Chapter 10
Stream Access and Recreational Channels

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1.0 Introduction and Overview

When channels are readily accessible to the public, public safety must be a primary design objective. The term "recreational channels" refers to all open channels that are readily accessible to the public. The planning, design, and construction of recreational channels should provide safe public access and use to all accessible areas. Unintended entry into the water by the public should also be considered during the planning and design phase. This chapter is relevant to virtually all open channels in urban areas and is largely focused on safety.

This chapter provides criteria and guidance for design of special structures, such as drop structures and pedestrian crossings, as well as larger scale considerations such as egress and signage for the length of a reach. It covers design of shared use paths, equestrian trails, low-flow crossings, underpasses, cross drainage and other considerations specific to paths adjacent to streams. This chapter also provides criteria for recreation channels that are also considered to be "boatable."

Boatable channels represent a subset of recreational channels. Channels should be planned and designed to address public safety issues related to this use when they are considered to be boatable or this use is planned for the future or when the channel is classified by the Colorado Water Quality Control Commission as having existing or potential "primary contact use."

Some boatable channel criteria may also be appropriate for recreational channels where boating does not typically occur. The degree of this consideration will depend on issues such as:

- Level of activity around the water's edge both for current conditions and anticipated future uses,
- Frequency and range of flows within the recreational channel, and
- Potential consequences of accidentally falling into the water (low water and high water conditions).

2.0 Public Safety Project Review

As an increasing number of design professionals and developers promote the natural and beneficial functions of the floodplain, encouraging passive recreation in the floodplain and drawing people toward the water's edge, public safety becomes even more critical. This chapter focuses largely on to public safety issues, providing detailed criteria in Sections 3.0 and 4.0 for areas designed for some level of use by the public. This section, including the inset on the next page, is intended to identify when a comprehensive public safety review for a project is recommended and to guide the engineer and owner on key public safety issues. The safety criteria provided in the inset are additional to criteria provided in Sections 3.0 and 4.0 of this chapter. The *Public Safety Guidance for Urban Stormwater Facilities* (ASCE 2014) is also a good resource for public safety.

Although the engineer should consider public safety throughout the design process, the following siting and design components should trigger a comprehensive project review for public safety:

- Projects in densely populated areas and with populations that may require specific site requirements (e.g., high populations of children or elderly);
- Projects adjacent to schools, playgrounds, or within a public park;
- Projects designed with the intent to draw the public toward water,
- Drop structures taller than 3 feet from crest to stilling basin floor,
- Vertical drop structures of any height,
- Walls (including boulder walls and channel edging) exceeding 3 feet,
- Channel side slopes steeper than 4:1,
- Detention basins and outlet structures,
- Retention ponds and outlet structures,
- Inlets to storm drains and long culverts,
- Below grade paths, and
- Low-flow crossings.

The following considerations may be helpful when conducting this review:

- At what locations and with what frequency might a person become trapped by flood water?
- At what locations could signage be beneficial to public safety?
- What dry weather and wet weather risks exist in the project area?
- What locations present potential fall hazards during dry weather, wet weather, or when snow or ice is present?
- Do maintenance personnel have safe access to all required areas?
- How will channel degradation impact safety associated with various elements of the project?

Public safety criteria found elsewhere in the Urban Storm Drainage Criteria Manual (USDCM):

From the Open Channels Chapter:

Channel side slopes steeper than 2.5H:1V are considered unacceptable under any circumstances because of stability, safety, and maintenance considerations.

From the Hydraulic Structures Chapter:

Drop faces should have a longitudinal slope no steeper than 4(H):1(V). The formation of overly retentive hydraulics is a major drowning safety concern when constructing drop structures. Longitudinal slope, roughness and drop structure shape all impact the potential for dangerous conditions.

When designing [underground conveyance] systems with flared-end sections that are larger than 36 inches in diameter, pedestrian railing may be warranted if public access will occur. If this is the case, railing can be more easily mounted to a combination headwall/wingwall.

It is important to note that vertical [drop] structures can cause dangerous hydraulic conditions, including keeper waves, during wet weather and are generally discouraged. In addition, vertical drop structures are to be avoided due to impingement energy, related maintenance and turbulent hydraulic potential (ASCE and WEF 1992).

Vertical drops are not appropriate where fish passage is needed, design flow (over the length of the drop) exceeds 500 cfs or a unit discharge of 35 cfs/ft, net drop height is greater than 2 feet, or the stream is used for boating or there are other concerns related to in-channel safety.

From the Culverts and Bridges Chapter:

Based on UDFCD investigations of culvert and storm drain deaths, safety grating should be required when any of the following conditions are or will be true:

- It is not possible to “see daylight” from one end of the culvert to the other,
- The culvert is less than 42 inches, or
- Conditions within the culvert (bends, obstructions, vertical drops) or at the outlet are likely to trap or injure a person.

From the Storage Chapter:

The use of retaining walls within detention basins is generally discouraged due to the potential increase in long-term maintenance access and costs as well as concerns regarding the safety of the general public and maintenance personnel. Where walls are used, limit the length of the retaining walls to no more than 50 percent of the basin perimeter. Also, consider potential fall hazards associated with pedestrians, cyclists, and vehicles in determining the appropriate treatment between a sidewalk, path, or roadway and the top of the wall. Considerations include distance from the public to the wall, curvature of the path or roadway, single or terraced walls, and volume of traffic.

Potential solutions include dense vegetation, seat walls, perimeter fencing, safety railing and guardrail. In some cases walls less than 2 feet will warrant a hard vertical barrier; in other cases a 3 foot wall may be the point at which this barrier is appropriate. Check requirements of the local jurisdiction. UDFCD recommends providing a hard vertical barrier in any location where walls exceed 3 feet.

It should also be noted that retention ponds pose a greater risk to the public compared to detention basins and should be evaluated for unintentional entry by the public.

3.0 Shared-Use Paths Adjacent to Streams

This section provides guidance for shared use paths and equestrian trails, low-flow crossings, underpasses, cross drainage, and other considerations specific to paths adjacent to streams. Paths are an integral part of recreational channels, providing access for the public and channel maintenance. Paths are typically also part of the active conveyance area for the channel during a flood. When available, adhere to local jurisdiction shared-use path design criteria in addition to this section. The AASHTO Guide for Development of Bicycle Facilities is also an excellent reference and guidance and conformance to these criteria is frequently required for federally funded projects. Where criteria conflict, adhere first to local jurisdiction criteria, then this manual, followed by the AASHTO guide (when appropriate).

Additional Resources for Path Design

- AASHTO Guide for the Development of Bicycle Facilities
- National Trails Training Partnership website
- NACTO Urban Bicycle Design Guide
- www.bicyclinginfo.org
- Iowa Water Trails Toolkit, Iowa Department of Natural Resources FHWA Designing Sidewalks and Trails for Access
- FHWA Evaluation of Safety, Design, and Operation of Shared-Use Paths
- Architectural Barriers Act (ABA) Accessibility Standards
- Americans with Disability Act (ADA) Standards for Accessible Design

3.1 Path Use

Paths are often constructed along streams to provide access for maintenance vehicles. However, if public access is provided to the path, it should be assumed that the path will be used by the public. For this reason, it is important to design paths with the health, safety, and welfare of the public as a primary design objective. It is also important to evaluate when it is appropriate for a path to conform to accessibility criteria. Accessibility is a requirement for all paths described in this section with few exceptions (e.g., a gated section of path not intended for any public use). Depending on the design, users may include bicyclists, pedestrians, runners, equestrians, dog walkers, people with baby carriages, people in wheelchairs, skate boarders, and others. Not all paths will be designed for all of these users, but the following can be considered when determining type of use of the path:

- Does this segment of path fit into an existing master plan where use has been determined?
- What connections are made with the path? Who are the likely users?
- How can the path best provide continuity between its connection points? Alternating segments (in regard to intended use, material, or geometry) should be minimized.

Determining the expected types of path users expected will help in establishing geometry, selecting construction materials and techniques, and understanding safety considerations.

3.2 Frequency of Inundation

Photograph 10-1. Frequently inundated channels pose a high threat to public safety, especially in a walled channel where water can rise rapidly and egress is limited.

The frequency of inundation is one of the most important considerations for the design of a path adjacent to a stream. This criterion directly affects safety and maintenance and frequently impacts cost, conveyance capacity, and the users' path experience. Less frequent inundation is better from a safety and maintenance perspective. The public safety threat is especially high in channels susceptible to flash flooding and where egress from the channel section is limited (e.g., walled channels). Frequently inundated paths also require more frequent maintenance due to sediment deposit on the path surface and erosion at the path edges.

Photograph 10-2. Sediment frequently accumulates under crossings. Frequently inundated paths collect sediment and are maintenance-intensive.

Removal of sediment after runoff events typically involves collection and disposal of sediments. Washing the sediment back into the channel would violate typical MS4 permit requirements. Additionally, sediment deposition between the channel and the path can impede drainage away from the path and result in water or ice on the path. Paths constructed with new channel or roadway improvements should be constructed above the 5-year water surface elevation or higher. For highly used paths an elevation above the 10-year water surface elevation is preferred.

For a retrofit project, the same standards should be met when practical; however, existing conditions may not allow this for the entire length of the path. In this case UDFCD strongly recommends that the design elevation remain above the 2-year water surface elevation at all locations. Changes in channel section can occur over time resulting in the increased frequency of overtopping in the future. For this reason, it is also good practice to set the surface of the path a minimum of two feet above the estimated base flow elevation. When existing conditions do not allow for a path elevation meeting either of these two criteria, consider alternative alignments.

Exceptions to the above criteria may be appropriate in the area of a low-flow stream crossing where the crossing could be designed to pass up to a 2-year event before overtopping. This should be evaluated on a case-by-case basis taking into consideration frequency of use and the importance of the crossing as a path connection component. Benefits of constructing a low-flow crossing include conserving flood capacity for higher flows, improving user experience by bringing the user in closer contact with the stream, and potentially eliminating railing that could otherwise catch debris, become a maintenance issue, and further impact the floodplain. However, low-flow crossings have attendant safety risks of their own. See Section 3.6 for additional guidance on stream crossings.

Underpasses, where users frequently seek shelter in a storm event, present a more critical case for public safety as it relates to frequency of inundation. If the geometry of the surrounding area and configuration of the underpass combine to allow the user to see the water and seek higher ground, more frequent inundation may be acceptable. See Section 3.4 for additional guidance on underpasses.

Frequency of inundation criteria for paths is summarized in Table 10-1. Further discussion specific to path underpasses and stream crossings is provided in Sections 3.4 and 3.5.

Table 10-1. Frequency of inundation criteria summary

Path Type	Recommended Elevation (when practicable) (water surface elevation)	Minimum Elevation (water surface elevation)	Other Considerations
Stream Crossings	2 to 5-year	2-year	
Bridge Underpass	5-year	2-year	
Culvert Underpasses less than 100 feet in length	5-year	2-year	The user should be able to see when water is rising and climb to safety.
Culvert Underpasses greater than 100 feet in length	10-year	5-year	The culvert should be straight. The user should be able to see when water is rising and climb to safety.
All Other Locations (New)	10-year	5-year	Elevating the path to the 10-year WSE is preferred.
All Other Locations (Retrofit)	5-year	2-year	Where practicable also elevate the path two feet above the baseflow.

3.3 Path Geometry

3.3.1 Typical Sections

The minimum recommended width for a path that facilitates light maintenance vehicles is ten feet. A reduced width typically results in edge damage from maintenance vehicles. This is also consistent with AASHTO's width recommendations for two-directional shared-use paths. In many cases it may be desirable to increase the width to 12 or even 14 feet to accommodate conflict points or when high volumes of users are anticipated. In very high-use areas multiple treads allow separation of uses that might conflict. An example of this is where the South Platte River path meets that of Cherry Creek. Within Confluence Park, users on foot and those on wheels are split on either side of the water. In the extremely high use area of Confluence Park where different users are not separated, the path is widened to 14 feet and all railing includes rub rails (see photo 10-22). Rub rails on bridges are horizontal members that help mitigate injury to cyclists crashing into them.

Trail Conflict Points

Trail conflict points include underpasses, trail intersections, blind corners, areas with steep grade and other locations where an accident between users is more likely to occur.

These areas require special consideration. Depending on the scenario, the following could be added to reduce the probability of or resulting damage from an incident:

- Railing
- Yellow Striping (indicating separation between two-directional users)
- Increased trail width
- Signage
- Wide-angle Mirrors
- Signals Lights

On each side of the path the adjacent grade (shoulder) should be no steeper than 6(H):1(V) for a minimum width of two feet. This is regardless of the edge treatment and provides a place for the user to safely move off the path and also protects the path from potential damage due to adjacent sloughing grade. Sloughing grade adjacent to the path can eventually undermine the path or cause a rumble strip to become separated from the path. It is best to provide a section in the construction drawings that shows the shoulder and specifically calls out for backfilling the sides of the path. When the site does not allow for a shoulder, a thickened edge (see Figure 10-1) can protect the path from being undermined and allow maintenance personnel time to identify and repair the problem.

Photograph 10-3. Signing and striping help segregate bicyclists and pedestrians at Confluence Park where the two treads are separated by the creek.

In some cases (see Table 10-2), a safety rail parallel to the path is recommended. Rails are appropriate where a dangerous condition would otherwise exist. Common locations include steep side slopes, vertical walls, steep longitudinal slopes, bends, areas where cross drainages create isolated hazards, and where combinations of the above circumstances exist.

3.3.2 Use of Rails, Curb Rails, and Rumble Strips

Rails, curb rails, rumble strips, increased path width, changes in texture and/or color, signage and striping are all tools that can be used to improve path safety and heighten user awareness of a new or changing condition. For the purpose of these criteria the term "edge treatment" refers to rails, curb rails, and rumble strips. All above-grade stream crossings should include an edge treatment. For all edge treatments, increase the width of the path (in addition to the width of the approaching path) to allow for placement of the treatment. See Figure 10-2 for rumble strip details. When using rails (curb rails or full rails), provide a minimum of one foot clear beyond the edge of the approaching path to the rail. See Table 10-2 for a summary of recommendations and Figures 10-2 through 10-8 for plan views and sections.

Use of full rails (typically 42 inches when bicyclists are anticipated and 54 inches when the path provides equestrian passage) can cause adverse flooding conditions and should only be used when a curb rail or rumble strip does not provide an acceptably safe condition for the user. When rails are used, the hydraulic model should consider the full area of the rail to be clogged with debris. Based on the experience of UDFCD, "break-away" rails which are designed to collapse during high flow, are often ineffective over time and should not be relied on for floodplain analysis (i.e., they too should be modeled as fully blocked).

Photograph 10-4: Rumble strips warn the user of the path edge without reducing capacity for flood flows. Photo Courtesy Architerra Group.

Photograph 10-5. Most of the "break-away" rails on this crossing failed to break despite the capacity lost to debris.

Photograph 10-6. Curb rails are typically no higher than 12 inches and can be constructed from a variety of materials.

Table 10-2. Edge treatment criteria summary

Path Type	Difference in elevation from path surface to adjacent grade (design[1])	Edge Treatment
Paths perpendicular to the stream or in an underpass	Up to 36 inches	Rumble strip or curb rail
	up to 54 inches	Curb rail[2]
	Greater than 54 inches	Full rail[3] (typically 3'-6" inches for shared use and 4'-6" for equestrian)
Paths parallel to the stream and not in an underpass	Up to 36 inches	Rumble strip
	Greater than 36 inches or adjacent slope steeper than 3:1[3]	Full rail[3] (typically 42 inches for shared use and 54 inches for equestrian)

[1] Values provided assume that differences in elevation following construction may potentially increase in some areas by up to 20% due to stream degradation.
[2] Model flooding effects with rail fully clogged.
[3] Span 100-year floodplain (preferred) or model flooding effects with rail fully clogged.
[4] Adjacent slope refers to slope adjacent to the 2-foot shoulder.

Photograph 10-7. Horizontal members are placed on the users' side of the posts. This is an important consideration for both shared- use paths and equestrian trails in that it reduces the chance of snagging clothing, a bike pedal or a stirrup.

Photograph 10-8. At Confluence Park a rub rail was included as part of the rail design. This, in addition to the 14-foot path width, improves safety in this high-use area.

Considerations for Designing Safety Rails

- Minimize the likelihood of the rail catching debris. This is a maintenance issue and, if not maintained, can reduce capacity in the stream and cause flooding or damage to the safety rail
- Place horizontal members on the users' side of the posts. This provides a safer surface, less likely to catch clothing, a bike pedal, or a stirrup.
- Provide a rail height of at least 42 inches when cyclists are anticipated and 54 inches when the trail provides equestrian passage.
- Consider snow removal either by designing the rail to allow movement of snow through the bottom of the rail (without creating a safety hazard for small children) or by planning for snow storage in an alternate location.

Photograph 10-9. Striping used sparingly can be effective in alerting the user of a safety concern. In this photo, it is used where the path approaches a crossing.

Photograph 10-10. Along this section of the South Platte River, the combination of a steep longitudinal slope, a cross drainage structure, and a steep slope from the path to the water warranted both a safety rail and striping.

3.3.3 Path Overtopping Protection

Provide adequate protection to avoid damage caused when flows overtop the path. As a path turns perpendicular to the stream, or anywhere significant overland flows are likely to cross the path (e.g., downstream of side-channel spillways or at undersized culvert crossings), scour can occur along the downstream edge. This causes the path to act like a drop structure. Flows across the path accelerate, potentially damaging the upstream edge of the path, while scour downstream can eventually undermine the path (see Photo 10-11). For these reasons, a thickened edge on both the upstream and downstream sides of a path approaching a low crossing is recommended. The edge should extend a minimum of two feet below the surface of the path (see Figure 10-1). Soil riprap placed adjacent to the path can be used to provide additional protection.

Photograph 10-11. A soil cement path approaching a crossing on Sand Creek is undermined on the downstream side due to overtopping. Overtopping protection was not adequate to stop scour damage before losing a section of the path.

The length of the overtopping protection is site specific. If the bank of the channel is well defined, protection should extend from the crossing into the bank. If the bank is not well defined, extend the protection to a point where the path is more parallel with the stream than it is perpendicular. In either case, the length of overtopping protection typically does not need to extend higher than the 10-year surface elevation.

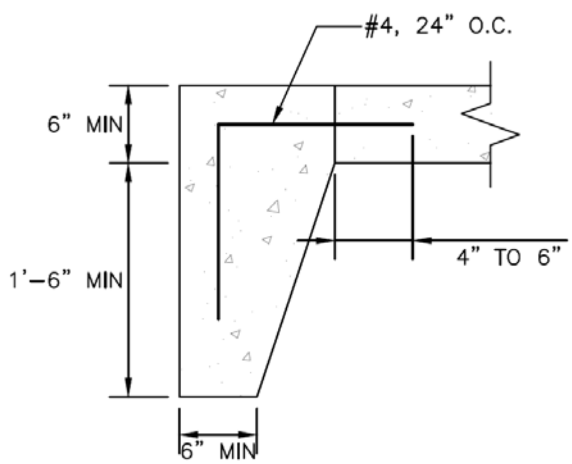


Figure 10-1. Thickened edge detail

3.3.4 Vertical Clearance in an Underpass

Maximizing vertical clearance improves the users' experience on the path. It increases light in underpasses and helps open the area so users do not feel trapped by the walls of a structure. However, increasing vertical clearance can also increase frequency of inundation because often the top elevation of the structure is fixed by the profile of existing utilities or the roadway crossing the stream (i.e., the path must be lowered to increase vertical clearance). In cases where the desired vertical clearance cannot be met without lowering the path to an elevation below the 2-year water surface elevation (at a minimum), the vertical clearance must either be reduced to the minimum allowable clearance in Table 10-3 or an alternative crossing (e.g., at-grade) considered. Ramps up to an at-grade crossing provide a good alternative for the path user (where feasible) and also serve as an escape route during a flash flood.

Table 10-3 provides minimum values for vertical clearance for various types of paths. Minimum values may be lower than those published by local communities within the UDFCD boundary. They are based on the minimum reasonable value for the respective use listed. Always check local criteria and conform to their vertical clearance requirements.

Table 10-3. Path geometry criteria summary

Path Type	Minimum Width (feet)	Minimum Width for High Use or Conflict Areas[3] (feet)	Minimum Vertical Clearance for Consideration[1] (feet)	Typical Minimum Vertical Clearance[2,4] (feet)	Preferred Vertical Clearence[4] (feet)	Typical Materials[5]
Maintenance Only	10	12	8	8	10	Concrete, Reinforced Grass
Hiking trail Only	n/a	n/a	6.67	8	10	Compacted Soil, Crusher Fines[3], Proprietary Materials
Shared-Use with Bicyclists	10	12 to 14	8	8 to 9	10	Concrete or Proprietary Material
Equestrian	1.5 to 2.5	8	10	10	12 to 14	Grass or Compacted Soil

1 Represents the minimum clearance that should be considered.
2 Represents typical minimum criteria common to reviewing agencies and owners.
3 Also recommended where a rail or wall is placed on both sides of the path.
4 Based on review of path criteria for several agencies nationwide. Values will vary based on community.
5 Not intended to be limiting.

3.3.5 Sight Distance

In order to avoid a crash, a cyclist must have time to identify potential conflicts and react accordingly. For all hard paths, or where bicyclists are otherwise anticipated, refer to tables and charts provided in *AASHTO Guide for the Development of Bicycle Facilities* to calculate the appropriate sight distances.

Photograph 10-12. Despite striping and signage, bicyclists frequently speed through the University Boulevard underpass along the Cherry Creek path.

Photograph 10-13. Understanding the popularity of the Cherry Creek path, designers worked to make the underpass at University safe for bicyclists and pedestrians while working within the limitations of the existing site. Land was purchased to create a suitable turning radius at this 90 degree bend. This provides bicyclists with additional time to react to the unexpected.

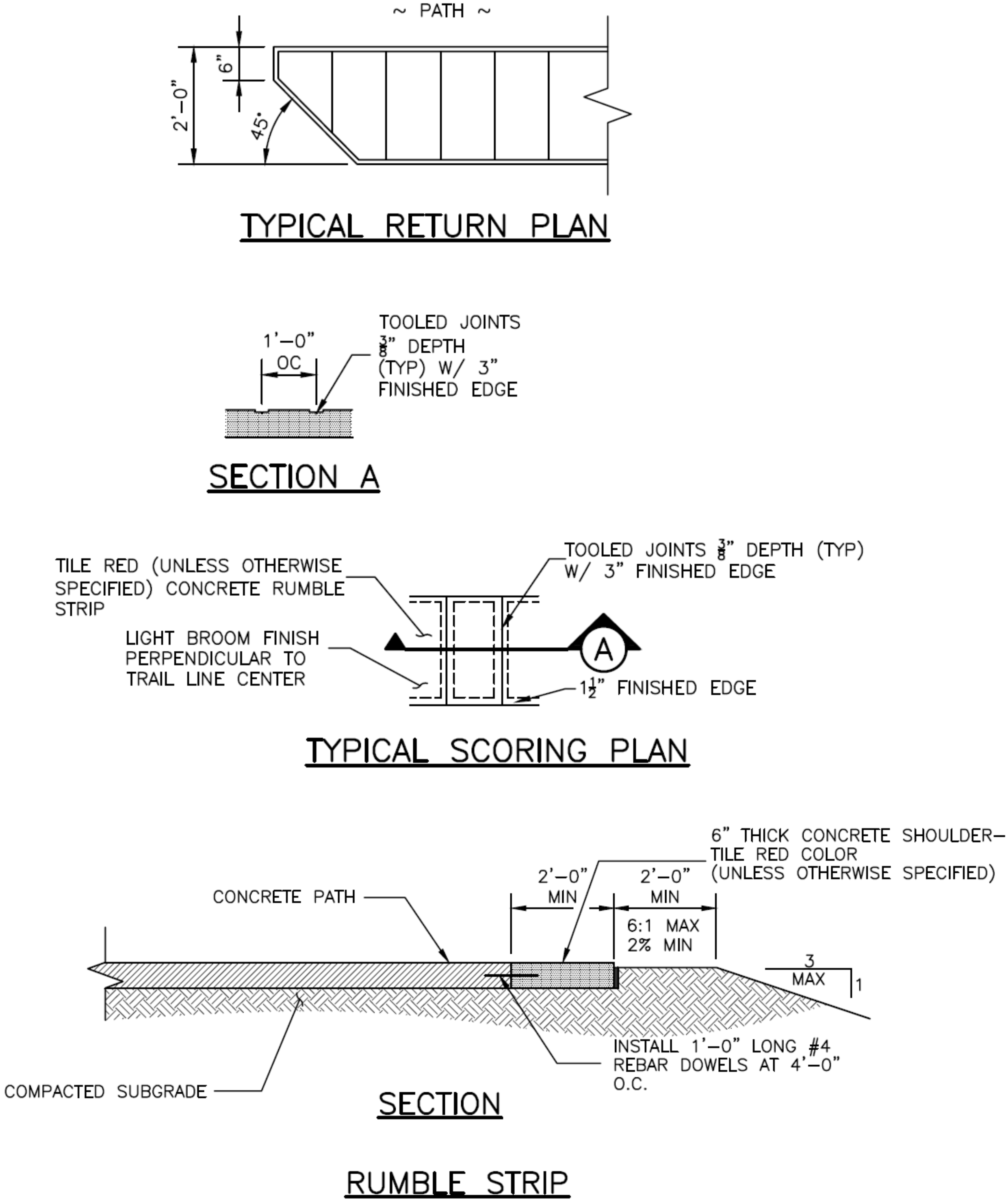


Figure 10-2. Rumble strip detail

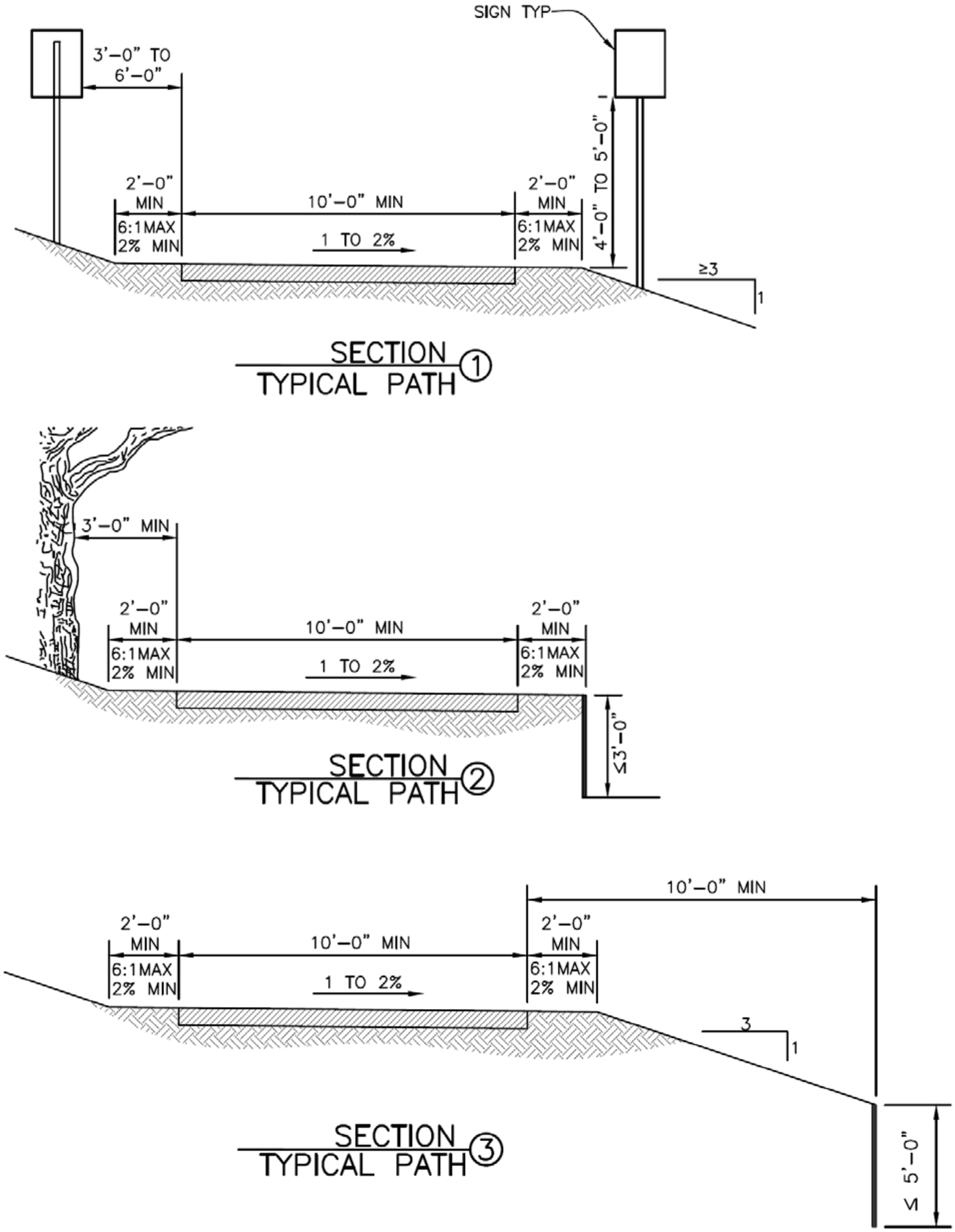


Figure 10-3. Typical path sections 1, 2, and 3.

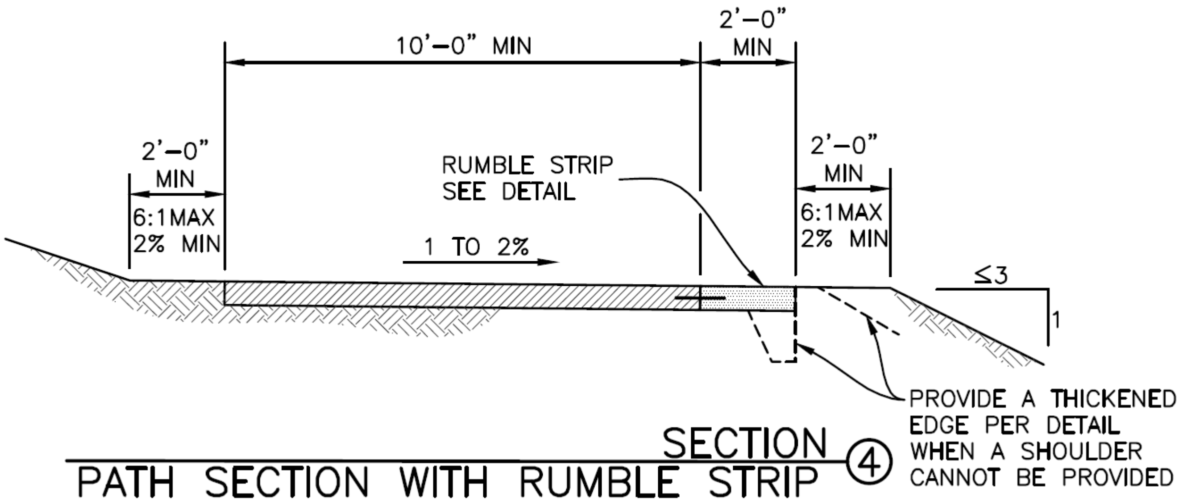


Figure 10-4. Path section with rumble strip

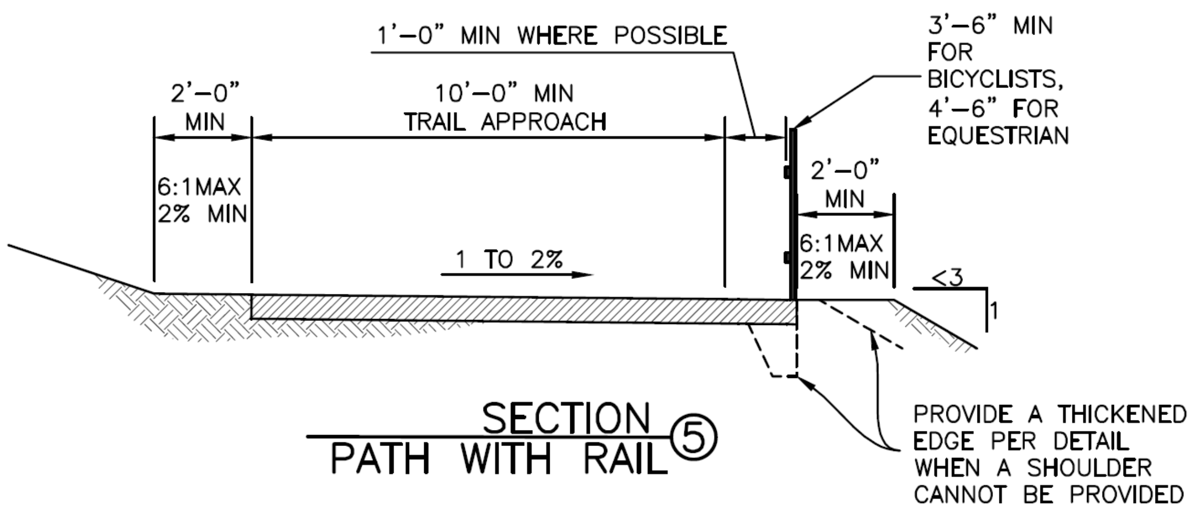


Figure 10-5. Path section with rail

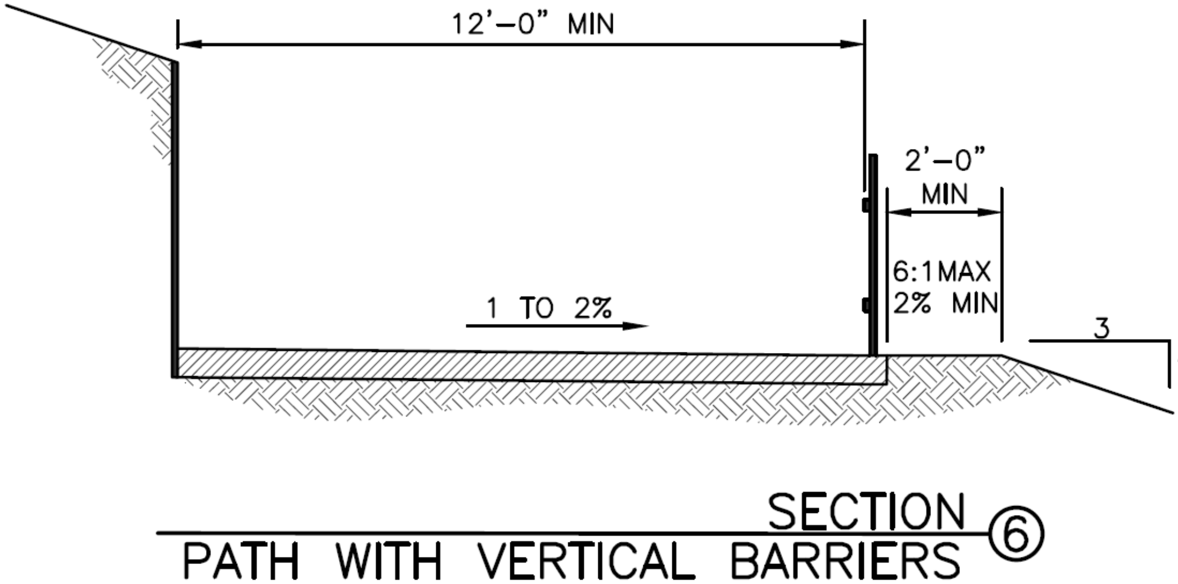


Figure 10-6. Path section with vertical barriers on both sides

3.4 Path Drainage

To avoid nuisance drainage problems, the path should have a cross slope toward the channel. The slope should not exceed two percent to meet accessibility requirements. Typically a cross slope of at least one percent coupled with a longitudinal slope provides adequate drainage. The bench on each side of the path should also be sloped a minimum of 2% to provide adequate drainage and should not exceed a slope of 6(H):1(V).

3.4.1 Cross Drainage

Where outfalls intersect the path, provide culverts below the path to provide conveyance for frequent events. This will minimize disruption of path use and icing. For small outfalls located below the path, a level spreader, in combination with a riparian buffer may also be used to spread low-flows, improve water quality, and benefit vegetation. See the *Grass Swales* Fact Sheet in Chapter 4 of Volume 3 for more information on level spreaders. Similarly, other linear BMPs could also be used to reduce stormwater on the path. Where constraints exist, a chase may be used to keep frequent flows off the path. Be aware that chases tend to clog with leaves, trash, and other debris and require frequent maintenance to function properly. They can also become damaged during snow plow operations and can result in more frequent icing than piped conveyance. Additionally, metal chases should not be used on equestrian paths.

3.4.2 Pumped Systems

In some locations, where an underpass is at a low point in the path, pump systems have been installed to drain the sump when water overtops the path. Electromechanical systems can be unreliable however, especially when needed most. Pumped systems can also require frequent and costly maintenance and may trigger requirements for water quality monitoring under an individual permit from the State. For all of these reasons UDFCD strongly discourages the use of pumped systems except as a last resort.

3.4.3 Paths Adjacent to Walls

Consider discharge from weep holes. This can cause unexpected icing on the path after a warm day followed by a cold night. Where possible, it may be appropriate to collect this flow and convey it under the path.

3.5 Path Underpasses

At roadway crossings, there are generally three alternatives for path connections: path underpasses, at-grade crossings, and pedestrian bridges. The type of crossing selected effects user safety, user experience, animal passage, and cost. The scope of this manual focuses on underpasses. At-grade crossings and pedestrian bridges are not specific to streams and are covered in detail by other path design manuals.

Underpasses are the preferred alternative when the structure and roadway profile allow for the design to meet both vertical clearance and frequency of inundation criteria. Underpasses include (in order of preference) bridges, single span culverts,

Underpass Safety

Underpasses are often used for shelter during inclement weather. The following should be included where possible.

- Visibility of rising water from any location within the underpass
- Ability to climb to a higher elevation.
- Signage discouraging use of the underpass as a shelter and warning of potential flash flood. This signage should be placed <u>inside</u> the culvert or under the bridge. UDFCD encourages use of the sign shown in Photo 10-17 as a regional standard.

and multiple cell culverts. When both vertical clearance and frequency of inundation criteria cannot be met, other alternatives (i.e., at-grade crossings and pedestrian bridges) should be explored.

3.5.1 Path Underpass through a Bridge

Bridges with path crossings below are preferred over culverts because they provide the user with a wider field of vision and bring the user closer to the stream. This improves the experience for the path user, and from a safety perspective, is especially important along flashy streams, where being able to see water rising and climb to higher ground during a flash flood could save a life.

Bridges tend to be favored over culverts by the US Army Corps of Engineers (USACE) as they provide better wildlife passage and sometimes result in less impact to wetlands.

Photograph 10-14. This bridge offers safe passage, providing the user with a view of potentially rising water and the path beyond the structure. Additionally, the slope from the path to the roadway offers the user a passable route to higher ground in case of flash flooding.

3.5.2 Path Underpass in a Culvert

Underpasses in a culvert are less desirable than bridges especially when the use of multi-cell culverts separates the user from the water. This creates a scenario where the user may not be aware that water is rising in other culverts and a potential flashflood threat exists. When a bridge cannot be provided, the design should include a connection to street level on both sides. This will ensure maintenance access and improve safety. A culvert underpass presents a location where users may seek shelter during rain or hail, placing them in danger from flooding. Provide signage inside each end of the culvert to discourage users from seeking shelter within the structure. UDFCD recommends the sign provided in Photo 10-17 to promote consistency throughout the region.

Photograph 10-15. This single-cell three sided box culvert offers safe passage, providing the user with a view of potentially rising water and the path beyond the structure.

The confined space within culvert underpasses can frighten horses, making them problematic for equestrian paths.

Photograph 10-16. Multi-cell culverts can be uninviting, especially if the user is not able to see the other end.

3.5.3 Floodwalls

A wall placed between the stream and the path to allow use of the path while flows exceed that of the path surface is a type of floodwall. The use of floodwalls to meet frequency of inundation criteria is discouraged. Floodwalls require a high level of maintenance with both sediment removal and nuisance drainage issues.

3.5.4 Culvert Geometry

Within any underpass, the path section should allow for pedestrians to safely move off the path if another user speeds by. For this reason, a shoulder is recommended on each side of the path (see Figure 10-3). This can be an extension of the path section or can be surfaced differently as long as it provides a stable surface (e.g., a rumble strip).

Photograph 10-17. Place cautionary signage inside the structure where it is most likely to be seen by someone using the culvert for shelter.

The length and geometry of the culvert also affect safety. The length should be minimized to enable the user to evacuate quickly. Long culverts (over 100 feet) should be elevated to the 5-year water surface elevation (at a minimum) and should be straight to increase visibility and natural light. Culverts in excess of 200 feet are strongly discouraged. Reducing the length may require increasing the size of the wing walls, raising the elevation of the path, and/or acquiring land and placing the culvert at an alternate location. When the culvert design length exceeds 200 feet consider an alternative crossing for the path, e.g. at-grade.

See the Path Geometry section and Table 10-3 for vertical clearance recommendations. Also consider the vertical alignment immediately upstream and downstream of the culvert as it relates to maintenance access and drainage. Ensure passage of maintenance vehicles through the culvert. This may require a vertical curve or shifting a grade break further away from the culvert. Where practical, drain water away from each end of the culvert in an effort to minimize flow on the path inside the culvert.

Photograph 10-18. A skylight between C-470 travel lanes brings natural light into the Willow Creek path underpass. Note also sediment deposition on path, typical of a long culvert with a mild slope. Photo courtesy City of Lone Tree.

3.5.5 Lighting

The *AASHTO Guide for the Development of Bicycle Facilities* recommends average maintained horizontal illumination levels of 5 lux to 22 lux. Even relatively short culverts can require lights. Look for opportunities to increase natural lighting. This is especially important for long culverts (over 100 feet). Divided roadways sometimes allow for natural light to be brought in through a median. Bends reduce visibility and natural light in long culverts and should be avoided to the extent practicable.

3.5.6 Underpass Drainage

Drainage within the culvert is often problematic as well as maintenance-intensive. As shown in Photo 10-18, a long culvert constructed on a mild slope will deposit sediment on the path surface. The long flow path can exacerbate nuisance drainage issues and cause icing. When the design relies on inlets within the culvert, maintenance requirements should be specified to minimize problems due to clogging.

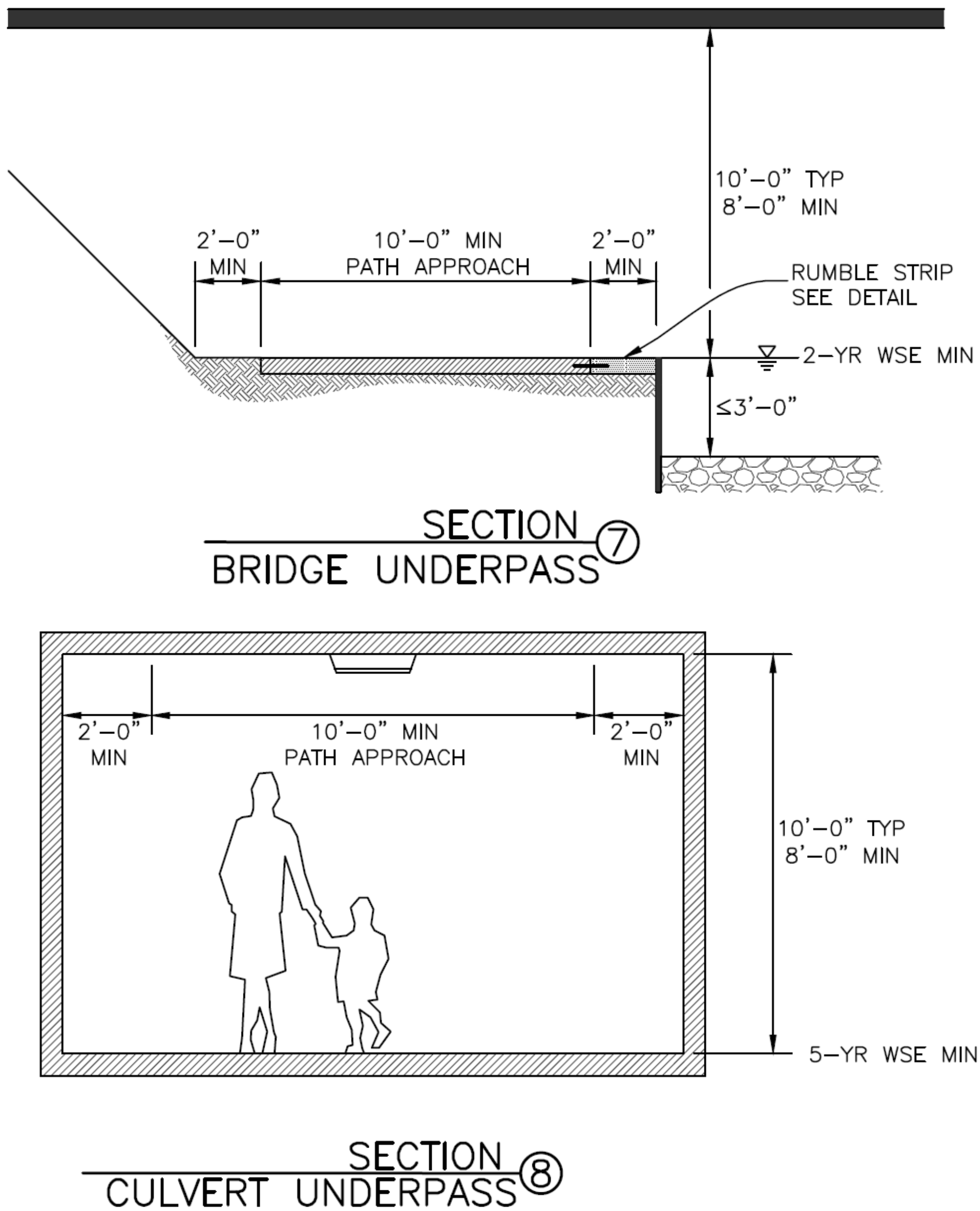


Figure 10-7. Path underpass sections

3.6 Stream Crossings

Photograph 10-19. A cast-in-place concrete culvert crossing with rumble strips. Photo Courtesy Architerra Group.

This section generally pertains to path crossings within the floodplain and includes structures that may be designed to overtop as frequently as during a 2-year event. These structures are sometimes referred to as low-flow crossings, low water crossings, or pedestrian crossings. These criteria are also intended for golf cart bridges, equestrian crossings, boardwalks, and any other similar structures with the exception of a temporary construction crossing. Discussion on larger crossings can be found in Chapter 8, *Hydraulic Structures*.

All stream path crossings need to be evaluated as part of the proposed hydraulic model and must be constructed to withstand forces associated with the 100-year flood event as well as wear and tear from frequent inundation without structural damage. Crossings should not include components that might break from the structure and cause debris blockage downstream. This can cause flooding and/or damage to downstream structures. All crossings should have a maintenance plan to address periodic and post-runoff debris and sediment removal. The designer should consider debris collection and blockage at the crossing and minimize potential for this while providing adequate safety components as described in this manual.

Photograph 10-20. This Cherry Creek crossing was split into three segments to accommodate the long span. Curb rails were used and the path was kept low to minimize impediment to flood flows. Photo Courtesy Muller Engineering.

3.6.1 Crossing Type and Materials

The two most common types of path crossings in the UDFCD region are bridges and cast-in-place concrete culverts. Bridges can be constructed in-place or prefabricated and can be concrete, wood, steel, or a combination of materials. Bridges, designed to span the main channel and sometimes other environmentally sensitive areas within the floodplain, can provide the benefit of reduced disruption when the project does not otherwise include disturbance of the channel. Concrete culverts can often be constructed without rails or with curb rails and provide a structure that has little impact to the water surface elevation of major events in the stream. Three-sided box culverts offer the added environmental benefit of a continuous streambed.

Photograph 10-21. A Bear Creek cast-in-place concrete culvert crossing with rumble strips and a crossing with rails in the distance.

3.6.2 Placement

When the placement of a crossing is flexible, (i.e., not dictated by existing constraints), the designer can add more thoughtfully considered user experience and potential future geomorphic changes to the requisite safety considerations. As discussed in Section 3.2, elevation of the path as it relates to frequency of inundation is an important consideration as the invert of the channel can change over time. Locating a crossing just upstream of a grade stabilization structure (check or drop structure) or incorporating a crossing into a grade stabilization structure, offers a stable channel invert at the crossing. This means the channel invert should not increase, causing more frequent inundation and related maintenance and loss of use issues, and that it also should not decrease, causing a potentially dangerous condition for the user. Depending on the design, locating a crossing downstream of a drop structure may offer the same benefit and also benefit user experience, bringing the user in contact with the sight and sound of the water flowing over the drop.

Photograph 10-22. A pedestrian bridge crossing with rails at Confluence Park.

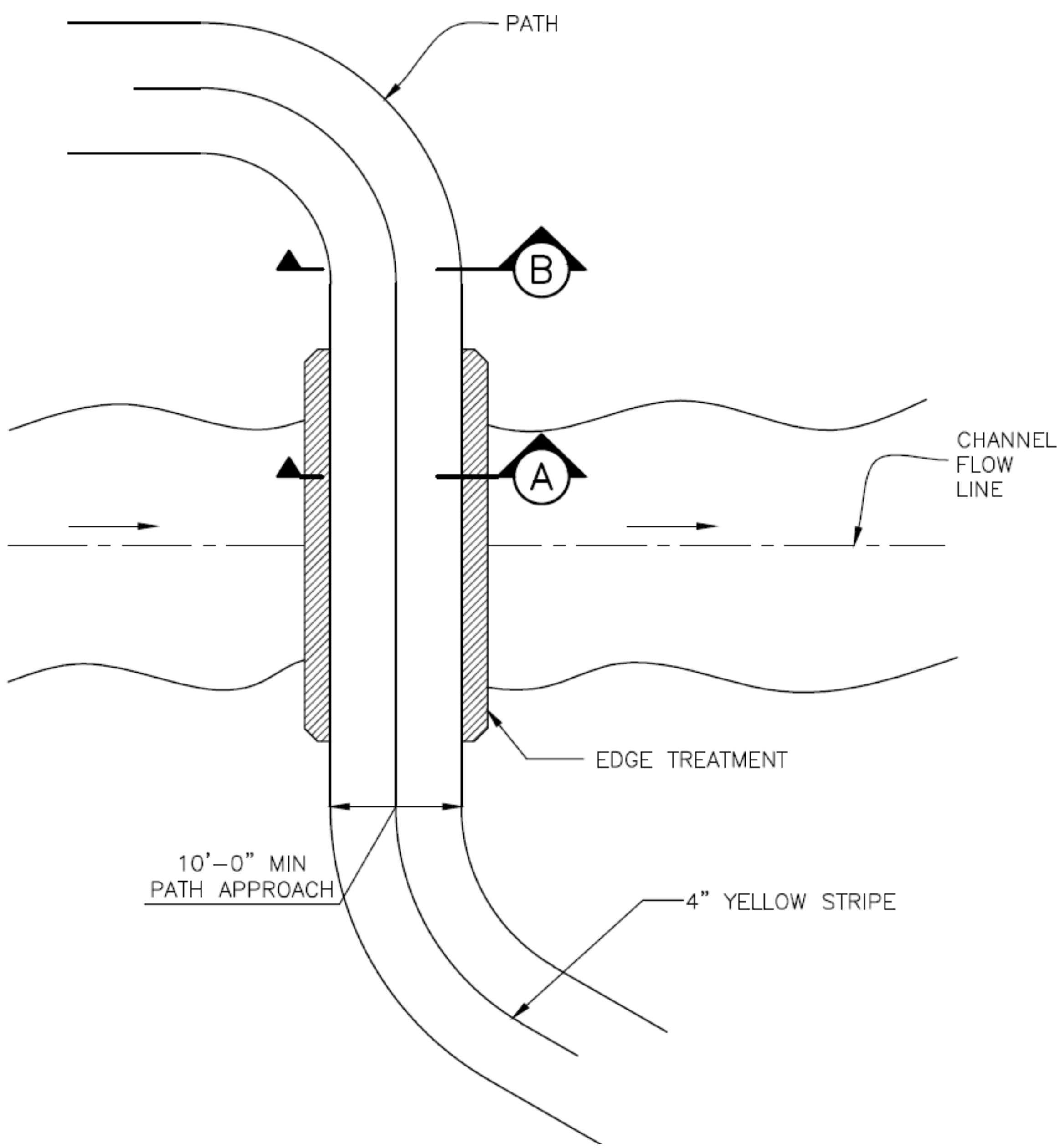
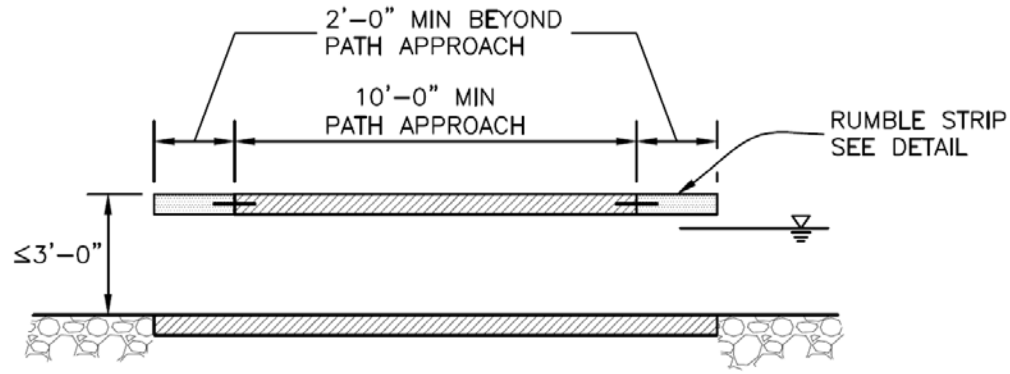
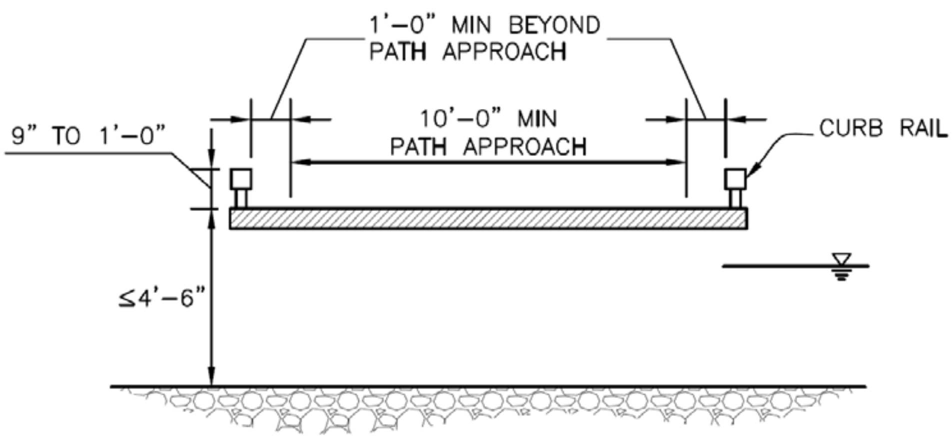


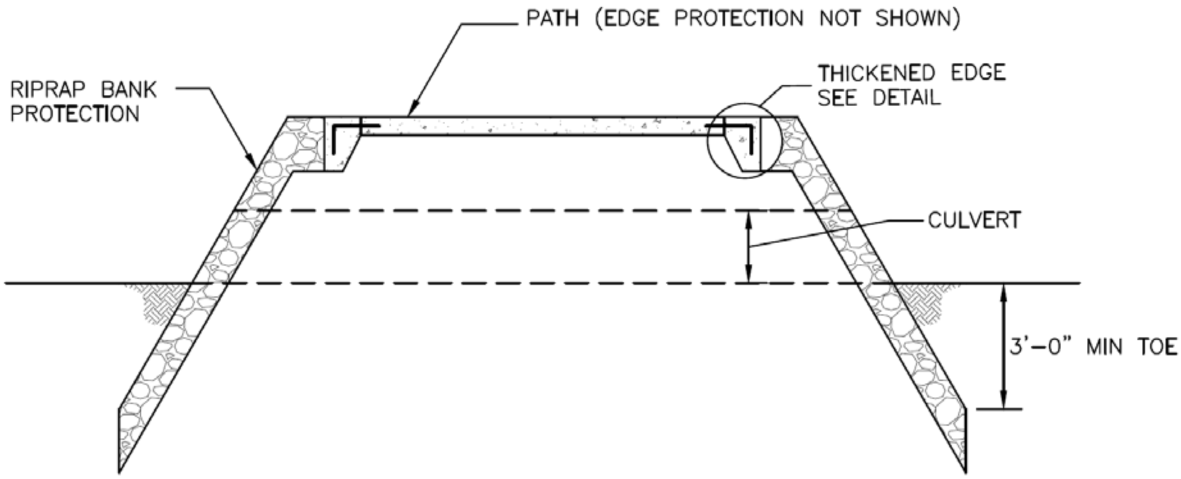
Figure 10-8. Typical low-flow crossing



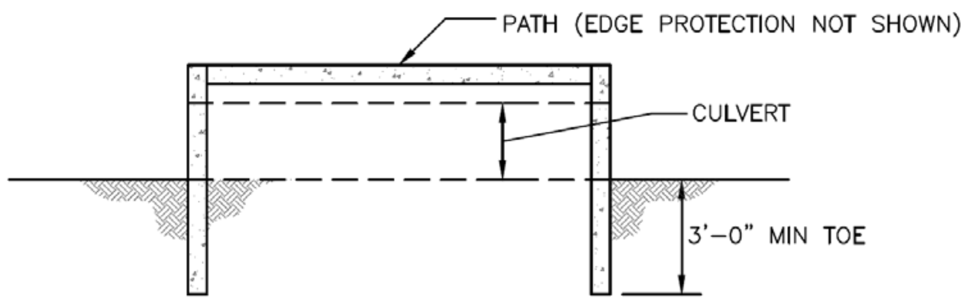
SECTION A1
CROSSING WITH RUMBLE STRIP



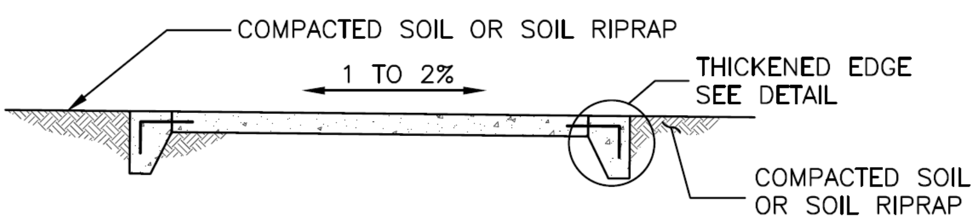
SECTION A2
CROSSING WITH CURB RAIL



SECTION A3
CROSSING WITH CULVERT AND RIPRAP



SECTION A4
CROSSING WITH CULVERT AND HEADWALL



SECTION B
OVERTOPPING PROTECTION

3.6.3 Equestrian Crossings

Horses are not always compatible with other types of path users and a separate tread for equestrian use, where practicable, is a good idea. This is especially true at crossings and underpasses where an animal may experience additional anxiety due to other users. When this is the case, equestrian crossings consist of a stabilized section of the stream marked for equestrian use. Equestrian crossings should consider safety for the horse. The smooth face of a horseshoe can cause a slip on a smooth hard surface such as concrete or metal especially when placed on a slope. Placement of an equestrian crossing is best where typical flows will be two feet or less and the channel is relatively straight. Equestrian crossings can be constructed by filling cellular confinement material with crushed rock. Use of geosynthetic materials (e.g., cellular confinement systems), in general, offers the desired surface for the animal while also providing the stability needed in areas of the path that are frequently wet (including crossings). Methods such as plating the channel with riprap (pushing riprap onto the channel bottom) and constructing a textured concrete (e.g., tooled joints similar to a rumble strip) crossing, such as the one shown in Photo 10-23, have also been used in the Denver Metropolitan area.

Smooth and hard surfaces become more dangerous on a slope. The Federal Highway Administration recommends that paths that have hard surfaces and slopes steeper than five percent need to be treated (e.g., terraced such as the crossing shown in Photo 10-24) to increase traction.

Photograph 10-23. An equestrian crossing parallels a separate multi-use crossing. Photo courtesy Arapahoe Park and Recreation District.

Photograph 10-24. Timber steps filled with roadbase are constructed to provide traction approaching a water crossing. Photo courtesy Arapahoe Park and Recreation District.

3.7 Material Selection

UDFCD has used several surfacing techniques for paths, including stabilized rock, reinforced grass, crusher fines, asphalt, concrete, and other proprietary surfaces. The following sections provide considerations for each.

3.7.1 Stabilized Rock and Reinforced Grass Paths

Stabilized rock and reinforced grass paths are generally used for "maintenance only" paths. To avoid rutting, compact both the subgrade and rock and use a rock that is well graded. Road base works well in this application. As with all path materials, backfilling the edges after construction is recommended to help hold the material in place and reduce chance of injury.

Photograph 10-25. This stabilized rock trail was constructed for maintenance.

Photograph 10-26. Reinforced grass pavement shortly after construction.

3.7.2 Crusher Fines

Crusher fines are not recommended below the 10-year water surface elevation or where the longitudinal slope exceeds 5%. Crusher fines typically wash out when stream flow (or concentrated cross drainage) flow over the path. Provide a weed barrier over the subgrade when using crusher fines.

Photograph 10-27. Geotextile is all that is left of this crusher fines trail that washed out on Goldsmith Gulch.

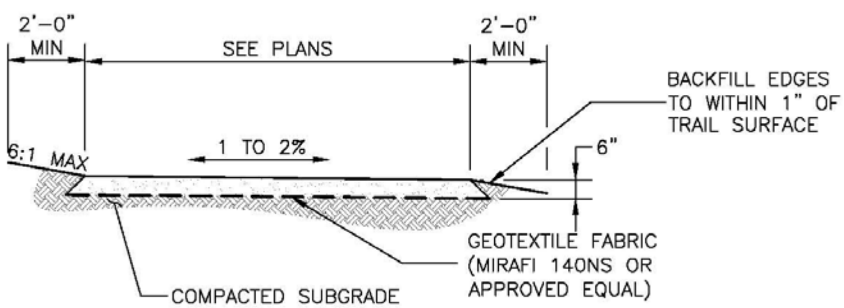


Figure 10-9. Crusher fines path section

3.7.3 Asphalt

UDFCD no longer uses asphalt for path construction due to maintenance issues. Problems with this material near the stream include vegetation, both with tree roots damaging the pavement and with weed growth through the pavement. Cracking, especially near the edges of the pavement was also a significant issue. If used for this purpose an herbicide should be applied on the subgrade prior to placement.

3.7.4 Concrete

Concrete is the most common path material for shared-use paths. A 6-inch depth section of fiber-reinforced concrete on top of compacted subgrade is generally adequate depending on soil conditions and the types of vehicles anticipated. The concrete should be finished to provide a safe surface for the user. Broom finish is typical.

Control joints should be placed 10 to 12 feet on center. Hand-tooled joints are highly discouraged as they often catch debris. Provide expansion joints at all cold joints and locations where the path abuts another structure, (e.g., a low-flow culvert crossing or bridge abutment).

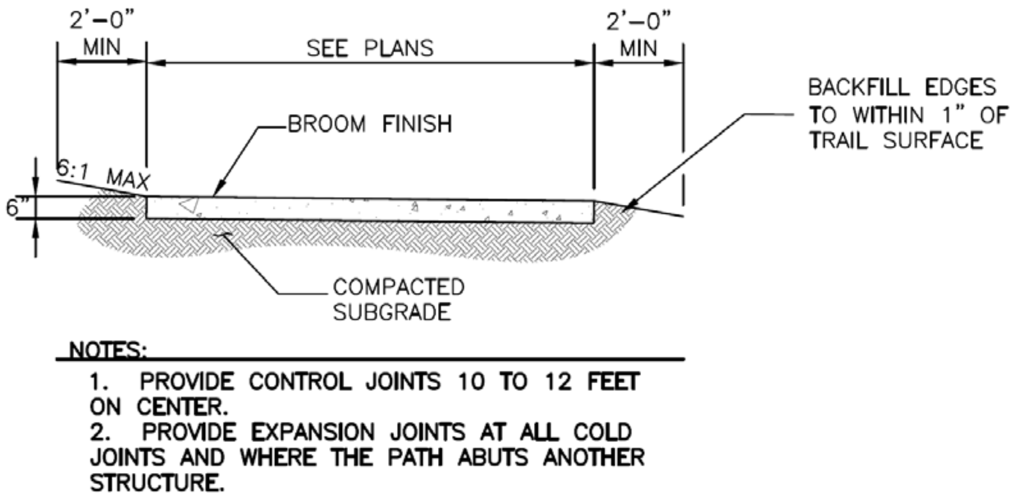


Figure 10-10. Concrete path section

3.7.5 Proprietary Surfaces

Proprietary surfaces expand the range of alternatives available for the surface of the path and sometimes offer qualities not found in conventional surfacing. Use of proprietary surfaces on UDFCD-maintained streams is generally allowable when the surface provides a structurally sound, maintainable surface that allows for frequent inundation without requiring repair.

Photograph 10-28. StaLok® paving material, a proprietary surface consisting of resin bound gravel, has replaced failed portions of the crusher fines Goldsmith Gulch path.

4.0 In-Channel Safety

> Planning, design and construction of channels and related structures such as low-head dams, drop structures, bridges and armoring, mandate a standard of care consistent with common-sense safety concerns for the public that responsibly uses the rivers and waterways.

This chapter focuses on the safety of public users in or near the water in recreational channels. The term "in-channel users" refers to people that are in the water. Swift Water Rescue manuals often refer to this as the "Hot Zone". In-channel users include recreational enthusiasts in river craft such as rafts and kayaks, tubers, anglers, waders, and swimmers. In-channel users also include personnel maintaining or operating various structures and facilities in and sometimes adjacent to channels. Observers or others within a recreational channel that accidentally fall into the water are also considered in-channel users. The area where such incidents can occur is referred to as the "Warm Zone" in Swift Water Training and has been typically identified as within 10 to 15 feet of the edge of the water.

While the identification and nomenclature of zones used in Swift Water Rescue are used in this chapter, note that issues and criteria related to these zones in Swift Water Rescue manuals and training may be different than used in this chapter. Discussions within this chapter refer to planning and design issues in and around water in recreational channels and are not related solely to "rescue" or "swift water" conditions, i.e. rapids.

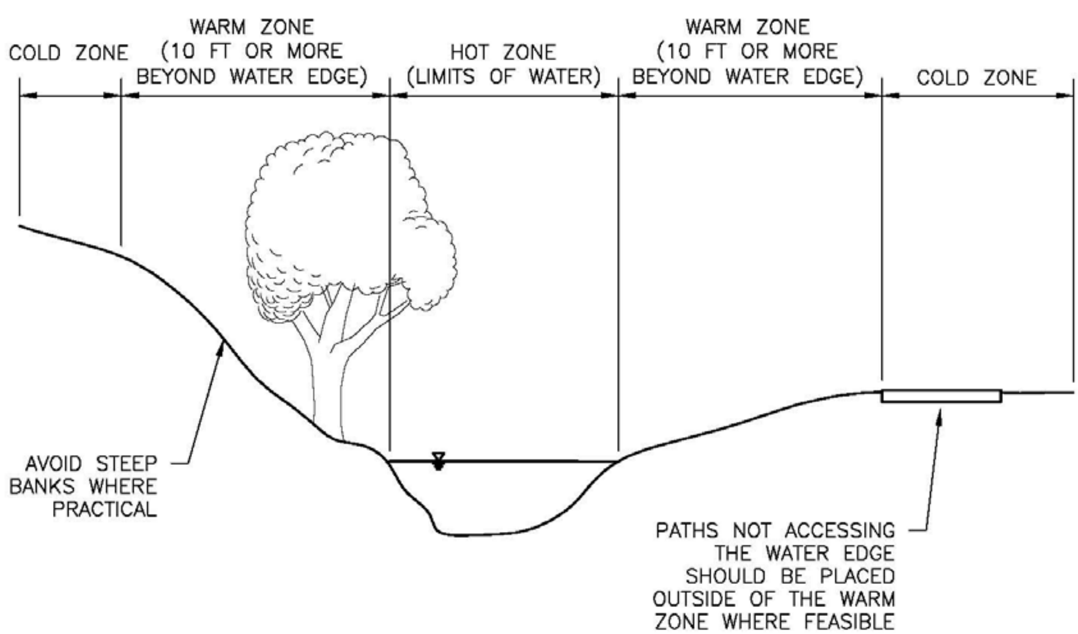


Figure 10-11. Zones of operation

In general, personal safety risks related to in-channel users include drowning, injury, and infection. These risks are primarily attributed to:

- An overly-retentive hydraulic jump (sometimes referred to as "submerged hydraulic," "keeper," or "drowning machine");
- Impacts, blunt trauma, cuts, and abrasion;
- Ingestion of pathogens in water:
- Hypothermia;
- Infection from cuts and abrasions;
- Foot or extremity entrapment;
- Pinning or entrapment against or in an obstruction;

These risks are greatly increased if proper equipment is not correctly used by the in-channel user.

Channels and rapids, with or without man-made structures are inherently hazardous. There are inherent and unavoidable risks related to recreating in and around channels. A primary objective in the planning, design, and construction of structures is that:

Structures should be designed and constructed so that they are predictable and without hidden or unobvious hazards to responsible users. (Charlie Walbridge, Safety Chairman, American Whitewater).

4.1 Recreational and Boatable Channels

4.1.1 Recreational Channels

The design, planning, and construction of recreational channels should take into consideration the potential for unintended entry into the water. Therefore, some planning and design considerations outlined in the Boatable Channels section (Section 4.1.2) may need to be addressed in the planning and design of all urban channels. The degree of this consideration will depend on issues such as the volume of traffic around the water's edge, adherence to the criteria presented in Section 3.0 of this chapter, frequency and flow rate, the presence of railings, and the resulting consequences of accidentally falling into the water. Safety considerations during dry conditions related to public access to the bottom of the channel should also be made.

Photograph 10-29. These rafters are running the largest and most turbulent hydraulic features ever constructed. However this feature has been successfully run by tens of thousands of recreationalist and is hailed by safety expert Charlie Walbridge. Photo courtesy of Thanis McLaughlin

Design and planning considerations for recreational channels should consider bank conditions and conditions within the Warm Zone. Design channel banks to avoid hidden safety issues (e.g., tripping hazards) that could cause unintended entry into the water and provide egress for those who may accidentally fall into the water.

Safety considerations related to the presence of flowing water during flooding in the Cold Zone may also need to be made. Some of these issues are discussed in Section 3.0, Paths Adjacent to Streams.

4.1.2 Boatable Channels

Boatable channels are considered a sub-set of recreational channels. Planning and design considerations within boatable channels include but are not limited to: drop structures; whitewater recreational areas or other recreational whitewater features; bridge piers; all types of bank armoring; woody vegetation; debris and debris accumulation; jetties; bendway weirs; fish passages; intake structures; etc.

The design of these features and structures must avoid the development of overly-retentive hydraulic jumps, sharp edges, foot entrapments, restricted egress, and address other dangers listed in Section 4.3. Within this manual, the term “drop structures” includes grade control structures, low-head dams, boatable passage structures or chutes, recreational features which form holes or waves, and others described herein. Some of these considerations, albeit to a reduced level, may need to be addressed in recreational channels that are not considered boatable.

Photograph 10-30. Recreational users in personal water craft at Confluence Park and most other constructed features are more common than experienced boaters. Photo courtesy of Rick McLaughlin.

Photograph 10-31. Recreational whitewater features in rivers are used by both children and adults. Appropriate use of a river and proper gear can be encouraged through recreational and educational programs. Photo courtesy of Thanis McLaughlin.

4.2 Glossary of Related Terms

The following glossary is intended to improve consistency and accuracy in communications with the river recreating community. The reader should note that the definitions of all terms are not universally recognized within this specialized industry.

Term or Abbreviation	Meaning
Aggradation	Aggradation involves the raising of the channel bed elevation through sedimentation, an increase in width/depth ratio, and often a corresponding decrease in channel capacity.
Bed Load	Coarse sediment transported along the bottom of the river by saltation (hopping), sliding, rolling,etc.
Benthic Macro-invertebrates	Benthic Macroinvertebrates are small animals living among the sediments and stones on the bottom of streams, rivers and lakes. Insects comprise the largest diversity of these organisms and include mayflies, stoneflies, caddisflies, beetles, midges, crane flies, dragonflies, and others. Other members of the benthic macro invertebrate community are snails, clams, aquatic worms, and crayfish. They are extremely important in the food chain of aquatic environments as they are important players in the processing and cycling of nutrients and are major food sources for fish and other aquatic animals
Counter Weir	A counter weir is a secondary drop structure or armored channel section downstream of a drop structure, pool, or hydraulic disturbance. It is usually smaller than the upstream drop structure and maintains the elevation of the tailwater experienced by the upstream drop structure or other hydraulic disturbance. An end sill, as described in the *Hydraulic Structures* chapter, could also be used for this purpose. They are often placed at the downstream limit of the Recovery Pool.
Drop Structure	A constructed feature or structure in a channel that creates a downward step in the water surface and a resulting hydraulic jump downstream of the structure. These can typically have a hydraulic drop of one-half to eight feet. These structures can be used for a number of purposes including diversions, recreation, and stream stability. They can also be called grade control structures, diversions, low-head dams, weirs, or just drops. They are typically constructed of grouted boulders or sculpted concrete with additional concrete or sheet pile cutoff walls. Regarding recreational whitewater, a drop structure is a physical feature that forms a “wave” or "hole", boat chute, whitewater park or whitewater feature.
Eddies	Eddies are usually formed downstream of an obstruction or curvature in a river or channel. Eddies swirl on the horizontal surface of the water. Typically, they are areas where the downward movement of water is partially or fully arrested and currents flow in an upstream direction – if slow enough, a nice place to rest or to make one's way upstream.
Freestyle	Competitive event where boaters perform tricks on a “breaking wave” or “hole”.

Hole(s)	A "hole" is formed when the supercritical jet on the downstream face of an obstruction within the channel is directed toward the invert within the formation of the hydraulic jump. This causes the surface water and the upper portion of the water column to flow back upstream toward the obstruction. A strong breaking wave (see below) is often confused with a hole. It differs from a hole in that the supercritical jet is lifted and directed within the upper portion of the water column within the initial formation of the hydraulic jump. The distinction between a hole and a breaking wave however is not consistently made within the whitewater community. In hydraulic design terms, it is a particular formation of a hydraulic jump (see below). In the design of man-made whitewater or other structures within a river or waterway, it is usually created by a drop structure or structure(s) that create a significant constriction in the channel. Holes in recreational structures are typically designed for entertainment and skill-building, places where paddlers use the features to perform various moves. Poorly designed holes can be dangerous. They can dramatically aerate the water, possibly to the point where they lose the capacity to carry watercraft. In overly-retentive holes or "keepers" (see below) a boater may become stuck in the recirculating water. Some of the most dangerous types of holes are formed by low-head dams (weirs), ledges, and similar types of obstruction. Low-head dams or other structures that form a uniform hydraulic with no irregular or weak point are particularly dangerous. Low-head dams are insidiously dangerous because their danger cannot be easily recognized by people who have not studied whitewater.
Hydraulic	The term "hydraulic" refers to a hydraulic jump and is river recreationalist jargon sometimes used when referring to a "hole" or "wave." It could also be used to describe a hydraulic formation known as a supercritical shock wave.
Hydraulic Drop	Sometimes referred to as just "drop". The vertical distance between the upstream and downstream water surface elevation. This can be applied to a single feature or to multiple features within a river reach or whitewater course.
Hydraulic Jump	A hydraulic transitional formation that occurs between supercritical and subcritical flow. This occurs downstream of a constriction or Drop Structure when the fast flow collides with the slower moving flow in a downstream pool. It is commonly referred to by river recreationalists as a "hole", "wave", or "hydraulic".
Keeper	See Overly-Retentive Hydraulic.
Overly-Retentive Hydraulic	A hydraulic condition –technically a specific form or a hydraulic jump –that can occur downstream of a natural or man-made feature (such as a low-head dam). This condition tends to trap boaters, swimmers, or other floating objects for an extended length of time. This condition can also be called a submerged hydraulic, keeper, reverse roller, drowning machine or a variety of negative descriptors followed by the term "hole" or "hydraulic".
Play Boating	Recreational boating primarily for surfing and performing "tricks" on breaking waves or in holes. These are typically whitewater kayaks and canoes. This type

	of recreational use can also include surfing, standup paddle boarding, and body boarding.
Pillows	Pillows are formed when a large flow of water runs into a large obstruction, causing water to "pile up" or "boil" against the face of the obstruction. Pillows are also known as Pressure Waves.
Portages or Portage Paths	Portages or portage paths are land routes used by in-river users to bypass or avoid dams, drop structures, or other in-channel obstructions. Portages can also serve as "detours" around sections of water that in-river users choose not to run.
Put-in	A put-in is a formalized area that facilitates access of in-river users and their craft to enter the water. They are often located at the downstream end of a portage path or upstream of a reach of river that is commonly used by recreationalists.
Recovery Pool or Zone	A recovery zone or pool is a slow moving reach of the river immediately downstream of a drop structure, series of drop structures, or other challenging hydraulic feature that allows for recovery by recreational users.
Slalom	Competitive event where boaters negotiate gates suspended over the river for the fastest time.
Strainers	Strainers can be deadly obstacles within a boatable channel. Water passes through but solid objects like boats or people do not, similar to a kitchen strainer used to drain spaghetti or clean vegetables. A fallen tree or branch is the most common type.
Structural Failure	Movement of rock or structures that: 1) is unanticipated or 2) results in a condition that negatively impacts safety. Also see Tuning or Adjustments.
Submerged Hydraulic Jump	See Overly-Retentive Hydraulic
Take-out	A take-out is a formalized area where in-river users can exit the river with their craft. They are often located at the upstream end of a portage path or at the downstream end of a reach of river that is commonly used by recreationalists.
Tailwater	Tailwater is the downstream depth of the water in a channel relative to a particular feature or structure. Tailwater has a significant impact on the performance of a drop structure and the resulting hydraulic jump.
Tuning or Adjustments	Due to the complex nature of hydraulics and the use of irregular boulders, some adjustments to rock or structure is usually required after the initial construction and the river is observed to flow through the features. This is usually conducted at the direction of the designer shortly after the initial construction or after the first year or two of operations. Also see Structural Failure.
Wave(s)	Waves found in most man-made structures are formed similarly to holes and are sometimes referred to as a "hydraulic". In hydraulic design terms, it is a formation of a hydraulic jump which is created downstream of supercritical flow. In the design of man-made whitewater or other structures within a river or channel, it is usually created by a drop structure or a structure which creates a

significant constriction in the channel. Waves are noted by a smooth upward sloping face as the flow enters the hydraulic jump. This “green water” at the upstream portion of the formation is followed by a crest and downward sloping face. A wave can have a significant amount of whitewater or “haystack” and appear similar to a hole. These are called breaking waves. Sometimes a particularly large wave will also be followed by a long series of waves or “wave train”. Waves in channels can also be created without the formation of a hydraulic jump.

4.3 Minimum Criteria

Within the UDFCD region, infrastructure typically meets or exceeds the criteria outlined in this section. There are, however, numerous examples elsewhere in the country where these criteria are ignored, posing danger to users. Here are some of the minimum design criteria for boatable and, in some instances recreational channels:

1. All drop structures, including recreational "wave" or "hole" features as described later in this chapter, are specialized drop structures and should be designed in accordance with appropriate recommendations, considerations, guidance and procedures established in the *Hydraulic Structures* chapter of this manual.

2. Drop structures or other recreational features in rivers or channels have been designed and constructed since the 1970s. They are “works of engineering” as they safeguard life, health, and property and promote the public welfare. They necessitate design work requiring intensive preparation and experience in the use of mathematics and the engineering sciences. Therefore, their construction must adhere to design drawings sealed by a registered professional engineer.

3. Drop structures made of “natural materials” such as boulders or riprap are still structures and are works of engineering. They must be designed in accordance with appropriate criteria within this manual.

4. Structures should withstand stream forces for all flows up to and including the 100-year flood. This is critical because structures that experience movement or failure can create hazardous or changing hydraulic conditions well after a flooding event. Typically, structural movement would occur during high flow events that preclude maintenance or repair of the structure and coincides with in-river recreation such as rafting and kayaking. Therefore, structures within boatable channels should be designed and constructed to survive flooding without change in hydraulic performance. It is sometimes advantageous, however, to plan and design adjacent landscaping and other features on the banks or uplands (that do not impact safety or that can be replaced or repaired during normal flows) for lesser flooding events.

5. When analyzing impacts on flood conveyance, caution should be taken to avoid accounting for flood conveyance areas within the channel cross-section that will not be effective during flooding events. These could include deep pools, eddies, or areas of the channel that will fill with sediment or cobble. If the design relies upon the depth of pools or effectiveness of various portions (particularly areas with slow moving water) of the channel cross-section for conveyance of flood flows, then multi-dimension hydraulic analysis or physical modeling may be needed. Design of new drop structures or modifications of existing drop structures for in-channel recreation should not negatively impact the regulatory floodplain, cause increased bank erosion, or create localized channel instability from deposition or scour.

4.4 Design Considerations for Structures and Features

The following considerations should be reviewed for boatable and, in some instances, recreational channels.

1. **Egress.** Provide multiple opportunities for egress from the channel – particularly in critical locations such as before and after rapids or drop structures.

2. **Create Opportunities for Self Rescue**. Avoid hydraulic and physical condtions that make it difficult for in-channel users to access the banks. For structures that significantly impair self rescue, consider sloped racks or sides and ladders or stairs.

3. **Sharp Edges.** Avoid sharp edges and protruding objects.

4. **Strainers.** Avoid the creation of “strainers” and the potential for debris to collect and act as such. Accumulation of debris may occur at bridge piers, intakes, railing, or other infrastructure and on woody vegetation, features used for fish habitat, or bank stabilization.

5. **Intakes and Screens.** Prevent accidental entry into gates or inlet works with bar racks or screens at intakes (headgates) and design for approach velocities so as not to create pinning hazards.

6. **Utilities and Apparatus.** Provide physical separation or barriers if practical and (at a minimum) warning buoys and signs when hydraulic grates or screens, sluice gates, etc. are accessible and present a hazard to in-channel users.

7. **Fish and habitat considerations.** When it is appropriate to provide fish passage within the reach, integral features that support both recreational use and fish passage or habitat are desirable.

8. **Safety Signage.** Include warning signs upstream of hazards (intakes, etc.) and at the start of a drop structure or a series of drop structures. Signs to advise positive actions, such as encouraging the use of proper equipment, are also prudent.

4.4.1 Pinning and Overhead Obstructions

To reduce the chance of an in-channel user being pinned or trapped on a grate, screen, rack, or other feature that could become a strainer, reducing velocities going through the screen or object (approach velocity) and increasing the velocities of the flow passing by the screen or object (sweeping velocity) can be effective methods of reducing these potentially dangerous conditions. Well documented limits on approach velocities for safety are not available. For relevance, maximum design values for approach velocities for fish can vary from 0.2 to 0.8 ft/sec while maximum design values for approach velocities to reduce accumulation of trash of 0.5 feet per second have been used by the USBR. Consider a maximum design value for approach velocities into a screen or grate, of 0.5 or 1.0 ft/sec to reduce pinning of in-channel users. Approach velocities used for a particular application can depend upon sweeping velocities, the frequency of recreational users, the velocity and direction of the upstream currents, and other factors. Means to evenly distribute the flow across the screen should be considered. Note that recommended approach velocities to grates, screens, or bar racks in boatable channels are typically less than recommended maximum design velocities through racks and grates used in the design of typical drainage infrastructure.

Overhead clearance at bridges, low water crossings, utility crossing, or other structures that span boatable channels or portions of boatable channels should be sufficient to reduce hazards to in-channel users. There are no widely accepted minimum design clearances for these types of boatable channels. Consider a minimum clearance (freeboard) in the range of six feet from the water surface of the recreational flow range to the underside of an overhead structure. Lesser amounts of freeboard may be appropriate during flood conditions.

4.5 Drop Structures

The following drop structure criteria are provided in addition to the criteria provided in the *Hydraulic Structures* chapter of this manual.

For the purposes of this chapter, the term “drop structure” refers to a constructed feature (or structure) in a channel that creates a downward step in the water surface and a resulting hydraulic jump downstream of the structure. These can typically have a hydraulic drop of as little as six inches or up to eight feet or more. These structures can be used for a number of purposes including diversions; various types of recreation including kayaking, paddle boarding, and swimming; river stability; and enhancement of habitat. Terminology for typical or specialized drop structures includes: grade control structures, control structures, holes, whitewater parks, boat chutes, diversions, low-head dams, weirs, riffles, glides, and sills. Regarding recreational whitewater, a feature or structure that creates a “wave” or "hole" is also considered a specialized drop structure.

Structures should be designed with carefully planned components that are consistent with recreational requirements for user safety. Drop structures in boatable channels should incorporate a boat chute, bypass, or full river passage to allow passage for boats. Intakes have been designed and operated successfully to create whitewater features and allow fish passage while keeping recreationalists out of the intake works. Engineers have used a wide variety of approaches depending upon site-specific requirements.

Photograph 10-32. The intake at Confluence Park, Denver is located on the side of the river opposite to where the whitewater bypass is located. In addition to this physical separation, buoys, two debris booms and a bar screen were included to help keep recreationalists away from the intake works. Photo courtesy of McLaughlin Whitewater Design Group.

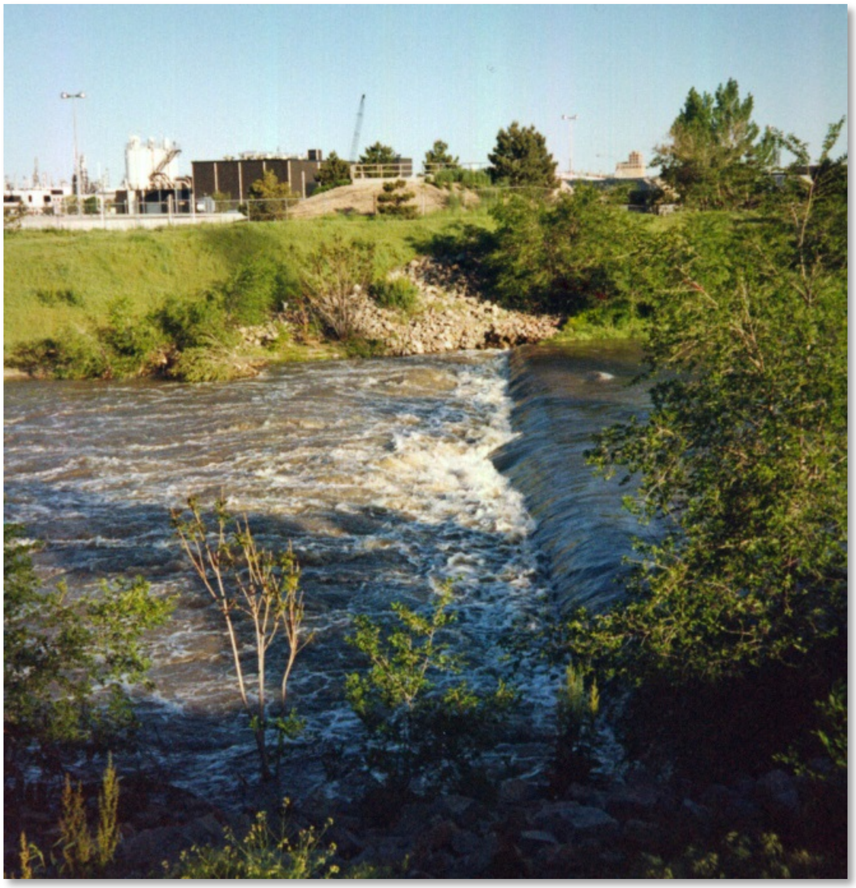
Photograph 10-33. The intake works on the American River near Auburn, California relies on a submerged self-cleaning fine screen. The screen is located in the invert of a boatable channel. This design eliminates intake apparatus that can be hazardous to recreationists, screens for fish and solids, and has proven to require relatively little maintenance. Photo courtesy of Placer County Water Agency.

Warning signs and portage routes around such structures are appropriate in various situations. This chapter outlines some specific approaches and guidelines that have been used in past design efforts to reduce hazards of boatable drops. Boatable drop should be designed by professional engineers with experience with previously constructed projects that incorporate boatable elements, hydraulic modeling, scour analysis and floodplain regulations.

These are not the only approaches available to the engineer and do not address all issues. Design of drop structures intended to provide specific recreational attributes required for freestyle kayaking, slalom kayaking and canoeing may not follow all of the suggestions outlined in the Simplified Design Approach of the *Hydraulic Structures* chapter.

4.5.1 Overly-Retentive Hydraulic Jump

In whitewater river recreation, the characteristic for a hydraulic jump , referred to as a “hole” or “wave”, to keep a boat within a hydraulic jump is referred to as retentiveness. Retentiveness can be a desirable quality of a recreational wave or hole, but if the hydraulic jump is too retentive, it can hold swimmers or submerged craft. In this chapter, this dangerous hydraulic phenomenon is referred to as overly-retentive, and the formation of overly-retentive hydraulics should be avoided. This hydraulic condition has a number of names including “submerged hydraulic jump,” “keeper,” “reverse roller,” and “drowning machine.”



Photograph 10-34. Currents downstream of dams or even drop structures can create an overly-retentive hydraulic jump that can trap in-channel users. Sometimes called “keepers” or “drowning machines,” these hydraulic conditions can be deceivingly dangerous. The misleadingly dangerous structure shown here created this condition with only 1.5 feet of hydraulic drop before UDFCD retrofitted it to be safely boatable.

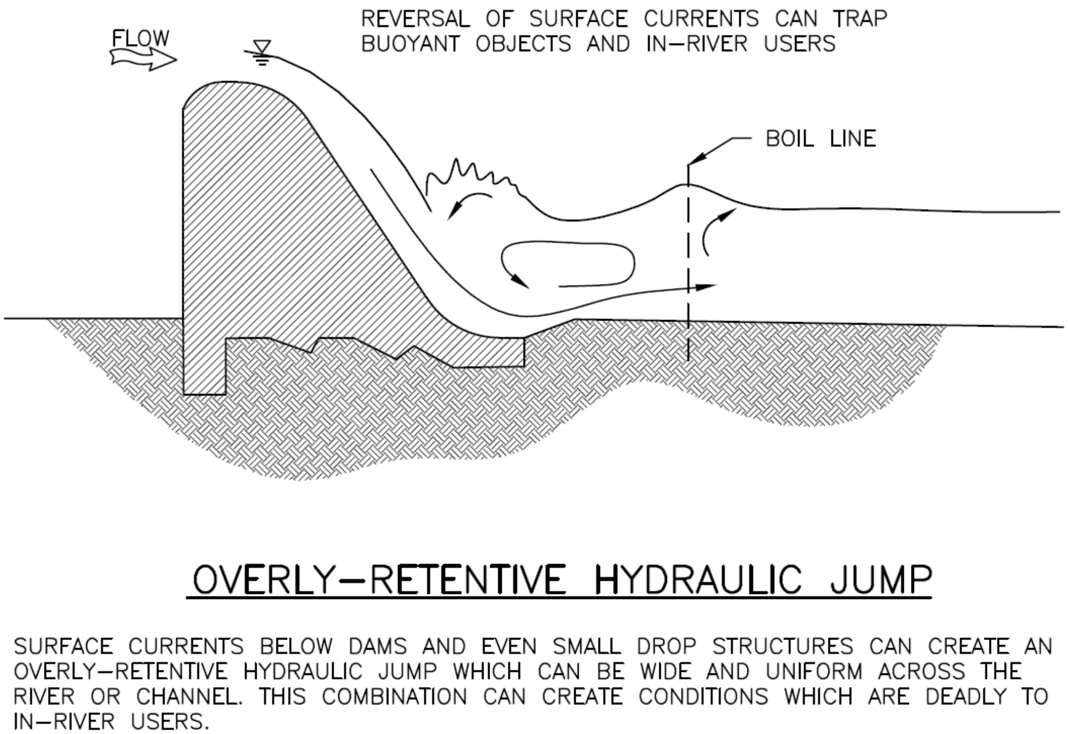
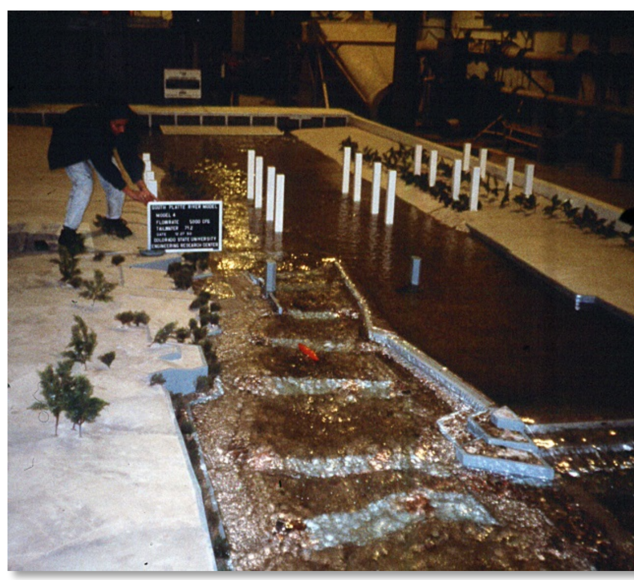


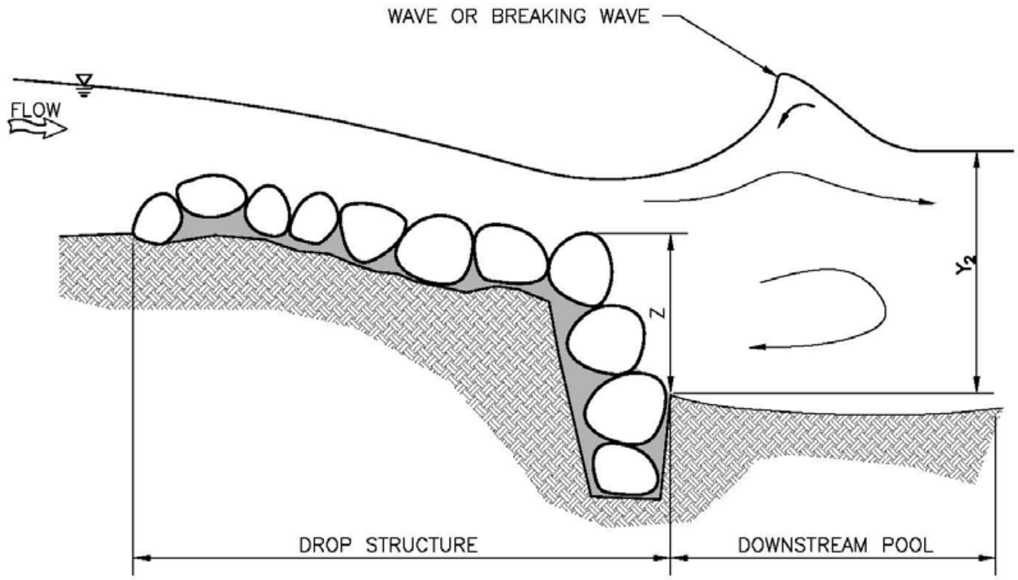
Figure 10-12. Overly-retentive currents at a hydraulic jump

One design approach to avoid an overly-retentive hydraulic jump is to direct the super-critical flow at a relatively flat angle. A downstream face on a drop structure having large grouted boulders and high roughness that is sloped at 10(H):1(V) has been used successfully on several projects in the UDFCD region. This slope should extend such that the jump occurs on the face of the drop structure.

Other approaches have also been used to avoid the formation of overly-retentive hydraulics. The stepped dam at Confluence Park in Denver has demonstrated that a stepped configuration can also be an effective approach to avoiding an overly-retentive hydraulic jump. The formation of a hydraulic jump at an abrupt drop has also been used to effectively avoid the formation of overly-retentive hydraulic jumps over a wide range of river flows. (Samad, et.al, 1986)

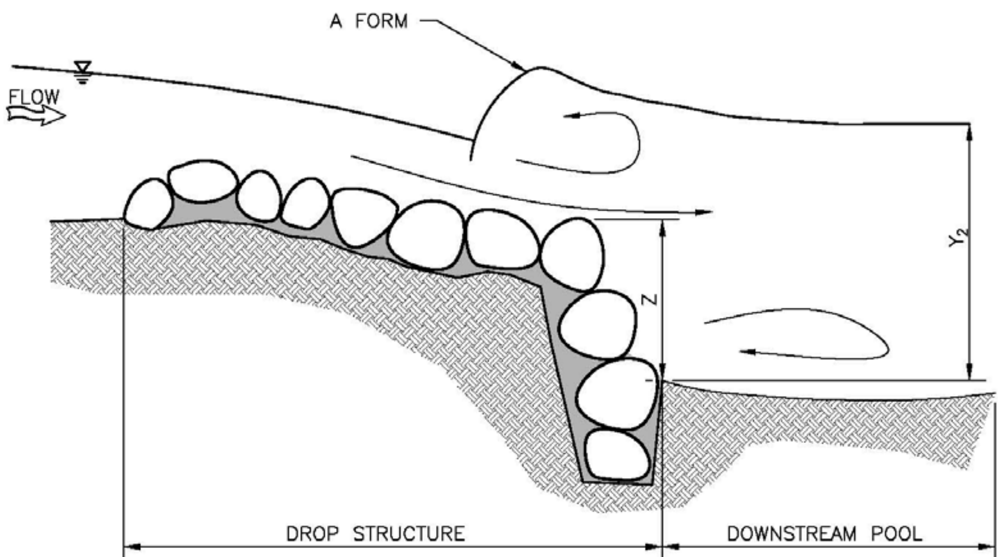


Photograph 10-35. A physical model aided in the 1996 design of Confluence Park. This was one of the first whitewater venues to employ the hydraulic jump at an abrupt drop design. As a result, the venue performed well over a very wide range of flows for a diverse user group. Photo courtesy of McLaughlin Whitewater Design Group.



'WAVE FORM'

NOTE: THE WAVE FORM CAN CREATE FUN FEATURES THAT ARE NON–RETENTIVE AND LOW HAZARD



'A' JUMP

THE A JUMP IS CREATED IF THE TAILWATER IS HIGH AND IS USUALLY UNAVOIADABLE THROUGHOUT THE ENTIRE RANGE OF RIVER FLOWS. THIS CONDITION CAN BE SOMEWHAT RETENTIVE AND POWERFUL, BUT NOT NECESSARILY HAZARDOUS.

Figure 10-13. Forms of a hydraulic jump at an abrupt drop

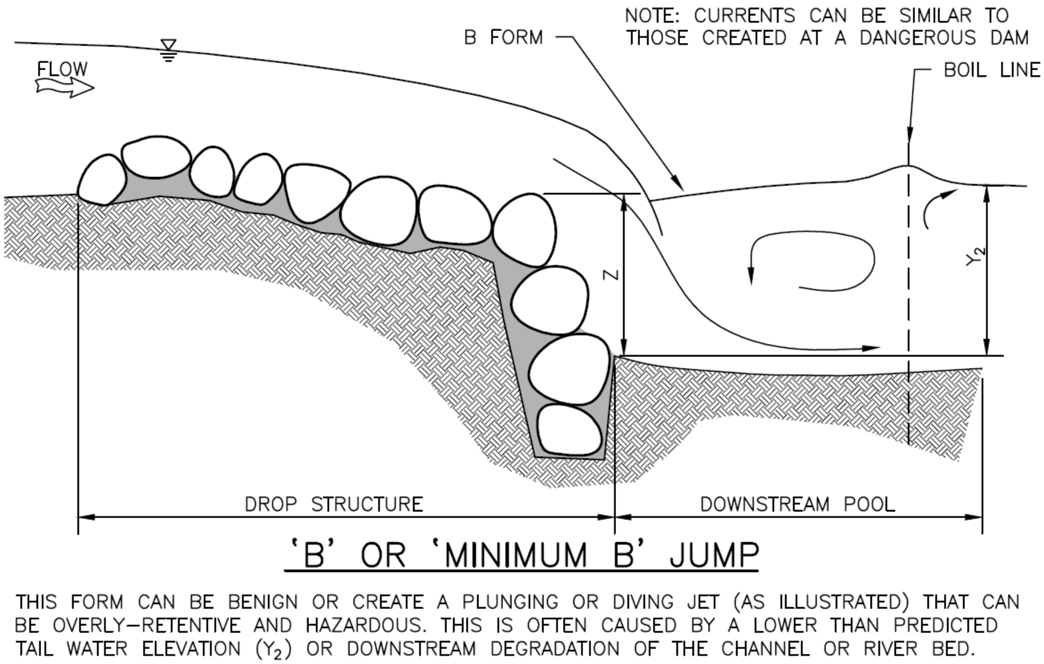


Figure 10-13. Forms of a hydraulic jump at an abrupt drop (continued)

Hydraulic Jump at an Abrupt Drop

Structures that employ a hydraulic jump at an abrupt drop have been effective in eliminating overly-retentive hydraulics. However, like many dams and drop structures, the elevation of the tailwater (Y_2) is critical to the resulting hydraulic formation. Figure 10-13 shows hydraulic jump forms and nomenclature as outlined by Moore and Morgan (1959). The reader is referred to this paper and papers by Hsu (1950), Rajaratnam (1977), Ohitsu, (1990), and Samad (1986).

Even in recreational channels that are not boatable (e.g., often have little or no flow), drop structures should be designed so as to avoid the creation of dangerous hydraulic conditions. Smaller drop structures with a 4(H):1(V) downstream sloped face have been used successfully throughout the UDFCD region.

4.5.2 Design Approach

The following considerations are oriented toward providing simple recreational passage around or through a drop structure located within a boatable channel. Considerations and issues provided in this chapter and drop structure criteria presented in the *Hydraulic Structures* chapter are still applicable. Design of specialized recreational features, boatable features with integral fish passage, reaches where deposition of sediments or cobbles are an issue, or other applications requires the expertise of an experienced professional which is beyond the scope of this chapter.

1. Select the maximum hydraulic drop (different than drop height) — generally one to four feet. If the hydraulic drop is more than 4 feet, a physical hydraulic model may be necessary. Physical hydraulic models may also be useful to optimize recreational hydraulics or when a complex structure is needed in a highly used recreational area. Allow for longer recovery zones downstream of drops with larger hydraulic drops. (See item 3.g below.).

2. Determine the type of structure and passage to be used. Be aware that boatable structures can increase the cost of the project. Structure selection should always be based on safety first, but may also be based upon costs, aesthetics, floodplain issues, sediment transport, and river morphology. These types include:

    a. **Full River Passage**. A structure or series of structures that span the entire channel width and are boatable throughout a range of flows, typical of most drop structures in Colorado that have been created primarily for recreational uses.

    b. **Bypass**. A boatable path that flows to one side of a drop structure or low-head dam and is typically constructed when a larger or existing drop structure is encountered. Design of a bypass can be more complex and costly and may likely fall outside of what would be considered to be appropriate for "simplified" design as described in the *Hydraulic Structures* chapter.

    c. **Boat Chute**. A localized passage through a drop structure such as at Alameda Avenue in Denver and at numerous locations along the South Platte River through the UDFCD region. These are often added to existing drop structures with the remainder of the drop structure not normally suitable for recreational passage.

When boat chutes or bypasses are employed, the drop structure or low-head dam is usually designed or modified with steps or other measures to reduce hazards associated with incidental passage. The stepped dam at Confluence Park is a successful example of this type of hazard reduction.

3. Determine basic drop structure characteristics to be compatible with public safety and recreational boating. Suggestions are as follows:

    a. Employ detailed multi-dimensional modeling or specialized design to avoid creation of an overly-retentive hydraulic condition:

        i. Design for a Froude number of less than 1.5 at the toe of the drop.

        ii. Use a downstream face slope no steeper than 10(H):1(V). This is particularly relevant during higher flow conditions.

    b. Extend the face of the drop 1 to 2 feet below the predicted range of tailwater elevations.

    c. Where tailwater elevations may decrease over time, consider use of a downstream grade control feature, sometimes referred to as a counter weir.

Photograph 10-36. The stepped dam at Confluence Park was physically modeled at multiple flows up to the 100-year event. It was shown to not produce overly-retentive hydraulics throughout this wide range of flows. Photo courtesy of McLaughlin Whitewater Design Group.

    d. Where the passage location will not be clear to the user based on site, inclusion of features to identify locations of passage — often pilot rocks, signs, or buoys may be appropriate. Pilot rocks should be spaced far enough apart and in a fashion to avoid collection of debris and to not create a blockage or hazard.

    e. Provide for energy dissipation downstream of the structure while maintaining structural stability of the drop structure, adjacent banks and adjacent structures such as bridges. Note that local scour depths downstream of various structures have been observed to be over ten feet.

    f. Provide a smooth invert — particularly toward the center of a drop to reduce abrasions and the potential for foot entrapment. Smooth inverts can be created by using rounded boulders, sculpted concrete, concrete, or high levels of grout.

    g. Provide a recovery pool of sufficient length downstream of each drop or a series of drops to allow for recovery of boaters that have capsized or otherwise lost control. The recovery pool should include eddies which can be formed by the drop, intermediate jetties, or other features.

    h. Provide portage facilities including signs, paths, jetties, pier noses

    i. and armoring to support ingress and egress over a wide range of flows.

j. Consider the addition of anchor points to attach ropes strategically located near drop structures. These can be used by emergency personnel so they have something to connect onto during rescues or for removal of debris.

4. Obtain peer review of the preliminary and final designs.

5. Be onsite during placement of rock and features to reduce the occurrence of sharp edges and poor local hydraulic conditions. Be attentive to specific or nuanced placement detailed in drawings.

6. Plan for post-construction adjustment (tuning), adding or removing of boulders or portions of the structure after initial construction. Typically this would be conducted after a range of flows has been observed.

4.5.3 Retrofitting Existing Structures

When an existing dam or drop structure lacks features outlined in this chapter, retrofitting with portages, boatable passages, or other physical modifications may be needed. Retrofitting these structures may include installing a stepped or sloped surface along the downstream face of the dam or drop structure and providing appropriate barriers, signing and accessible portages with take-out and put-in landings. It may also include the addition of a boat chute or bypass to allow for passage of appropriate river craft. A structure that has too much drop may be replaced with two or more structures to reduce the drop at a single location. For example, replacing a 4-foot drop with two 2-foot drops could reduce a hazardous hydraulic condition.

Photograph 10-37. Pilot rocks can help recreationalists find a boat chute or preferred path through a drop structure. This is particularly helpful in wide rivers with a prominent horizon line. Photo courtesy of McLaughlin Whitewater Design Group.

Retrofitting dams or drop structures requires specific care to ensure that the retrofit meets the objective of improving public safety. Due to specific site and structure conditions, physical hydraulic models are sometimes appropriate in the design phase for retrofitting of dams and drop structures.

4.5.4 Integral Roughened Channel Fish Passage

Fish passage through drop structures can be critical in certain reaches of rivers and engineers should be alert to where they are needed. Fish passage usually refers to the ability of fish to swim upstream through the drop structure, but it can also include downstream passage of fish. The need and specific requirements can be established by the Colorado Parks and Wildlife, the US Fish and Wildlife Service, and other local governmental agencies. While identification of any regulatory requirements or project objectives should be established early, they can also arise through the USACE 404 permitting process. Where both fish passage and passage of in-channel users is desired, inclusion of integral fish passage features into boatable drop structures is preferred. Integration of these objectives into one passage usually results in a “roughened channel” type of fish passage, also referred to as rock ramps, natural fishways, riffle-pool fishways, and many others. Roughened channel fish passages can be readily included into boatable drop structures. In addition to fish passage at drop structures, recreational features and other infrastructure can be designed to improve aquatic habitat.

Integrated features and objectives to improve habitat and provide for fish passage can include:

- Deep pools and thalwegs that are self-scouring,
- Resting areas,
- Creation of currents that encourage passage,
- Avoidance of depositions of fine or organic sediments,
- Avoidance of shallow zones to avoid bird predation,
- Creation of conditions conducive to benthic macroinvertebrates such as small sheltered spaces,
- Avoidance of fish stranding areas where rapid decreases in flows commonly occur, and
- Attraction flows that lead to the zones intended for upstream fish passage.

Care should be taken when incorporating the objectives above so that safety in not inadvertently impacted.

Criteria and objectives when fish passage is integrated into drop structures include:

- Selection of fish passage type and design to meet swimming capabilities and behaviors of target species,
- Maximum darting and sustained velocities,
- Maximum vertical drop heights, and
- Minimum depths.

Specific criteria depend upon the target species identified for passage and other factors. There are numerous agencies, publications, texts, and technical papers that can be used to establish criteria and provide design guidelines. Some of these include the US Bureau of Reclamation, the National Oceanic Atmosphere Administration (NOAA) in addition to the regulatory agencies listed earlier in this section. References for more detailed design/discussions include *Fisheries Handbook* (Bell 1991). In cases where fish passage or habitat is an important element or a permit requirement, it is best to include specialists in fish passage on the design team. However it should be recognized that the steepness, width, and depth criteria for whitewater boating can be compatible with those for fish passage.

Slopes of roughened channels or drop structures to meet fish passage objectives and criteria depend upon the target species, other related factors, and the size and configuration of the boulders that comprise the channel or slope of the drop structure. A typical range of slopes that have been used are 0.5 to 8 percent (Wildman, Parasiewicz, Katopodis, Dumont).

4.5.5 Supplemental Guidance for Drop Structures

Photograph 10-38. Multi-use design of the whitewater bypass at Confluence Park conveys flood flows, offers continual access, and avoids overly-retentive hydraulic jumps over a wide range of flows. Photo courtesy of Thanis McLaughlin.

In addition to the appropriate recommendations, considerations, guidance, and procedures established in the *Hydraulic Structures* chapter, and those outlined in this chapter, the following should be considered in the design and construction of boatable drop structures.

1. Determine and evaluate hydraulic conditions throughout the range of flows and tailwater elevations.
2. Allow for future downstream channel degradation and inaccuracies in estimation of tailwater elevations throughout the range of flows or consider the need for a downstream grade control structure (counter weir or small drop structure).
3. Include recovery zones or pools downstream of the drop structure where appropriate.
4. Avoid large recirculating eddies and enhance favorable swimming conditions to the banks to promote self-rescue.
5. Provide downstream bank protection as higher velocities can be carried farther downstream (compared to a conventional drop structure).
6. Include smooth inverts in the areas where velocities are high, depths are shallow, and there is a concentration of boating traffic.
7. Incorporate features to address sediment and bed material transport and other dynamic river processes.
8. Observe performance over a range of flows after initial construction. Adjustments after initial construction (or *tuning*) are advantageous and often needed. This can include adding or removing boulders and grouting. This does not include rebuilding portions of the structure that have failed or replacing important boulders that have moved during high flows.

4.6 Bridge Piers or other Steep-Sided Structures

Clear span bridges are preferable but may be cost prohibitive. Where practicable, keep piers out of the floodway and main channel corridor. Often two piers, one at each bank, are preferable to one pier in the center of the channel. However, piers with debris accumulation located near the toe of a steep-sided bank can be a hazard and may trap rafters between the bank and pier.

Efforts should be made to reduce the chance of pinning, broaching, or wrapping on bridge piers or other vertical or near vertical midstream obstructions, especially where approach velocities are high. Piers can be made less hazardous by extending them or their noses upstream of the bridge deck into less constricted portions of the channel where velocities may be lower. Design of piers or features that reduce the accumulation of debris without creating other hazards should be investigated.

Photograph 10-39. The "pier nose extensions" on this bridge reduce the accumulation of debris and thereby improve safety for in-river users. Photo courtesy of McLaughlin Whitewater Design Group.

4.7 Access and Portages

Egress from the water in a boatable channel should be evaluated by the design professional and impediments in critical areas avoided where practical.

Provide pathways (portages) around all drop structures, even if designed for boat passage, and around potentially dangerous obstructions or hydraulic conditions. Consider the use and maintenance of a buoy system upstream of these areas. Portages around boatable drop structures provide alternative route for those who do not wish to run whitewater due to hazardous flow conditions, presence of debris, or other reasons.

Photograph 10-40. Buoys upstream of Confluence Park Dam guide recreationalists away from the downstream dam and intake. Photo courtesy of McLaughlin Whitewater Design Group.

Portages should include an appropriately located "take-out" with slow velocities throughout a range of flows, such as an eddy. A jetty can be used to create an eddy or provide slow currents for access and portages as well as provide bank stabilization benefits. Locate take-outs and associated signage sufficiently upstream of a structure or obstruction. Design take-outs to resist local scour. Locate the downstream "put-in" far enough from the structure to avoid potential hazards associated with a range of flow conditions. For non-boatable structures such as dams, state or federal regulations may govern the boating exclusion zone upstream and downstream. These exclusion zones set the minimum distance from the dam or non-boatable structure to the beginning and endpoints of the portage path.

Photograph 10-41. This sculpted concrete jetty forms a small eddy downstream to enhance access to the river. The sculpted concrete surfacing also provides for direct access into the water's edge. Photo courtesy of McLaughlin Whitewater Design Group.

Improved access benefits all users. Accessibility standards for the pathways and facilities adjacent to the water are triggered by project funding from or use of lands of Federal, State or local governments. It should be noted that there are no accessibility standards for hand carried boat launches at the point at which the water is accessed; however, there are accessibility standards applicable to the pathways and facilities leading up to the water's edge.

Photograph 10-42. This access ramp was designed with universal access in mind. Photo courtesy John Anderson.

Guidance for universal design that works well for most people, including individuals with physical disabilities, should be reviewed. See the user accessibility guidance provided in the River Management Society and National Park Service publication titled *Prepare to Launch!* Most recent larger recreational venues with whitewater features incorporate improvements that provide better access for all. Access improvements and equipment to facilitate rescue personnel should be located in close proximity to drop structures and recovery zones where practical.

Recommendations for accessible portage paths and ingress and egress points include:

- Avoid longitudinal grades that exceed 1:12 for short rises and 1:20 for longer rises where practical. This is typically most challenging at points of entry and exit to and from the water.
- Provide durable, permanent, nonslip paving material capable of withstanding locally high water velocities without damage or undercutting.
- Provide a cross slope of no more than 2%.
- Avoid use of guard railings where practical as they tend to be damaged by flood waters and accumulate debris. Accordingly, avoid abrupt drop offs or excessively steep grades adjacent to paths. Where local conditions require guards within the floodway, consider solid, durable walls instead of open-work railings.
- Site the portage path above the one-year flood level where practical.

Access for the disabled is governed by the Architectural Barriers Act of 1968 (ABA, triggered by Federal funding of programs and facilities) the Americans with Disabilities Act of 1990 (ADA, applicable to facilities for public accommodation) and Section 504 of the Rehabilitation Act of 1973 (programs or activities that receive Federal funds). The applicability of these standards and guidelines for access to the disabled to a project should be researched by the design professional. The guidelines and recommendations above are not substitutes for this research. See the inset on the following page for resources pertaining to accessibility.

Accessibility Resources and Guidelines

ABA Accessibility Standards (www.access-board.gov)

ADA Accessibility Standards for Accessible Design (www.ada.gov)

American Canoe Association (ACA)

American Trails, Resources and Library

2010 ADA Standards Excerpts for Recreational Boating Facilities, California Department of Boating and Waterways (2013)

Best Management Practices, Western Wood Preservers Institute

Designing Accessible Launches in Accordance with Americans with Disabilities Act Accessibility Guidelines, National Park Service

Environmental and Aesthetic Impacts of Small Docks and Piers, NOAA Coastal Ocean Program

Floating Trail Bridges and Docks, US Forest Service

Guidance on the 2010 Standards for Accessible Design, Department of Justice

Guidelines for Developing Non-motorized Boat Launches in Florida, Florida Fish & Wildlife Conservation Commission

Guidelines for Public Safety At Hydropower Projects, Federal Energy Regulatory Commission

Hydropower Relicensing, Recreational Liability, and Access, American Whitewater

Iowa Water Trails Toolkit, Iowa Department of Natural Resources

Layout, Design and Construction Handbook for Small Craft Boat Launching Facilities, California Department of Boating and Waterways

Non-Motorized Boating in California (see Table 3.1: Overview of Key Facility Needs by Non-Motorized Boat Types in California)

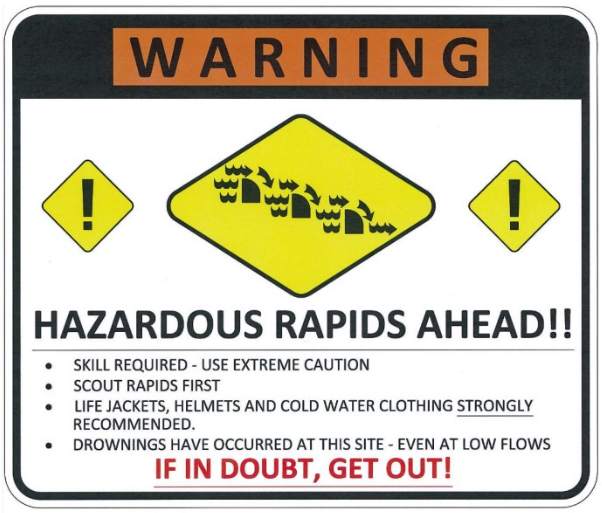
Prepare to Launch! Guidelines for Assessing, Designing and Building Access Sites for Carry-in Watercraft, River Management Society and National Park Service

Streambank Revegetation and Protection: A Guide for Alaska, Alaska Department of Fish & Game

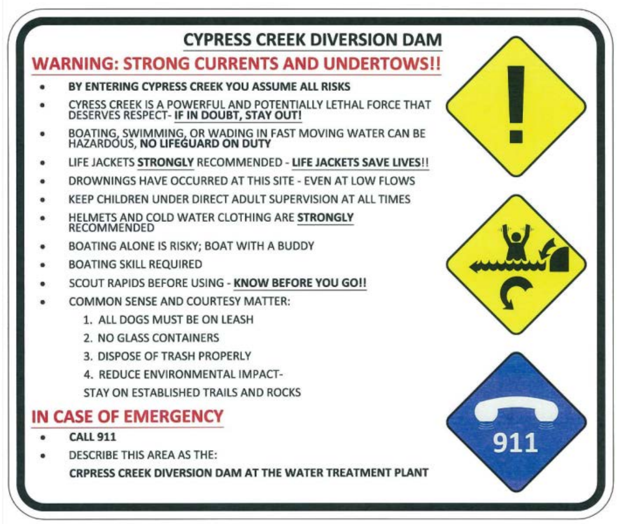
Wetland Trail Design and Construction, US Forest Service

4.8 Safety Signage

In addition to responsible design, signage should be provided at locations where public use is intended near hydraulic structures and where hazards are not obvious to the responsible user. Warning signs for dams or drop structures that are to be avoided (i.e., having no passage) are critical. There are a number of signage examples and guidelines across the United States.



Photograph 10-43. Signage prior to a boatable diversion in Florence Alabama. Courtesy of McLaughlin Whitewater Design Group.



Photograph 10-44. Additional signage placed adjacent to the facility in Florence Alabama. Photo courtesy of McLaughlin Whitewater Design Group.

There are currently no widely accepted standards for warning signage at river parks or boatable drop structures. One of the primary safety concerns is the prevalence of users without approved lifejackets, or Personal Floatation Devices (PFDs). Signage that emphasizes the need for PFDs is of utmost importance.

Signage wording should be reviewed by persons knowledgeable with both effective signage and river-related activities. Some considerations for wording include:

- Warning: Strong Currents and Undertows — Life Jackets Required
- Use Helmets and Cold Water Clothing
- Emergencies Call 911 (and/or provide phone number of fire department)
- Rapid Ahead - Scout Before Using (place upstream of portage)
- Skill Required
- Paddle Responsibly
- Bank Drops Off Quickly
- Don’t Go in the Water Alone
- Keep Children Under Direct Adult Supervision at All Times
- Drownings Have Occurred at This Site — Even at Low Flows

- Use at Your Own Risk

Signage to warn in-channel users of poor water quality, especially during wet-weather flow in urban areas, may also be appropriate.

Efforts to develop more universally accepted recommendations and suggested wording are being considered by several entities but do not exist at the time of publishing this manual. Some examples of signage are included in Chapter 7 of the Colorado Water Conservation Board's (CWCB) Floodplain and Stormwater Criteria Manual.

4.9 Maintenance Considerations

Maintenance of boatable channels is important to avoid accumulation of debris that could create a strainer and to identify any rock movement or structural issues that could create hazardous conditions. Improvements should be planned, designed, and constructed to avoid excessive maintenance requirements. Potential areas of sediment deposition resulting in aggradation or areas that accumulate debris, particularly in pools or zones with low velocities, should be identified. Maintenance needs and frequency of cleaning should be roughly approximated in the planning and design process. Paths, grading, and other ancillary infrastructure or considerations should be included to facilitate identified maintenance needs.

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