesthetic and Safety Considerations
Aesthetics are what the public uses to judge how "successful" a dry basin is within the community. Because aesthetics are important, new facilities should be tastefully integrated into the neighborhood in consultation with a landscape architect.

When the facility is in operation, safety concerns need to focus on flow velocities, water depths, and keeping the public from hazardous areas. Safety is enhanced by reducing the use of high vertical walls and steep side slopes. Outlets, inflow structures and adjacent areas require special attention, and [ASCE] suggests the use of thorny shrubs and trash and safety racks at all outlet orifices, pipes, and weirs.

For large basins, the design should also address safety issues such as the structural integrity of the water-impounding embankment. As discussed earlier, the embankment should be protected from catastrophic failure.
(Pages 227 and 228)

8.0 Wet Basins
8.4 Aesthetic and Safety Considerations
Well-designed wet basins are often considered a community amenity, increasing property values and creating open space. They typically are more attractive than dry basins because sediment and debris accumulated within the sediment forebay and permanent pool are out of sight. Wet basins with healthy, diverse aquatic environments seldom become a mosquito or midge breeding area. However, some concern about safety may exist where there is public access to the basin. (Denver) Urban Drainage and Flood Control District provides guiding principles to design aesthetically pleasing wet basins, whether they are architectural or naturalized. Architectural basins are intended to appear as part of the built environment; naturalized basins are designed to appear as part of the landscape. For a naturalized look, it is important to attempt to hide the presence of the drainage structures and replicate forms that appear shaped by water. For example, the sides in the area of the surcharge volume should have varying slopes.

An emergency spillway must be provided and designed using accepted engineering practices to protect the basin's embankment. The designer should be certain that the basin embankment and spillway are designed in accordance with federal, state, and local dam safety criteria. [S]ide slopes along the shoreline of the wet basin should be 4:1 or less to facilitate maintenance (such as mowing) and reduce risk to the public of slipping and falling into the water. In addition, a littoral zone should be established around the perimeter of the permanent pool to promote the growth of emergent vegetation along the shoreline and deter individuals from wading. A safety bench may be designed providing a shallow area that allows people or animals that inadvertently enter the open water to exit the basin. If public access is not desired, a fence around the basin should also be considered, although this measure is typically considered unsightly.
(Page 251)

Urban Runoff Quality Management
WEF Manual of Practice No. 23
ASCE Manual and Report on Engineering Practice No. 87
Water Environment Federation
American Society of Civil Engineers
1998

Dam Embankment. Design and build the dam embankment so that it will not fail during storms larger than the water quality design storm. Provide an emergency spillway or design the embankment to withstand overtopping commensurate with the size of the embankment, the volume of water that can be stored behind it, and the potential downstream damages or loss of life if the embankment falls. Emergency spillway designs vary widely with local regulations. Embankments for small on-site basins should be protected from at least the 100-year flood, while the larger facilities should be evaluated for the probable maximum flood. Always consult the state's dam regulatory agency. (Page 217)

Safety. For larger on-site basins and regional facilities, safety has to also include the structural integrity of the water impounding embankment. As discussed earlier, the embankment should be protected from catastrophic failure. In the U.S., dam failure is almost always judged as an absolute liability of its owner. Always consider this principle of common law when designing detention facilities. (Page 220)

4. STORMWATER BMPs, INCLUDING LOW-IMPACT DEVELOPMENT (LID)

Manual of Practice: Design of Urban Storm Water Controls
Joint publication of WEF and ASCE/EWRI
McGraw Hill
2012

Chapter 6 Basins
3.0 Cisterns
3.4 Aesthetic and Safety Considerations
Consideration must be given to selecting rain barrels and cisterns that are vector-proof and childproof. If a cistern is provided with an operable valve and water is stored inside for long periods of time, the cistern must be covered to prevent mosquitoes from breeding. Large cisterns must have the same safety precautions of any potable water storage tank. (Pages 200 and 201)

5.0 Vaults
5.4 Aesthetic and Safety Considerations
[V]aults are useful on constrained sites. They are below-grade structures that require relatively small footprints, and are safer for children and pedestrians than open controls such as wet basins. (Page 208)

6.0 Oil and Water Separators
6.4 Aesthetic and Safety Considerations
Similar to vaults, oil and water separators are below-grade structures that require relatively small footprints and are safer for children and pedestrians than open controls such as wet basins. (Page 215)

Chapter 7 Swales and Strips
3.0 Swales
3.4 Aesthetic and Safety Considerations
Properly designed swales present few safety hazards given the shallow water depths at the treatment design capacity. Greater depths can occur if there is no bypass for the extreme events, but the swales will have lesser depths and velocities than found in traditional road ditch design. Rock treatments may be used at inlets where sediments may accumulate or where erosion may occur. The design should include some means of reducing the energy of the flow as it enters the upper end of the swale and spreading the flow across the swale width. (Page 277)

4.0 Strips
4.4 Aesthetic and Safety Considerations
Properly designed vegetated strips present few safety hazards as they should support shallow water depths at design capacity. As with swales, strips should be designed to blend into the landscape in a natural manner. (Page 283)

Chapter 8 Filters
3.0 Surface Sand Filter
3.4 Aesthetic and Safety Considerations
Materials collected by surface sand filters will build up on the surface, creating unsightly conditions if not routinely maintained. Filter areas should have mild side slopes to minimize the risk of falls, or be fenced to prevent entry. (Page 307)

4.0 Subsurface Sand Filter
4.4 Aesthetic and Safety Considerations
Subsurface sand filters are generally not visible and thus present few aesthetic and safety concerns if routinely maintained. Poor maintenance may cause the filter to clog, restricting release rates and potentially causing flooding or bypassing without adequate treatment. Often, entrance into the subsurface sand filters for maintenance or inspection is considered a confined space entry, and therefore proper personnel training and equipment are necessary. (Page 312)

5.0 Bioretention Filter
5.4 Aesthetic and Safety Considerations
Materials collected by bioretention filters will clog the infiltrating surface and create unsightly conditions if not routinely maintained. Vegetation needs to be maintained regularly for the same reason. Small bioretention filters do not involve substantial ponding depths; therefore, the associated risk is reduced but public safety needs to be considered if the ponded depth is significant. (Page 322)

6.0 Landscaped Roofs
6.4 Aesthetic and Safety Considerations
Extensive landscaped roof systems are not typically designed for public access and thus present few aesthetic concerns. Intensive roof designs require more maintenance, largely to support their aesthetic and recreational uses.

Roofing materials and drainage principles appropriate for any roofing system also apply to landscaped roofs to prevent leakage. (Page 328)

7.0 Drain Inlet Inserts
7.4 Aesthetic and Safety Considerations
Clogged filter inserts provide little pollution removal and may result in flooding unless a bypass or overflow is provided. (Page 332)

8.0 Manufactured Filters
8.4 Aesthetic and Safety Considerations
Manufactured filters are generally installed underground in chambers and present few aesthetic and safety concerns if designed to completely drain and are routinely maintained thus avoiding breeding mosquitoes and other vectors. (Page 335)

9.0 Subsurface Gravel Wetland
9.4 Aesthetic and Safety Considerations
Subsurface gravel wetlands are similar in context to bioretention filters and thus present few aesthetic and safety concerns if routinely maintained. Poor maintenance may cause the stone to clog, restricting release rates and potentially causing flooding or bypassing without adequate treatment. The subsurface gravel wetland is not limited by cold weather and freezing of the stone. (Page 341)

5. OPEN CHANNELS

Residential Storm Water Management: Objectives, Principles & Design Considerations
Urban Land Institute
American Society of Civil Engineers
National Association of Home Builders
1975

Open channels and swales should be routed and designed to avoid or minimize safety hazards. (Page 20)

Design and Construction of Urban Stormwater Management Systems
Water Environment Federation
American Society of Civil Engineers
1992

Choice of Channel
The choice (of channel type) must be based on a variety of factors which include:

(a) Regulatory—Federal, state and local regulation.
(b) Hydraulic—Slope of thalweg, right-of-way, capacity needed, basin sediment yield, topography, ability to drain adjacent lands.

(c) Environmental—Neighborhood character and aesthetic requirements, need for new green areas, street and traffic patterns, municipal or county policies, wildlife, water quality.
(d) Sociological—Neighborhood social patterns and child population, pedestrian traffic, recreational needs.

Whenever practical, the channel should have slow flow characteristics, be wide and shallow, and be natural in its appearance, and functioning.
(Pages 262 – 263)

Urban Runoff Quality Management
WEF Manual of Practice No. 23
ASCE Manual and Report on Engineering Practice No. 87
Water Environment Federation
American Society of Civil Engineers
1998

Precaution and Considerations in Planning and Design
Safety is another important consideration. Rooftop storage requires the design of a roof system to hold 7 to 10 cm (3 to 4 in.) of water for several hours without any structural damage. Parking lot storage has to be designed such that water will not cause any problem to pedestrians, vehicles, or buildings. In colder climates, precautions must be taken to minimize the hazards of ice on the surface of the pavement. Open ponds might have to be fenced, depending on the location, depth, and steepness of the side slopes. The breeding of mosquitoes, growth of algae, and decay of aquatic vegetation also have to considered as possible health concerns. (Page 154)

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Appendix B
Representative Quotations Regarding Safety from General Engineering and Landscape Architecture Literature

Quotations in this appendix are organized by the following topics:

1. General
2. Outlet Structures, Culverts and Trash/Safety Racks
3. Ponds, Dams, Embankments and Side Slopes

1. GENERAL

Operation, Maintenance, and Management of Stormwater Management Systems
Watershed Management Institute, Inc.
Office of Water, U.S. Environmental Protection Agency
August 1997

5. BMP Design Considerations: A Checklist
5.1 Safety

For many reasons, the safety of the stormwater management system must be the primary concern of the designer. Due to its structural nature and, in many instances, the fact that it will impound water either permanently or temporarily, a stormwater facility will inherently pose some degree of safety threat.

Those at risk will include people living, working, or traveling downstream of the system and whose safety and/or property will be jeopardized if the facility were to fail and release stored runoff. Since this is a risk that has been created solely by the system, the designer must assure that the probability of such a failure is acceptably small.

However, also at risk at the facility are maintenance personnel, inspectors, mosquito control personnel, and equipment operators, who must work in and around it. Typical hazards include deep water, excessively steep slopes, slippery or unstable footing, limited or unsafe access, and threats posed by insects and animals. As noted above**, the responsible stormwater designer understands the importance of minimizing and facilitating facility maintenance. Providing a safe working environment for the system maintainer is one important way to do it.**

Finally, those living, working, traveling, attending school, or playing in the vicinity of a facility may also be at risk, particularly if the system serves both as a stormwater management and recreational facility. Once again, such things as standing water, steep slopes, unstable footings, and insect and animal bites must be addressed by the designer in order to avoid creating a system that is a detriment to the community it is intended to serve. Failure to do so will only alienate those

members of the community that are being asked to play a vital role in the community's stormwater management efforts.
(Pages 3-13 – 3-14)

Handbook of Hydrology
David R. Maidment, Editor-in-Chief
McGraw–Hill, Inc.
1993

Safety. Safety is only partially a hydrologic design issue, and it also includes the structural integrity of the water-impounding embankment and its ability to withstand floods greater than the nominal design. Safety to the public when the facility is in operation and when the facility is dormant, namely, between runoff events, is very important. The designer needs to consider flow velocities, water depth, and how to prevent and to discourage the public from being exposed to high-hazard areas during periods of storm runoff. In addition, the designer needs to size an emergency spillway and/or design the embankment so it will not fail catastrophically during a very large event.

When the facility is not operational, which is most of the time, its layout should minimize the use of high vertical drops, deep water near the shore, and steep side slopes above and below the permanent water level. Also, outlet and inflow structures require special attention. Use of flat side slopes, flat benches above and below permanent pool water level, planting thorny shrubs around the inflow and outflow structures, and the use of trash/safety racks at all outlet orifices and pipes all help to enhance the safety of detention facilities.
(Page 28.33)

Detention Ordinances—Solving or Causing Problems?
Proceedings of the Conference on Stormwater Detention Facilities Planning, Design, Operation and Maintenance
Thomas N. Debo
American Society of Engineers and Engineering Foundation
1982

Health and Safety Problems. Closely associated with maintenance problems are several health and safety related problems. Stagnant pools and moist ground associated with many detention facilities become ideal places for mosquito breeding and attract rodents and other pests. Also many facilities located in or adjacent to residential areas can create safety problems. Since these facilities collect sediment and other litter, have steep banks, and often contain several feet of water, they are not ideal places for neighborhood children to play. The usual means to protect local residents is to install a fence around the facility. These fences are often unsightly and prone to vandalism and many times are a hazard to local children.

Drainage Manual
State of Florida Department of Transportation
January 2006

> Stormwater management facilities shall be designed with due consideration of the need for protective treatment to prevent hazards to persons. . . . Flat slopes shall be used when practical. Retention areas shall be fenced. . . to prevent entry into areas of unexpected deep standing water or high velocity flow. Grates shall be considered to prevent persons from being swept into long or submerged drainage systems. Guards shall be considered to prevent entry into long sewer systems under no-storm conditions, to prevent persons from being trapped. (Page 45)

Stormwater Manual
Lexington–Fayette Urban County Government
Lexington, Kentucky
January 1, 2009

> This manual includes requirements for the stormwater infrastructure that is routinely designed and constructed, including rational engineering principles and practices. However, more comprehensive methods of analysis and design may be required for unusual conditions not specifically covered in this manual or where otherwise appropriate from an engineering standpoint to assure public safety and quality in infrastructure design and construction. (Page 1–2)

Urban Surface Water Management
Stuart G. Walesh
John Wiley & Sons, Inc.
1989

[This book contains a section on calculating the force exerted on a person by moving floodwaters. The section contains a hydraulic analysis procedure using a drag equation and information on drag shapes and Reynolds numbers. The results are presented in the following table.]

TABLE 5.1 Forces Exerted on a Person by Moving Floodwater

Velocity (ft/sec)	Depth (ft)	Drag Force (lb)
1	1	1.7
	3	5.2
2	1	7.0
	3	21.0
4	1	27.9
	3	83.8
6	1	62.9
	3	188.6
8	1	111.7
	3	335.2
10	1	174.6
	3	523.8

(Page 177; reproduced with permission from John Wiley & Sons)

2. OUTLET STRUCTURES, CULVERTS AND TRASH / SAFETY RACKS

Georgia Stormwater Management Manual
Volume 2: Technical Handbook
August 2001. First Edition

2.3.6 Trash Racks and Safety Grates
In most instances trash racks will be needed. Trash racks and safety grates are a critical element of outlet structure design and serve several important functions:

- Ensuring that people and large animals are kept out of confined conveyance and outlet areas
- Providing a safety system that prevents anyone from being drawn into the outlet and allows them to climb to safety (Page 2.3–17)

The location and size of the trash rack depends on a number of factors, including head losses through the rack, structural convenience, safety and size of outlet. (Page 2.3–17)

There are no universal guidelines for the design of trash racks to protect detention basin outlets, although a commonly used "rule-of-thumb" is to have the trash rack area at least ten times larger than the control outlet orifice. (Page 2.3–18)

Trash racks at entrances to pipes and conduits should be sloped at about 3H:1V to 5H:1V to allow trash to slide up the rack with flow pressure and rising water level—the slower the approach flow, the flatter the angle. (Page 2.3–19)

Collapsible racks have been used in some places if clogging becomes excessive or a person becomes pinned to the rack. (Page 2.3–19)

The channel protection orifice . . . should be adequately protected from clogging by an acceptable external trash rack. (Page 3.4–4)

Stormwater Management Manual
City of Tulsa, Oklahoma
Public Works Department
September 2004

The outlet works create a potential hazard when in operation due to the possibility of a person being carried in the opening. Grating or trash racks are often used, however, a person can be forced against the grate or trash rack with substantial pressure, preventing escape. Low entrance velocities at the trash rack are recommended. Fencing or other effective measures should be provided to exclude people from potentially hazardous areas. Alternative measures include education, site grating, signing, planting of thorny shrubs, and grading for safety ledges along the pond perimeter. Outlet works can be designed to reduce the hazard to the public where heavy recreational use is anticipated. A vertical riser of concrete, timber or steel can have a series of openings of 12 inches or less from top to bottom with sufficient total area to cause low velocity at the entrances. The top of such risers can be grated or even closed. In some instances, the outlet works can be fenced.

Drainage and Flood Control Manual
Nebraska Department of Roads
August 2006

Grates or modified debris barriers should be provided at culvert openings where access by children or animals could create hazardous situations (primarily in urban areas).

Urban Surface Water Management
Stuart G. Walesh
John Wiley & Sons, Inc.
1989

Safety provisions potentially applicable to culverts and bridges include:

1. Cages or grates installed on entrances to long culverts
2. Fences or guardrails placed near the top edge of headwalls and wingwalls

(Page 169)

Drainage Criteria Manual
City of Lincoln, Nebraska
Public Works and Utility Department
February 2000

Trash racks and safety grates serve several functions. . . they provide a safety system whereby persons caught in them will be stopped prior to the very high velocity flows immediately at the entrance to outlet works and persons will be carried up and onto the outlet works allowing for a possibility to climb to safety. (Page 6-26)

Catalog of Stormwater Best Management Practices for Idaho Cities and Counties
Idaho Department of Environmental Quality
August 2001

Dangerous outlet facilities should be protected by enclosure. (Page 65)

Model Drainage Manual 1991
American Association of State Highway and Transportation Offices
1991

> Culverts shall be designed to accommodate debris or proper provisions shall be made for debris maintenance.
>
> Culverts shall be located and designed to present a minimum hazard to traffic and people. (Page 9–6)

Hydraulic Design of Highway Culverts
Hydraulic Design Series Number 5
Publication No. FHWA-NHI-01-020
U.S. Department of Transportation, Federal Highway Administration
September 2001 (Revised May 2005)

> Culverts have always attracted the attention and curiosity of children. In high population areas where hazards could exist, access to culverts should be prevented. Safety grates can serve this function. If clogging by debris is a problem, fencing around the culvert ends is an acceptable alternative to grates. (Page 171)

3. PONDS, DAMS, EMBANKMENTS, AND SIDE SLOPES

Model Stormwater Drainage and Detention Ordinance: A Guide for Local Officials
Northeastern Illinois Planning Commission (NIPC)
1990

> One of the principal objectives of detention basin design should be to eliminate the need to fence the final facility. Fencing increases maintenance difficulty and limits any multiple use and aesthetic value the detention basin may have had. In effect it is frequently an admission that comprehensive design objectives could not be achieved. The key to not fencing detention facilities is the design of specific safety measures to make basins reasonably safe under the full range of stormwater conditions it is likely to encounter.
>
> Specific recommendations have been suggested by a number of organizations. The [Metropolitan Water Reclamation District {Chicago}] has suggested that wet basins have a safety ledge of 4 to 6 feet in width and 30 to 36 inches below the permanent pool level to provide footing in the event someone falls into the pond. The MWRD also recommends a ledge 12 to 18 inches above the permanent pool elevation to prevent accidental falls into the basin. NIPC has also recommended safety ledges and flat shoreline (5 horizontal to 1 vertical) and underwater bank slopes (3 to 1). . . The APWA and ASCE have stressed the need to design safe outlet structures. . . They recommend a variety of sloping outlet trash racks which will not trap a person on them during high flows. Finally, they suggest that hand holds be provided to allow people to pull themselves out of steep areas of the

basin or areas where velocities may be high. MWRD has also recommended the installation of 20 foot wide safety ramps at slopes of 6 to 1 in detention basins to allow emergency exit from basins. (Page 1–39)

Evaluation and Management of Highway Runoff Water Quality
Federal Highway Administration
June 1996

The water depth at the perimeter of a storage pool should be limited to that which is safe for children. This is especially necessary if bank slopes are steep or if ponds are full and recirculating in a dry period. Restriction of access (fence, walls, etc.) may be a consideration if land availability dictates… The side slopes for grassed area should be gentle enough to facilitate maintenance and to reduce safety hazards.

Stormwater Best Management Practice Handbook: New Development and Redevelopment
California Stormwater Quality Association
January 2003

Safety Considerations—Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate drop-offs and other hazards. Earthen side slopes should not exceed 3:1 (H:V) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. The primary spillway opening must not permit access by small children. Outfall pipes above 48 inches in diameter should be fenced. (Page 6 of TC-22)

Conservation Practice Standard: Pond Sealing or Lining—Flexible Membrane Code 525A
Natural Resources Conservation Service
2006

Safety. Design shall include appropriate safety features to minimize the hazards of the structure. Warning signs, fences, ladders, ropes, bars, rails and other devices shall be provided as appropriate to ensure the safety of humans and livestock.

Time-Saver Standards for Landscape Architecture
Harris and Dines
1997

Figure 330-49 shows a typical cross section for a wet detention pond. Safety is a concern in pond design. Slopes along the shoreline should be gradual (1:4 or less) and/or protected by dense upland plantings. A 6000 mm (20 ft) flat shelf (1:10 slope or less) should be provided at the water's edge if possible. Safety fencing should be avoided, unless no other alternative is available.

Figure 330-49 is a sketch of "Recommended cross section for wet detention pond." It specifies a "dense barrier of upland woody plants" on a maximum 3:1 slope, with a 6:1 slope recommended for wildlife access. A "flat shelf (10:1 slope)" for "20 ft. typ." is specified, and the sketch shows thick vegetation on this shelf. From the shelf to the permanent pool depth, the slope is specified to be 3:1.

Site Engineering for Landscape Architects
Strom, Nathan and Woland
2004

Pool depth should be between 4 and 8 ft (1.2–2.4 m). Depths less than 4 ft can result in elevated water temperatures and resuspension of sediment due to surface disturbance. A level safety bench at least 10 ft (3 m) wide by 1 ft (0.3 m) deep should be provided around the perimeter of the pond to reduce potential safety problems.

Measures should be taken to reduce safety hazards that may be created by retention and detention ponds located in populated areas. Safety issues are related to access, large volumes of flowing water, constrictions created by pipes and culverts, and the intermittent nature of storm water storage. Safety measures may include installing fencing, avoiding steep side slopes or sudden drops, minimizing constriction points, and covering outlets with properly designed grates. As a minimum, the construction of detention and retention basins must meet all applicable federal, state, and local regulations, including state dam safety regulations where appropriate.

Urban Surface Water Management
Stuart G. Walesh
John Wiley & Sons, Inc.
1989

On-site safety provisions and devices that may be applicable to detention/retention facilities include the following:

1. Removable safety cages or grates mounted on the entrance to otherwise open storm sewers which flow either into or out of the detention/retention facility. Installation of safety cages or grates is critical where inlet and outlet pipes are connected directly to a long or extensive underground pipe system, that is, where such pipes are not simply short culverts beneath roadways or through berms. Cages or grates installed on the entrance to outlet pipes should be sloped so that water moving through the grate will tend to exert an upward force component on a person or object trapped against the grate. The total grate area should be large enough to reduce to safe levels drag forces at the face of the grate.
2. Guardrails or fences installed near the top edge of vertical or steep walls or slopes, especially along the top of headwalls and wingwalls at inlet and outlet structures.

3. Steps, including hand rails, strategically located on the periphery of a detention/retention facility if there are no or few mildly sloped areas to provide access to and exit from the lower areas of a detention/retention facility.
4. Signs placed around the perimeter of a detention/retention facility to indicate its occasional use for storage of water.
5. Use of mild side slopes (e.g., 7 horizontal to 1 vertical or flatter) under water around the periphery of a retention pond.
6. Maximum lateral and longitudinal slopes on concrete cunnettes or trickle channels of 4 percent (about 0.5 in./ft) to minimize the possibility of falling on wet, slippery surfaces.
7. Positioning of active recreation areas such as ballfields and playgrounds away from busy streets, and locating these facilities so that they are easily visible from areas outside, but close to, the detention/retention facility.
8. Provision of rescue equipment, such as lifesaving rings and small boats, near retention facilities.
9. Freeboard above design stages.

[A summary of off-site safety provisions is provided, including such items as an emergency spillway, emergency downstream flow path, seepage collars on outlet pipes, cut-off trench, riprap, and controls on downstream development or land use.]

(Pages 169–170; reproduced with permission from John Wiley & Sons)

The Journal of Dam Safety
"Hidden Dangers and Public Safety at Low-head Dams"
Bruce A. Tschantz
Kenneth R. Wright
Association of State Dam Safety Officials
Vol. 9, Issue 1, 2011

> Low-head dams, a.k.a. "killer dams" or "drowning machines," often present a safety hazard to the public because of their ability to trap victims in a submerged hydraulic jump formed just downstream from the dam. Most of these dams, normally producing vertical water surface drops ranging from one to a dozen feet, have been constructed across rivers and streams to raise the water level for the purpose of improving municipal and industrial water supplies, producing hydropower, and diverting irrigation water. Hundreds were built in the 1800s to power gristmills and small industries. Many have fallen into disrepair or been abandoned, posing dangerous conditions to the public. Kayakers, canoers, rafters, swimmers, and other water users are often unaware of the existence of hazards at low-head dams, and sometimes end up getting trapped and drowning in the strong recirculating currents. Although hundreds have been killed over the last four decades, few states regulate these dangerous structures because of their small heights. Moreover, state dam safety regulations focus primarily on structural integrity and prevention of failure, but they do not generally consider public safety issues at or around dams. (Page 8)

V. Proposed Measures to Reduce Drownings

As the number of people attracted to water recreational opportunities increases, water-related accidents and deaths are inevitable, but engineers, state and federal officials, boating safety organizations, and recreational watercraft organizations need to work together to reduce or eliminate the environmental hazards at low-head dams. A five-step approach is proposed to reduce the risk to the public from dangerous conditions at low-head dams:

1. **Public awareness programs** that promote safety education and cognizance of the potential dangers at low-head dams.
2. **Warning markers and effective legislation and regulation** at the state level requiring dam owners to install appropriate warning signs and buoys, escape, portage, safety and other devices at low-head dams.
3. **Structural modification** of low-head dams. The physical hazard to boaters, fishermen, and swimmers around and below low-head dams needs to be reduced or eliminated wherever practical, given the reality of technical, legal, environmental, and financial constraints.
4. **Rescue training** programs to help state and local water rescue professionals understand and respond to the special hazards created at low-head dams.
5. **Develop comprehensive national guidelines for public safety** at dams for identifying potential hazards and evaluating risks; changing operating practices; installing standardized warning systems, signage and safety controls; developing site-specific public safety plans and inspection and maintenance programs; and developing a continual review and improvement process for dam owners and operators, design engineers, and other stakeholders. (Pages 15 – 16)

Table B-1. Examples of Criteria from Governmental Entities

	Maximum Slope	Safety Ledge	Surface Requirements	Safety Fencing	Comments
Stormwater Drainage Manual Columbus, OH Division of Sewerage & Drainage	4:1 below water line; 6:1 above water line		5 ft of rock centered on water line	5 ft fence around pond, only near single-family homes	
Technical Reference Manual Lake County, OH Stormwater Management Commission	2:1 beneath the safety shelf and "gentle slopes" above water line; 5:1 preferred	Safety shelf 10 ft wide, 18 in. deep beneath 30% to 35% of the pond's surface area			Specifically addresses danger of deep waters to children
Stormwater Management Rules and Regulations: Part 1, Technical Reference Manual Cincinnati, OH Department of Public Works, Division of Stormwater Management Utility	4:1 generally; 3:1 if fenced		10-ft-wide embankment surrounding pond	Fencing discouraged for maintenance reasons	
Pond Sealing or Lining; Pond Construction and Management Michigan Department of Environmental Quality	3:1; flatter slopes should be considered for safety; 4:1 if a pond liner is used	10-ft- to 20-ft-wide ledge	Buffer strip around the pond and soil on the pond floor to support vegetation	Fencing should be considered for safety	Notes that retention ponds are often used as golf course hazards and can be safety concerns
Development Regulations Gwinnett County, GA Department of Planning and Development	3:1	10-ft-wide (15 ft recommended) safety bench with 10:1 slope surrounding areas of water deeper than 4 ft	Side slopes planted from 2 ft below to 1 ft above water line		
Standard Specifications and Details Manual City of Asheville, NC	3:1	Safety ledge, flat shore line, and maximum depth of 4 ft required if there is no fence		6-ft fence at least 25 ft from pond edge	
2000 Maryland Stormwater Design Manual, Volumes 1 & 2 Maryland Department of the Environment		Safety bench (maximum 6% slope) and aquatic bench with minimum combined width of 15 ft	25-ft buffer surrounding pond and backfilling of uncompacted soil to allow vegetation growth		
Drainage Criteria Manual for Montgomery County, TX Montgomery County, TX	3:1	10-ft-wide safety bench with maximum slope of 10:1		Fencing required if side slope is steeper than 3:1	

Best Management Practices, Volume 4 Metropolitan Government of Nashville and Davidson County, TN	3:1	15-ft-wide safety bench with maximum 6% slope (not necessary if pond slope shallower than 4:1)			Requires aquatic bench extending inward from safety bench
Design and Construction of Dams and Impoundments Fairfax County, VA	2-1/2:1; 3:1 recommended	5- to 10-ft-wide ledge, 1-2 ft deep in general; 6- to 10-ft-wide bench every 10 to 15 ft of slope if total height of embankment is greater than 15 ft		Fencing required around spillways or accessible drops greater than 3 ft	Safety signs required
Stormwater Manual Lexington Fayette (KY) Urban County Government		10-ft-wide bench 1 ft deep, slope 10:1			
Surface Water Design Manual King County, WA	3:1 interior slope; 2:1 exterior slope	Required if no fencing	Ensure stable slopes	Required if interior slope is steeper than 3:1 and permanent depth greater than 2 ft (barrier shrubs also acceptable)	
Development Regulations City of Snellville, GA	3:1	Bench with 10:1 slope required if pond slope is steeper than 4:1 and permanent depth is greater than 4 ft	Slope must be grassed; no exposed stumps underwater	4-ft fence required if depth of 4 ft or more is possible and slope steeper than 2:1	
Stormwater Management Design Manual New York State Department of Environmental Conservation	3:1	15-ft bench with 6% slope if pond side slope is steeper than 4:1			
Stormwater Management Manual for Western Washington Washington State Department of Ecology	3:1		25-ft buffer surrounding pond	Fencing should be used if more than 10% of slopes are steeper than 3:1	Highly visible signage
Handbook: Urban Runoff Pollution Prevention and Control Planning US EPA	4:1	10-ft-wide safety bench, 10-ft-wide aquatic bench	Vegetated, aquatic bench, pond surrounded by filter strip		
Storm Water & Urban Runoff Control National Association of Home Builders	3:1	10-ft-wide bench with 10:1 slope	Buffer vegetation to discourage children from approaching the pond	Fencing to keep children from dangerous areas	

Note: Water line refers to permanent water line.

Appendix C
Representative Photographs Involving Public Safety Considerations and Approaches

GENERAL

Photograph 1. The public is drawn to water, and attractive, well maintained, multiuse BMPs that are community assets enhance public safety.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 2. Channels that encourage boating and wading for families often include safety features such as good visibility, shallow depths, slow velocities, sound footing and appropriate edge treatment.

Source: Donald Brandes, RLA; reproduced with permission.

Photograph 3. Many studies have demonstrated that attractive greenways with ponds, wetlands, trails and other features not only promote good water quality but also add to adjoining property values; public safety is an integral aspect of this.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 4. Sometimes urban stormwater improvements—such as bank stabilization in this case—are urgently needed to protect the public. Attractive, environmentally sensitive stabilization consistent with local conditions can enhance public safety by promoting more public interaction with the channel.

Source: Watershed Protection Department, City of Austin, Texas; reproduced with permission.

Photograph 5. The hazards in this situation are striking—unstable, high vertical wall, little separation distance from house to channel, undersized channel with high-velocity flows, and home in floodplain.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 6. A demonstration of four *unsafe* practices: This inspector (1) is alone in the boat, (2) is standing in the boat, (3) is not wearing a life vest, and (4) is wearing waders, which would act as an anchor if he fell in.

Source: William Hunt, Ph.D., P.E.; reproduced with permission.

OUTLET STRUCTURES, CULVERTS AND TRASH / SAFETY RACKS

Photograph 7. Detention pond outlet pipes often require debris/safety racks, which should be sloped and have large surface areas to reduce the risk of a person being pinned against the rack and to enable debris to rise up on the rack as the water level in the pond rises.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 8. Large sloping rack discourages entrance into long multibox culvert. (Note: People behind the rack are inspectors.)

Source: Kenneth R. Wright, P.E., D.WRE; reproduced with permission.

Photograph 9. Unprotected opening in outlet structure, which allows children access to the interior, where they could be trapped or injured.

Source: William Hunt, Ph.D., P.E.; reproduced with permission.

Photograph 10. Fencing is necessary (and required by local building code) at this outlet structure headwall. Fencing and railings should be visually appealing.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 11. Traditional dry pond with an outlet structure that has small orifices and a grate on overflow.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 12. An outlet structure that was *not* designed to facilitate maintenance, creating a risk of injury to maintenance workers. Maintenance is essential to promote economic, environmental and community benefits.

Source: William Hunt, Ph.D., P.E.; reproduced with permission.

PONDS, DAMS, EMBANKMENTS AND SIDE SLOPES

Photograph 13. In a retention pond next to a playground, the side slopes are very mild (approximately 10H:1V) both above and below normal water level.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 14. Extended dry pond with mild side slopes, low retaining walls, shrubs discouraging access, good visibility and access, racks on outlet structures, wetland vegetation to discourage access to outlet and rock (cobble) on banks.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 15. Retention pond in office park with rack on outlet pipe, mild side slopes above and below the normal water surface, and good footing around edge.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 16. Banks of wet pond that were not stabilized with groundcover have eroded, resulting in a gulley through which children could gain access to the pond.

Source: William Hunt, Ph.D., P.E.; reproduced with permission.

Photograph 17. Dry pond serves as park when it is not raining; it has mild side slopes and good visibility, is aesthetic and is well integrated into the neighborhood.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 18. Fountains help to maintain water quality and reduce mosquito problems by avoiding stagnant, quiescent water.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 19. Fencing is provided around retention pond, along with mild side slopes and good visibility.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 20. Storage facilities with vertical retaining walls or steep slopes absolutely require a safety fence or other means to keep the public away from the walls, and terraced walls are encouraged, especially near the top.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 21. Warning signs are often used at retention and detention ponds.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

STORMWATER BMPs, INCLUDING LID

Photograph 22. Encouraging public education and access to stormwater facilities enhances public safety.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 23. Wetland swale integrates nicely into residential area and does not pose a significant safety risk to residents, since flows spread out and slow down and tall vegetation discourages access.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 24. Sinuous low-flow channel in created wetland (under construction) promotes water quality enhancement while also addressing public safety with good footing, shallow depths and safe outlet structure.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 25. One of the advantages of rain gardens and other low impact development (LID) practices is that they typically do not create public safety hazards, provided that standing water does not occur, which is conducive to mosquitoes, and that tripping/footing hazards along curbs and sidewalks are addressed.

Source: Andrew Earles, Ph.D., P.E., D.WRE; reproduced with permission.

Photograph 26. These LID retrofits at an office building significantly increased onsite storage and infiltration compared to the traditional drainage facilities they replaced and are safe for building tenants and visitors.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 27. Additional LID practices which drain well and are sited and graded to avoid creating public safety concerns.

Source: Andrew Earles, Ph.D., P.E., D.WRE; reproduced with permission.

Photograph 28. Bioswales can provide significant hydrologic and water quality benefits while also being safe.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 29. Erosion caused by improper velocity check for liner has created a tripping hazard.

Source: William Hunt, Ph.D., P.E.; reproduced with permission.

Photograph 30. An attractive bioretention basin with mild side slopes that has good access and visibility, and which drains well and interfaces nicely with the walkway.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 31. Terraces that infiltrate stormwater with favorable safety characteristics (shallow steps and wide, good footing).

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 32. A dry pond that has been allowed to convert to *Typha* (cattail) monoculture, creating an ideal habitat for mosquitoes.

Source: William Hunt, Ph.D., P.E.; reproduced with permission.

Photograph 33. Poor plant selection and lack of maintenance have resulted in an overgrown rain garden, which could provide cover for those with criminal intent, an obvious danger to passersby.

Source: William Hunt, Ph.D., P.E.; reproduced with permission.

Photograph 34. Large trees in bioretention facilities should be staked for the first year for stability. These unstaked trees have become a hazard during a high-wind event.

Source: William Hunt, Ph.D., P.E.; reproduced with permission.

Photograph 35. Green roof with railing.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 36. Grit filter in a rain harvesting system with mesh that is too fine for adult mosquitoes to pass through.

Source: William Hunt, Ph.D., P.E.; reproduced with permission.

OPEN CHANNELS

Photograph 37. Facilities like this bioengineered drainage channel with a low-grade control structure are attractive to the public and must provide good egress, mild slopes and solid footing.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 38. At an engineered grass-lined major drainageway with a low-flow channel, a trail is set back far from the channel and higher than the 10-year flood elevation, and there is a mild side slope from the trail to the channel bottom.

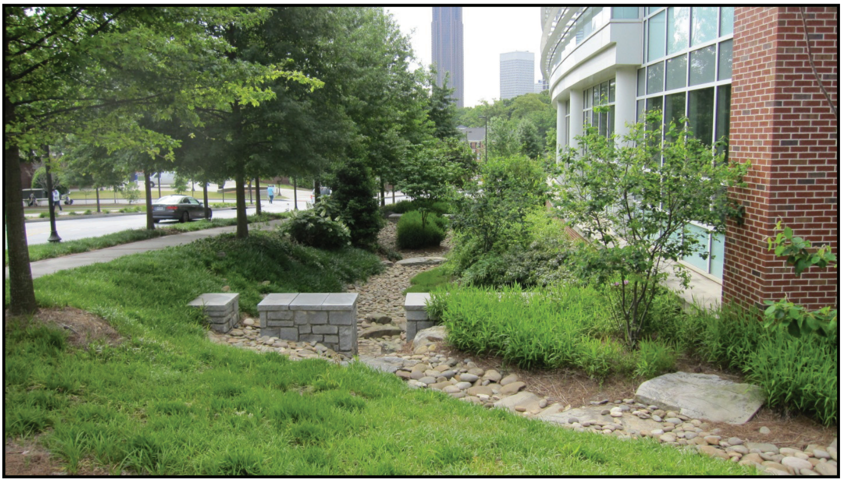
Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 39. Grass swale with mild invert slope and side slopes and shallow invert slope into grate.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 40. Pedestrian bridge across engineered urban channel. Note fencing and railings to protect trail users.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

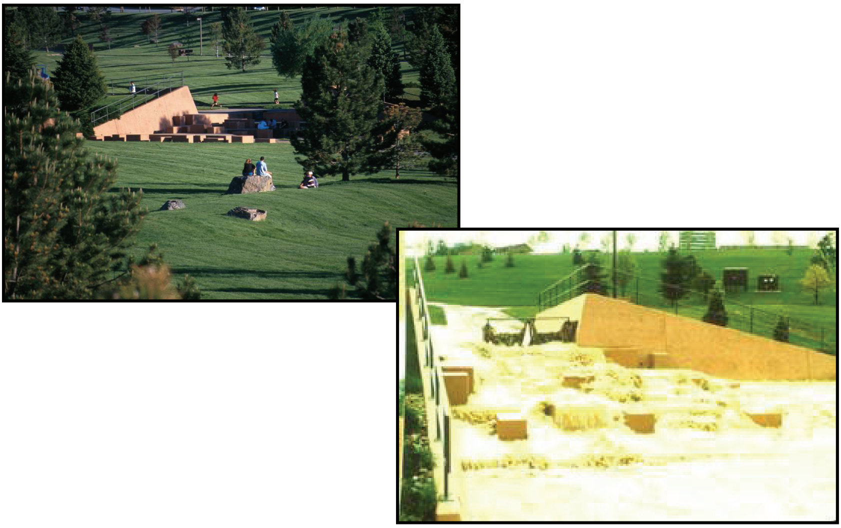


Photograph 41. Small channel with good footing, shallow design depth, low design velocities, grade control and good access.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 42. Railings at elevated crossings of major drainageways are standard.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.



Photograph 43. Drop structures on open channels can be safely integrated into a park setting and effectively dissipate energy in a controlled manner.

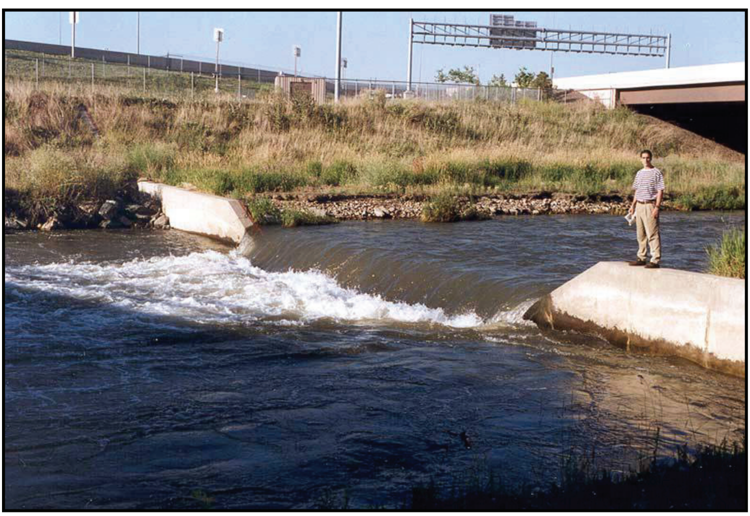
Source: William Wenk; reproduced with permission.

Photograph 44. Transitions from open channels into long underground culverts and pipes must be carefully evaluated and will often require a rack at the inlet.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

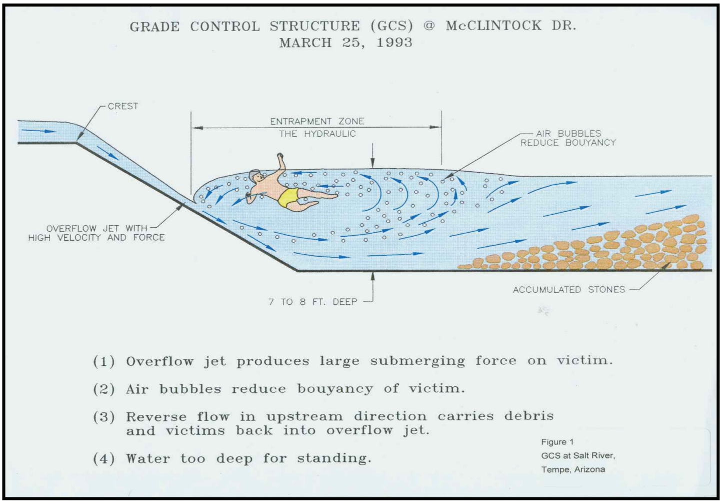
Photograph 45. Low-head dams in urban settings can be very dangerous, but various techniques can be used to eliminate the "keepers" (reverse rollers) often found on the downstream side of the dam.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.



Photograph 46. Low-head dam with reverse roller immediately downstream.

Source: Kenneth R. Wright, P.E., D.WRE; reproduced with permission.



Photograph 47. Schematic of hydraulic phenomenon known as "reverse roller," "hydraulic" or "keeper" downstream of low-head dam.

Source: Wright Water Engineers, Inc.; reproduced with permission.

Photograph 48. At this steep gabion wall with rock toe protection, separation from the parking lot is essential and is provided by both guardrail and fence.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 49. Whitewater courses on urban streams involve specialized design and construction knowledge and great attention to hydraulics.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 50. Attractive fencing adjacent to trail promotes public safety and minimizes foot traffic in riparian zone next to stream

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 51. Grouted boulder drop structure with safe hydraulic characteristics—essential given public use in area.

Source: Jonathan E. Jones, P.E., D.WRE; reproduced with permission.

Photograph 52. Wildfires adjacent to urban areas can create extraordinary public safety hazards.

Source: Ian Paton, P.E., CFM, CPESC; reproduced with permission.

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Appendix D
Conceptual Design Drawings for Selected Facilities

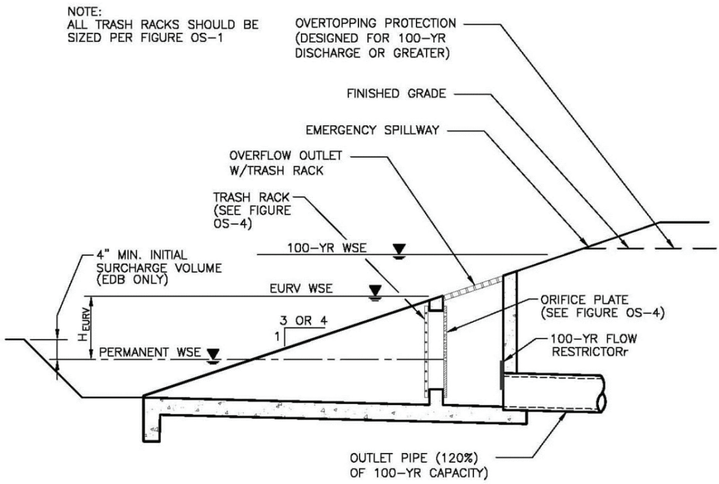


Figure OS-2. Typical Outlet Structure for Full Spectrum Detention

Figure D-1. Typical Outlet Structure for Full Spectrum Detention

Source: Urban Drainage and Flood Control District (2010c), page OS–10; reproduced with permission.

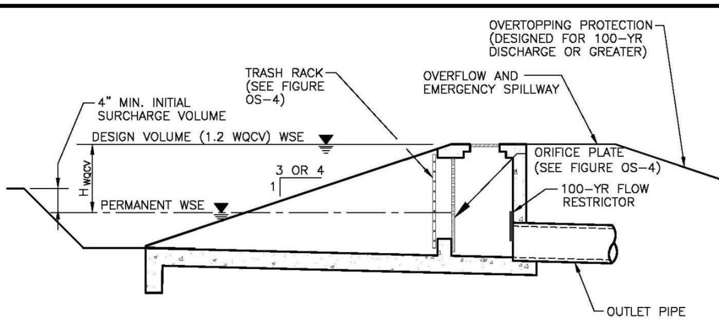
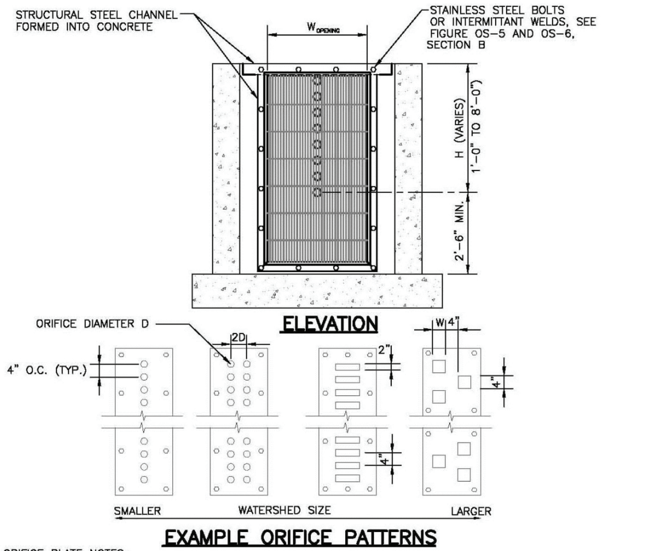


Figure OS-3. Typical Outlet Structure for WQCV Treatment and Attenuation

Figure D-2. Typical Outlet Structure for WQCV Treatment and Attenuation

Source: Urban Drainage and Flood Control District (2010c), page OS–10; reproduced with permission.



ORIFICE PLATE NOTES:

1. MINIMIZE THE NUMBER OF COLUMNS.
2. PROVIDE GASKET MATERIAL BETWEEN THE ORIFICE PLATE AND CONCRETE.
3. BOLT PLATE TO CONCRETE 12" MAX. ON CENTER.

EURV AND WQCV TRASH RACKS:

1. WELL-SCREEN TRASH RACKS (FOR CIRCULAR ORIFICES) SHALL BE STAINLESS STEEL AND SHALL BE ATTACHED BY INTERMITTENT WELDS ALONG THE EDGE OF THE MOUNTING FRAME.
2. BAR GRATE TRASH RACKS (FOR RECTANGULAR ORIFICES) SHALL BE ALUMINUM AND SHALL BE BOLTED USING STAINLESS STEEL HARDWARE.
3. TRASH RACK WIDTHS PROVIDED IN TABLE OS-2A AND OS-3A ARE FOR SPECIFIED TRASH RACK MATERIAL AND NEED TO BE ADJUSTED FOR MATERIALS HAVING A DIFFERENT OPEN AREA/GROSS AREA RATIO (R VALUE)
4. STRUCTURAL DESIGN OF TRASH RACKS SHALL BE BASED ON FULL HYDROSTATIC HEAD WITH ZERO HEAD DOWNSTREAM OF THE RACK.

OVERFLOW TRASH RACKS:

1. ALL TRASH RACKS SHALL BE MOUNTED USING STAINLESS STEEL HARDWARE AND PROVIDED WITH HINGED AND LOCKABLE OR BOLTABLE ACCESS PANELS.
2. TRASH RACKS SHALL BE STAINLESS STEEL, ALUMINUM, OR STEEL. STEEL TRASH RACKS SHALL BE HOT DIP GALVANIZED AND MAY BE HOT POWDER COATED AFTER GALVANIZING.
3. TRASH RACKS SHALL BE DESIGNED SUCH THAT THE DIAGONAL DIMENSION OF EACH OPENING IS SMALLER THAN THE DIAMETER OF THE OUTLET PIPE.
4. STRUCTURAL DESIGN OF TRASH RACKS SHALL BE BASED ON FULL HYDROSTATIC HEAD WITH ZERO HEAD DOWNSTREAM OF THE RACK.

Figure OS-4. Orifice Plate and Trash Rack

Figure D-3. Orifice Plate and Trash Rack

Source: Urban Drainage and Flood Control District (2010c), page OS–11; reproduced with permission.

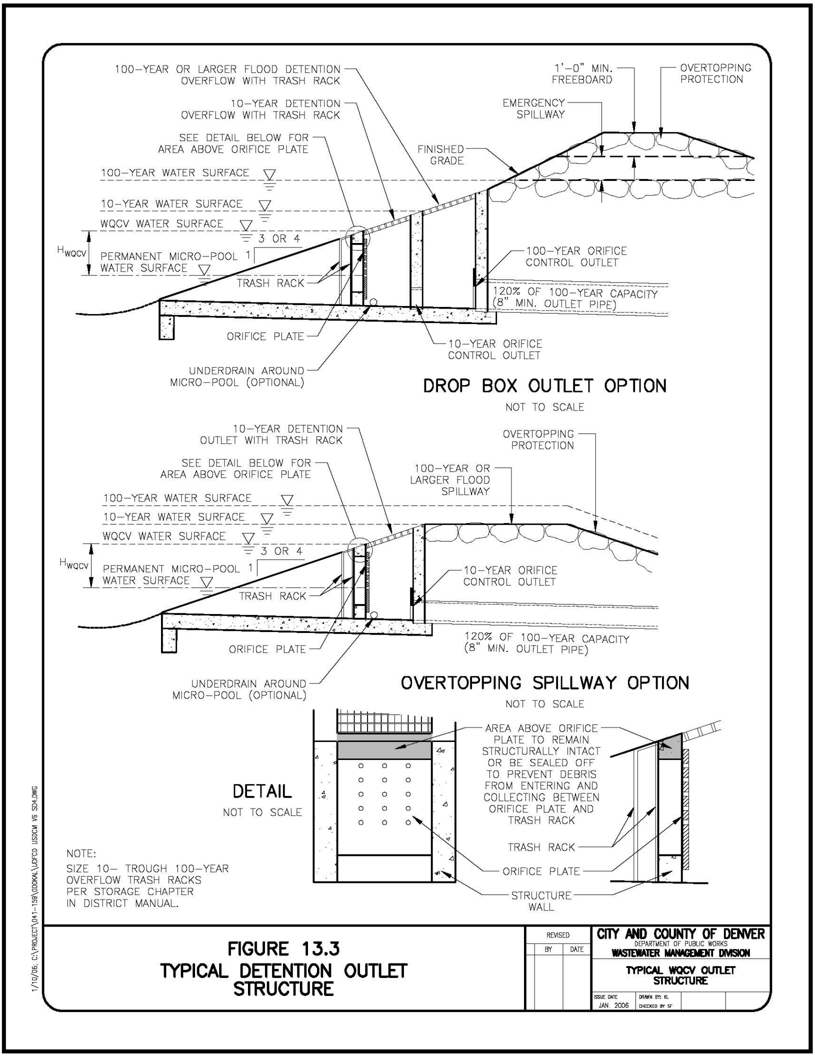


Figure D-4. Typical Detention Outlet Structure

Source: City and County of Denver (2006), page DET–17; reproduced with permission.

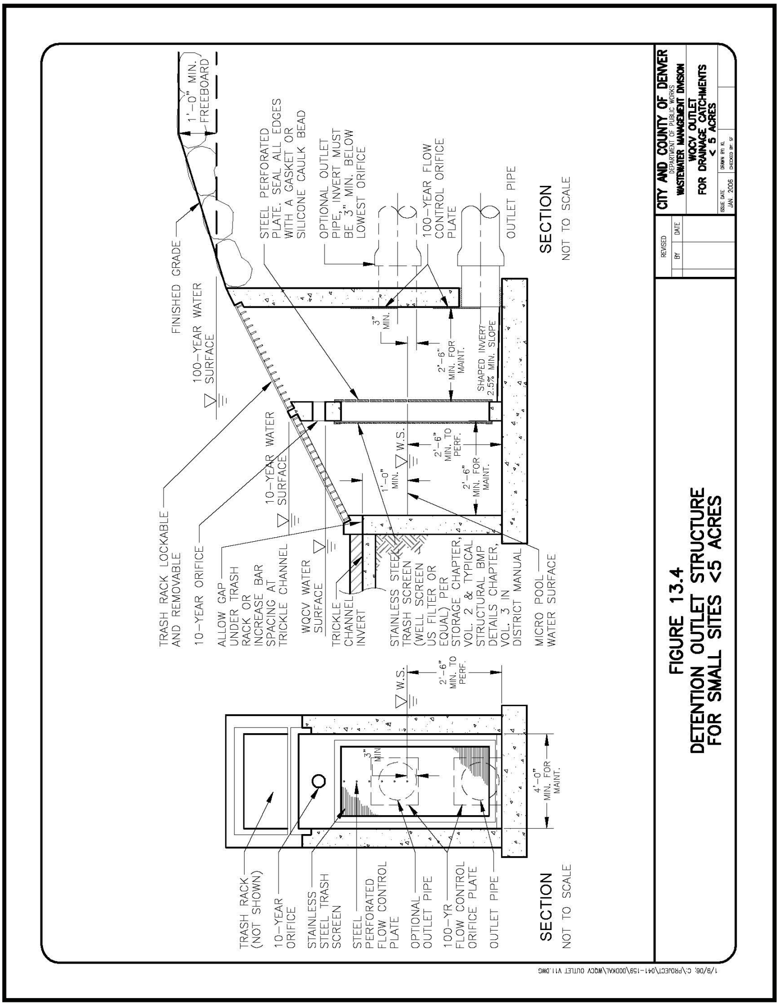


Figure D-5. Detention Outlet Structure for Small Sites Less than Five Acres

Source: City and County of Denver (2006), page DET–18; reproduced with permission.

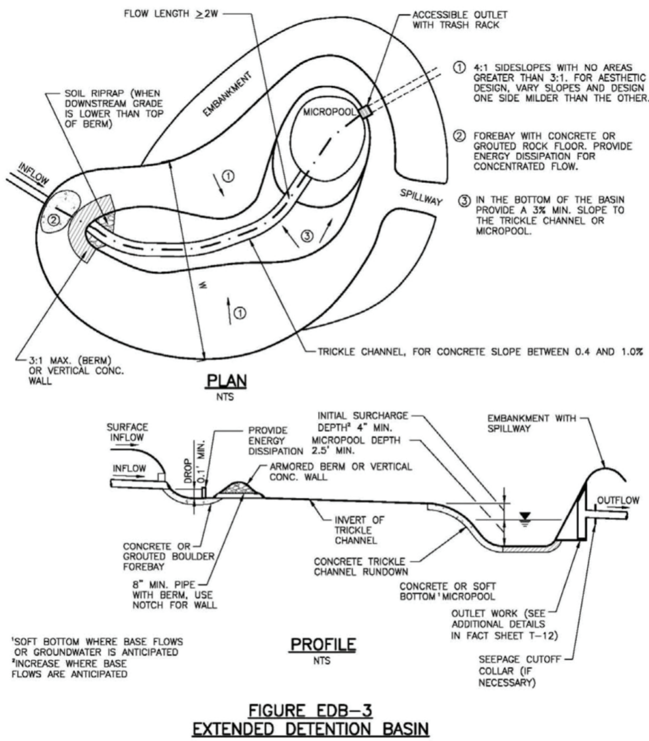


Figure EDB-3. Extended Detention Basin (EDB) Plan and Profile

Figure D-6. Extended Detention Basin Plan and Profile

Source: Urban Drainage and Flood Control District (2010c), page EDB-11; reproduced with permission.

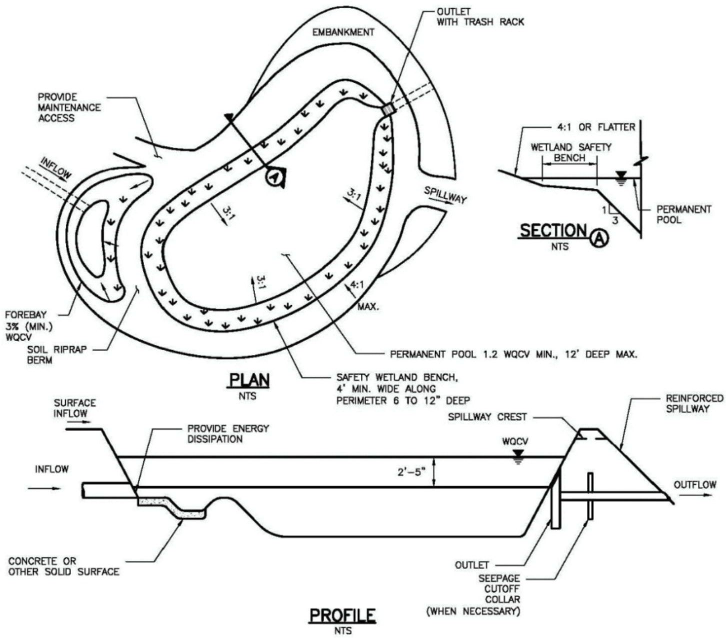


Figure RP-1. Retention Pond Plan and Sections

Figure D-7. Retention Pond Plan and Sections

Source: Urban Drainage and Flood Control District (2010c), page RP-6; reproduced with permission.

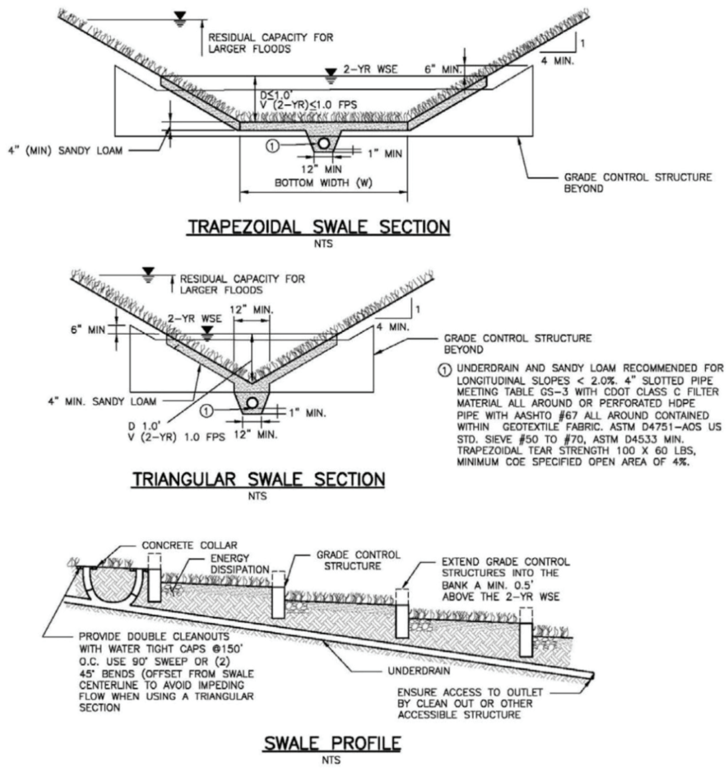


Figure GS-1. Grass Swale Profile and Sections

Figure D-8. Grass Swale Profile and Sections

Source: Urban Drainage and Flood Control District (2010c), page GS-6; reproduced with permission.

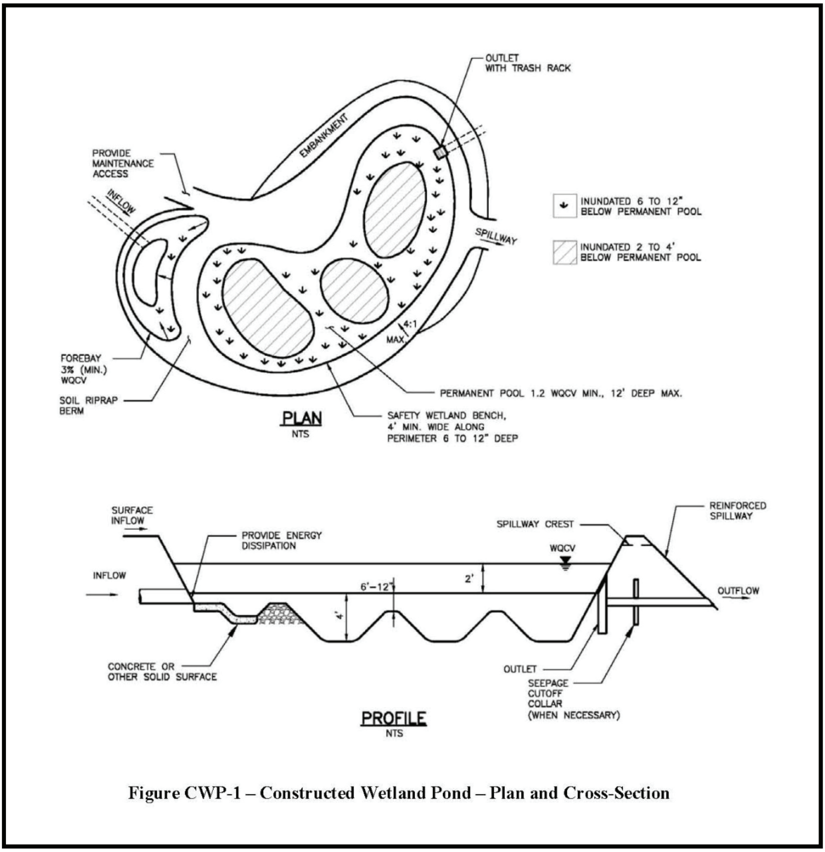


Figure D-9. Constructed Wetland Pond Plan and Cross-Section

Source: Urban Drainage and Flood Control District (2010c), page CWP-6; reproduced with permission.

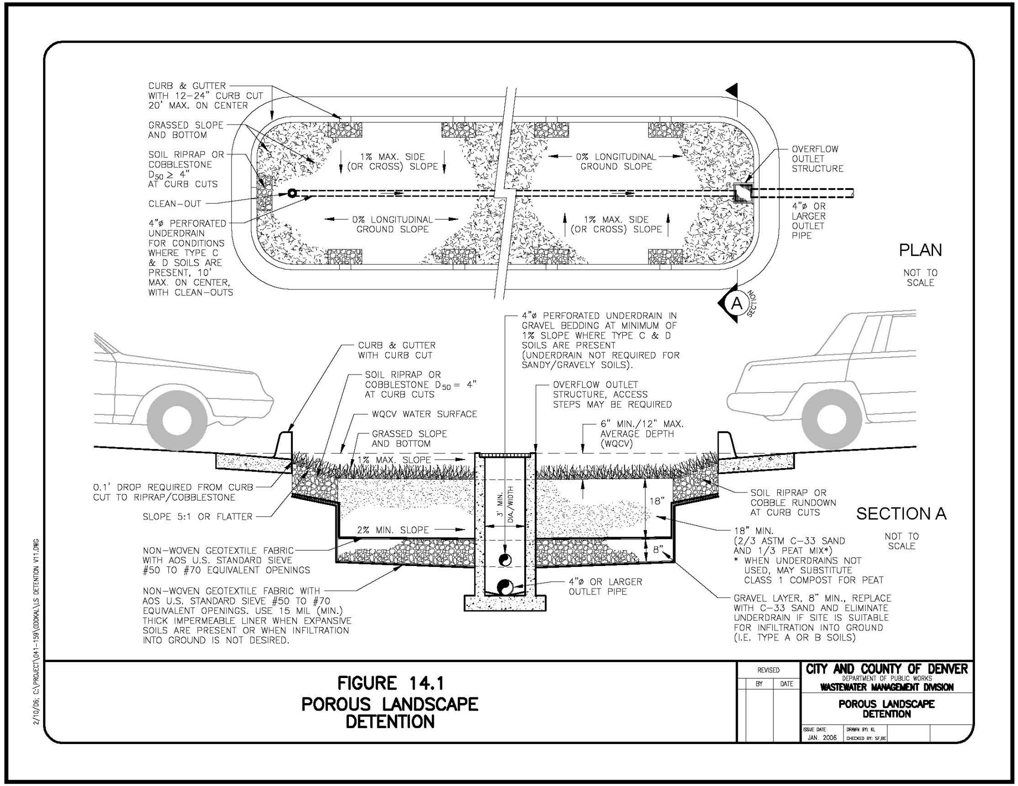


Figure D-10. Porous Landscape Detention

Source: City and County of Denver (2006), page WQ-10; reproduced with permission.

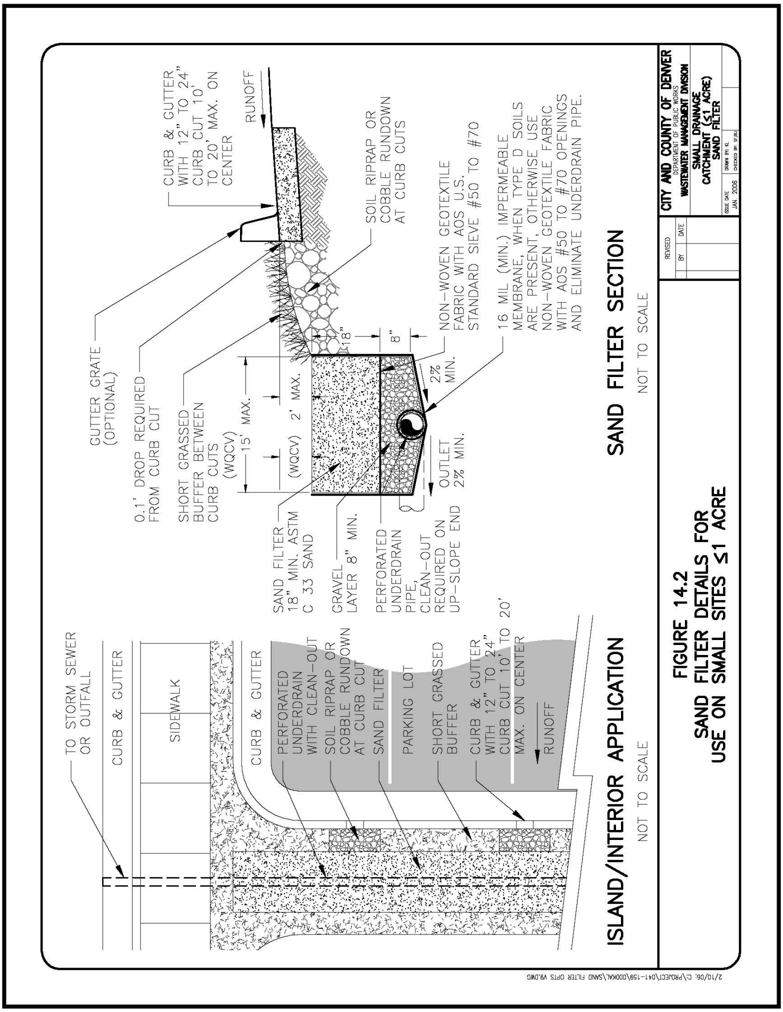


Figure D-11. Sand Filter Details for Use on Small Sites Less than One Acre

Source: City and County of Denver (2006), page WQ-11; reproduced with permission.

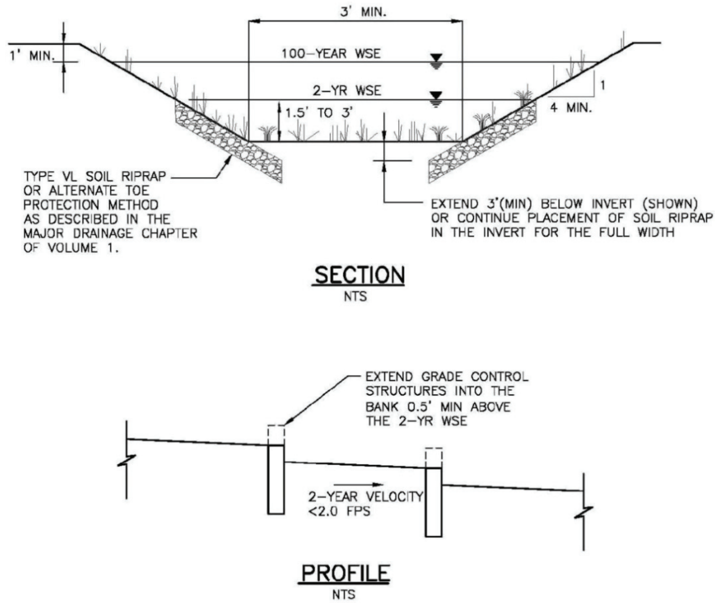
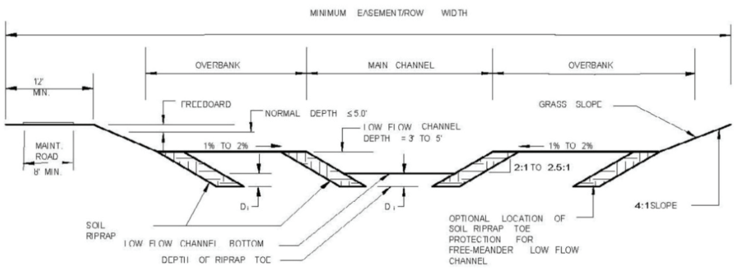


Figure CWC-1. Constructed Wetland Channel Plan and Section

Figure D-12. Constructed Wetland Channel Plan and Section

Source: Urban Drainage and Flood Control District (2010c), page CWC-4; reproduced with permission.



NOTE:

1. LOW FLOW CHANNEL: CAPACITY TO BE THE EQUIVALENT OF $\frac{1}{3}$ TO $\frac{1}{2}$ OF THE 2-YEAR FLOW BASED ON FULLY DEVELOPED TRIBUTARY WATERSHED PEAK FLOW.
2. NORMAL DEPTH: FLOW DEPTH FOR 100-YEAR FLOW SHALL NOT EXCEED 5 FEET, NOT INCLUDING THE LOW FLOW CHANNEL DEPTH. 100 YEAR FLOW VELOCITY AT NORMAL DEPTH SHALL NOT EXCEED 7 FT/S FOR CHANNELS WITH EROSION RESISTANT SOILS OR 5 FT/S FOR CHANNELS WITH EROSIVE SOILS.
3. FREEBOARD: FREEBOARD TO BE A MINIMUM OF 1 FOOT.
4. MAINTENANCE ACCESS ROAD: MINIMUM STABLE WIDTH TO BE 8 FEET WITH A CLEAR WIDTH OF 12 FEET.
5. ROW WIDTH: MINIMUM WIDTH TO INCLUDE FREEBOARD AND MAINTENANCE ACCESS ROAD.
6. OVERBANK: FLOW IN EXCESS OF MAIN CHANNEL TO BE CARRIED IN THIS AREA. AREA MAY BE USED FOR RECREATION PURPOSES.
7. D_1 = 3-FOOT MINIMUM FOR EROSION RESISTANT SOILS
   D_1 = 5-FOOT MINIMUM FOR SANDY SOILS
8. CHANNEL SIDESLOPE ABOVE LOW-FLOW CHANNEL 4H:1V OR FLATTER, EVEN IF LINED WITH SOIL RIPRAP.
9. FROUDE NUMBER FOR ALL FLOWS SHALL NOT EXCEED 0.8 FOR EROSION RESISTANT SOILS AND 0.5 FOR EROSIVE SOILS.
10. THE CHANNEL CAN BE DESIGNED TO HAVE THE LOW-FLOW SECTION TO HAVE A WETLAND BOTTOM.

Figure MD-7—Composite Grass-line Channel with a Low-Flow Channel, including a Wetland Bottom Low-Flow Channel

Figure D-13. Composite Grass-Line Channel with a Low-Flow Channel, Including a Wetland Bottom Low-Flow Channel

Source: Urban Drainage and Flood Control District (2010a), page MD-82; reproduced with permission.

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Index

Page numbers followed by *e*, *f*, and *t* indicate equations, figures, and tables, respectively.