Figures

Photos

Chapter 14. Drainage Structures

A drainage structure is used to facilitate a trail crossing through or over a naturally occurring watercourse or seep without altering or disrupting the natural flow of the water.

14.1. Understanding Drainage Patterns

Over time, geomorphic processes shape the topography of the land, resulting in the development of distinct dendritic drainage basins and shallow sub-surface groundwater accumulation. During rainfall or snow melt, soil becomes saturated and water that is not absorbed flows along the ground as sheet flow until it collects into small, ephemeral depressions (swales) that combine to form streams. These streams combine to become rivers of various sizes. Trails often bisect watercourses and capture and disconnect the natural flow of the water. When a trail intercepts and captures sheet flow, sub surface flow, or watercourses it too can become a watercourse.

Water absorbed by the soil infiltrates downward and moves through permeable strata ("unsaturated zone") until encountering the water table ("saturated zone") or an impermeable layer. When water reaches the saturated zone or an impermeable layer, it moves laterally until it emerges from the hillslope as a spring or a seep. These hydrologic features can be large and dispersed or concentrated in a small area. (See Figure 14.1.)

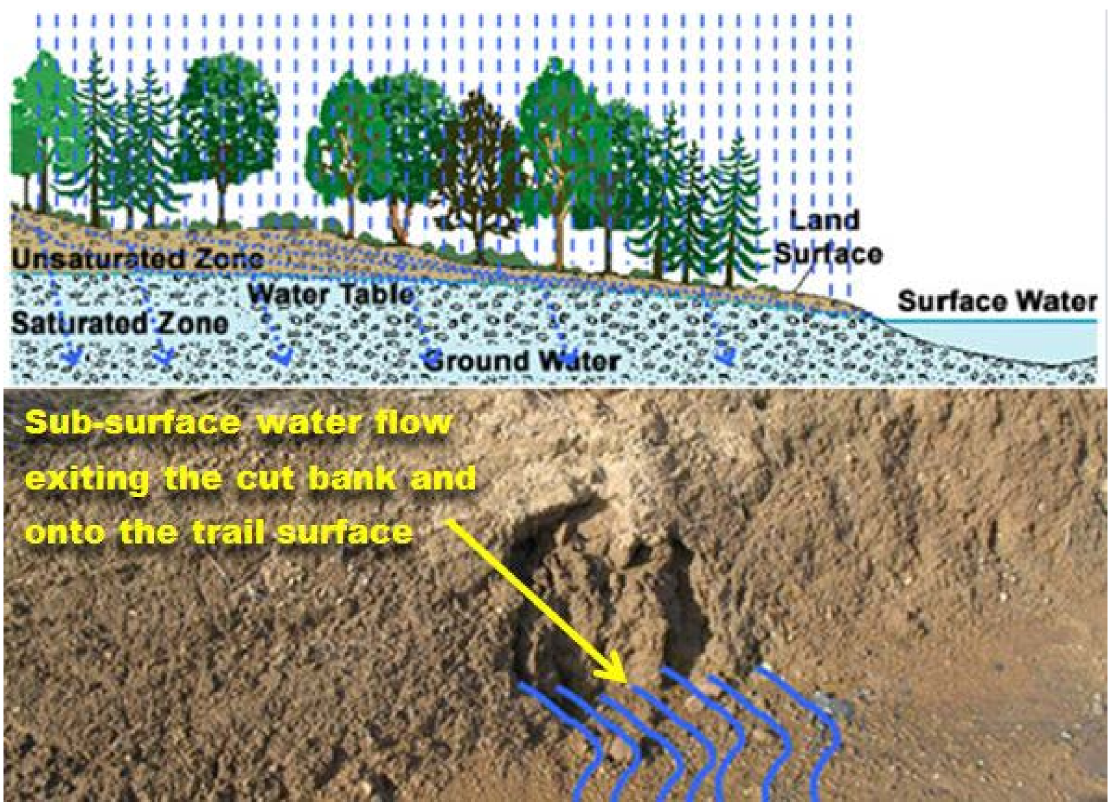


Figure 14.1 - Sub-Surface Water Flow

The lower in the watershed, the more likely these features will be encountered. Constructing a trail into a hillslope can expose a sub-surface water flow that may result in seepage across the trail. In flat, broad river valleys, trails are often constructed where the water table is close to the surface and watercourses are dynamic, resulting in frequent channel adjustments and flooding. Problematic trail conditions are the result of the designer not understanding or thoroughly investigating the watercourse patterns and the geomorphic processes occurring on the landform. Such an oversight can result in significant problems with erosion, resource damage, and trail maintenance that grow in magnitude over time. A properly laid out trail will maintain the natural watercourse patterns of the landform and minimize interruption of the natural flow.

There are many elements that affect natural watercourse patterns, including annual precipitation amount, rainfall intensity, rate of snow melt, soil type and its ability to absorb and hold water, soil competency and resistance to erosion, surface vegetation, canopy cover, hillslope and watercourse gradients, and the size of the area being drained (watershed). These factors need to be considered when evaluating watercourse patterns.

14.2. Estimating Channel Flow Area

Understanding the amount of water (volume of flow) that needs to be accommodated is important when determining the type and size of a drainage structure. There is no substitute for field review. Being able to read and understand evidence of past high water elevations is essential to this assessment. (See Chapter 5, *Principles of Trail Layout and Design*.) The minimum flow that a trail designer should use for evaluation purposes is the 100-year event.

14.2.1. <u>The Rational Method</u>

Besides relying on field evidence, there are other methods available to help a trail designer estimate peak flow. One flow prediction tool is the rational method. This method uses a formula (Q_{100}=CIA) to estimate the height of flood waters at a watercourse crossing. In this formula, "Q100" equals the quantity of water measured in cubic feet per second passing through a designated water crossing in a 100-year storm. "C" equals the runoff coefficient of the watershed above the crossing site. "I" equals the rainfall intensity (inches per hour) of the 100-year flood event. "A" equals the area of the drainage basin above the crossing.

The rational method relies on hydrological data developed on a state or regional level. Rainfall runoff coefficient and intensity data is available from the United States Geological Service. Remote watersheds do not always fit a model based on a homogenous landform. Local topography and the direction of prevailing winds can significantly influence precipitation levels. Variation in canopy cover, understory vegetation type and density, exposed bedrock, soil types, soil depths, and the amount of organic material on top of the soil influence the amount of runoff in a watershed. Because of these limitations, the rational method is not recommended for use on watersheds greater than 200 acres.

14.2.2. Magnitude and Frequency Method and Flow Transference Method

Other models used to predict rainfall intensity and coefficient of runoff for a 100-year flood event are the "USGS Magnitude and Frequency Method" and the "Flow Transference Method". Both of these models rely on gauging station data. The Magnitude and Frequency Method uses gauging station averages derived from regional data. The Flow Transfer Method uses data from gauging stations located on the watercourse being crossed or a similar watercourse nearby. The use of gauging station data produces more a reliable rainfall intensity estimate and a better prediction for watersheds over 100 acres in area. Since the Flow Transfer Method uses gauging data from the drainage basin where the crossing structure is located, it provides the most accurate prediction for peak flow events. Given the size, remoteness, and complexity of most watersheds where trails are located, it is extremely unlikely that a gauging station is located on or near the watercourse that a trail will be crossing. Determining a 100-year flood elevation using the methods discussed above is much more complex than what is described here and should be performed by a qualified hydrologist, engineering geologist, or engineer. Given the limitations of these models, they should not be used for the final calculation of maximum flow levels. For bridge sites, the determination must be verified by a channel investigation previously discussed in Chapter 5, *Principles of Trail Layout and Design*. For closed watercourse crossings such as culverts, the field methods discussed below should be used. A good practice is to use one of the models above coupled by field observations to estimate a 100-year flood level.

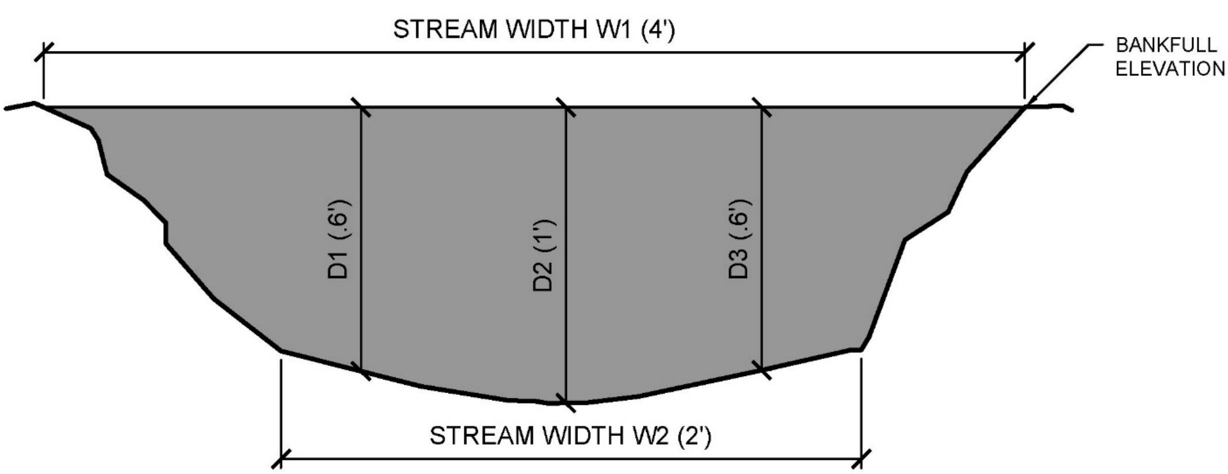
14.2.3. Triple Bankfull Method

Two field observation methods can be applied to determine the maximum flow in a given watercourse. This flow is then used to size the appropriate culvert for the watercourse crossing. These methods require specific channel profiles, which may not be present at the intended crossing site. Therefore, it may be necessary to survey the watercourse channel above or below the intended crossing to locate the appropriate channel profile.

One of these methods is the "Triple Bankfull Method." The "bankfull" stage occurs when the watercourse fills its primary channel to the top of the bank and begins to pour over into the floodplain. The flow associated with this event would occur on average every one to two years. This field method requires observing a channel profile that is sufficient in size to contain an average annual flow level but has bank elevations low enough for higher flows to escape onto the flood plain. To obtain the area of the bankfull channel (Abf), measure the width across at the upper bank (W1), the channel width (W2), and the total depth (D). Calculate the bankfull cross-sectional area of the stream using the equation below. Multiply this area by three to determine the final cross section area. (See Figure 14.2.)

$$\text{Abf} = \frac{(\text{W1} + \text{W2})}{2} \times \text{D}$$

TRIPLE BANKFULL STREAM CHANNEL CROSS SECTION MEASUREMENT



1. LOCATE STREAM CHANNEL PROFILE WHERE BANKFULL ELEVATION IS EVIDENT
2. MEASURE HORIZONTALLY ACROSS THE TOP OF THE CHANNEL (W1)
3. MEASURE HORIZONTALLY ACROSS THE BOTTOM OF THE CHANNEL (W2)
4. ADD W1 (4') AND W2 (2') TOGETHER AND DIVIDE BY 2 TO OBTAIN THE AVERAGE CHANNEL WIDTH (4'+2'=6'/2=3')
5. MEASURE THE DEPTH OF THE CHANNEL AT DIFFERENT LOCATIONS TO OBTAIN AN AVERAGE DEPTH
6. ADD D1 (.6') AND D2 (1') AND D3 (.6') AND DIVIDE BY 3 TO OBTAIN THE AVERAGE CHANNEL DEPTH (.6'+1'+.6'=2.2'/3=.7')
7. MULTIPLY THE AVERAGE WIDTH (3') BY THE AVERAGE DEPTH (.7') TO OBTAIN THE SQUARE FOOTAGE OF THE CHANNEL (3'x.7'=2.2 SQUARE FEET)
8. MULTIPLY 2.2 SQ FT x 3 TO OBTAIN TRIPLE BANKFULL AREA (2.2x3=6.6 SQ FT)

Figure 14.2 - Triple Bankfull Method

TRIPLE BANKFULL METHOD

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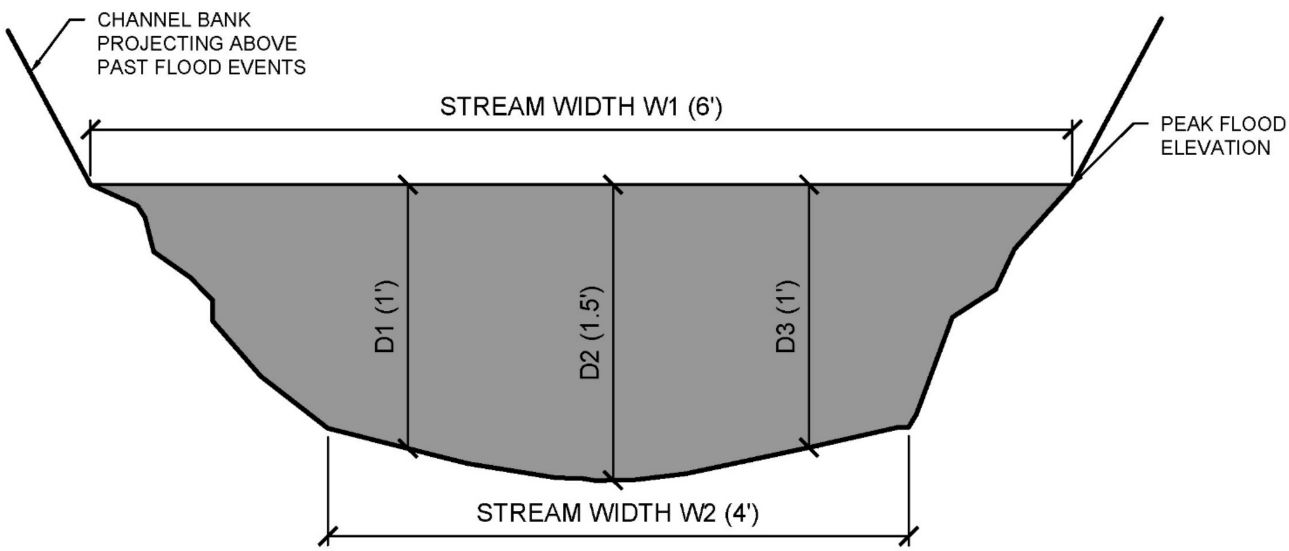
14.2.4. Double Peak Flow Method

The second method is the "Double Peak Flow Method". The height of the largest recognizable past flood event is determined by evaluating locations within the watercourse where the banks are above past flood events. This observational method requires watercourses with banks that are higher than past 100-year flood levels. Indicators of the magnitude of past events include scour marks on streambanks, vegetation loss or similar changes related to past floods, driftwood debris deposited on ledges or flat areas, pieces of grass and flotsam left hanging on vegetation, silt lines left on trees or rocks, and tree bark scarred by flood debris. Estimate the probable elevation of the maximum flood event and measure the cross-sectional area using the equation below. Multiply this area by two to determine the final cross sectional area. (See Figure 14.3.)

$$Apf = \frac{(W1 + W2)}{2} \times D$$

Both of these methods provide the total cross sectional area (in square feet) that is occupied by water during a maximum flow event. In addition to estimating the cross sectional area, the loss of flow rate through the culvert must also be estimated. Once water flowing through a culvert reaches about 90% of the culvert's capacity, the amount of friction is increased within the culvert and the flow rate is reduced by approximately 10%. To compensate for this loss, the cross sectional area should be increased by 10%. This area is then used to size the culvert used in the watercourse crossing. For example, the triple bankfull area of 6.6 square feet identified in Figure 14.2 is multiplied by 10% to identify the additional cross sectional area needed (6.6 sq. ft. x 0.10 = 0.66 sq. ft.). Add the numbers together to calculate the total cross-sectional area required for the culvert (6.6 sq. ft. + 0.66 sq. ft. = 7.26 sq. ft.). Thus, the cross sectional area of the culvert should be 7.26 sq. ft. (See Figure 14.4.) Using the culvert capacity chart below, a round culvert needs to be a minimum of 48 inches in diameter and an oval culvert needs to have an opening of 57 x 38 inches. Note, always round up to the larger culvert size.

DOUBLE PEAK FLOW STREAM CHANNEL CROSS SECTION MEASUREMENT



1. LOCATE STREAM CHANNEL PROFILE WHERE PEAK FLOOD ELEVATION IS EVIDENT
2. MEASURE HORIZONTALLY ACROSS THE TOP OF THE CHANNEL (W1)
3. MEASURE HORIZONTALLY ACROSS THE BOTTOM OF THE CHANNEL (W2)
4. ADD W1 (6') AND W2 (4') TOGETHER AND DIVIDE BY 2 TO OBTAIN THE AVERAGE CHANNEL WIDTH (6'+4'=10'/2=5')
5. MEASURE THE DEPTH OF THE CHANNEL AT DIFFERENT LOCATIONS TO OBTAIN AN AVERAGE DEPTH
6. ADD D1 (1') AND D2 (1.5') AND D3 (1') AND DIVIDE BY 3 TO OBTAIN THE AVERAGE CHANNEL DEPTH (1'+1.5'+1'=3.5'/3=1.16')
7. MULTIPLY THE AVERAGE WIDTH (5') BY THE AVERAGE DEPTH (1.16') TO OBTAIN THE SQUARE FOOTAGE OF THE CHANNEL (5'x1.16'=5.8 SQUARE FEET)
8. MULTIPLY 5.8 SQ FT x 2 TO OBTAIN PEAK EVENT FLOW AREA (5.8x2=11.6 SQ FT)

Figure 14.3 - Double Peak Flow Method

DOUBLE PEAK FLOW

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Culvert Sizing Chart			
Round Pipe		**Elliptical (Oval) Pipe**	
Opening Size (inches)	**Cross Sectional Area (ft^2)**	**Opening Size (inches)**	**Cross Sectional Area (ft^2)**
12	0.79	17 x 13	1.1
18	1.75	21 x 15	1.6
24	3.14	27 x 21	3
30	4.9	35 x 24	4.5
36	7	42 x 29	6.5
48	12.5	57 x 38	11.6
60	19.6	71 x 47	18.1
72	28.2	83 x 57	26
96	50.2	112 x 75	48
108	63.6	128 x 83	60.5
120	78.5	142 x 91	74.5

Figure 14.4 - Culvert Sizing Chart

14.2.5. Other Considerations

When estimating the capacity of a culvert, consider the volume of woody debris or aggregate that might be carried downstream in a flood event. Wood and aggregate add volume to the water flowing in the channel, thereby increasing the area of the water in the channel. Floating logs and limbs may project above the high water mark and plug the mouth of the culvert. Additional freeboard is required for these objects to pass through the drainage structure. Regardless of how the peak flow is estimated, structures should be designed for sustainability, which means over-sizing the structure to prevent premature failure.

Identify the appropriate location for a watercourse crossing during the layout and design process. The criteria for locating a site and designing a crossing is explained in Chapter 5, *Trail Layout and Design*. Following this approach, the selected crossing site and structure will be sustainable, have the least environmental impact, and meet the needs of trail users. When selecting a crossing site and design, the simplest solution should be selected first. More complex designs should only be used when conditions warrant them.

Many factors must be addressed when locating, designing, and constructing a watercourse crossing. Watercourses are complex systems and subtle changes can easily disrupt the equilibrium of a watershed. Many stream crossing structures discussed in this chapter have the potential to adversely impact the watercourse if they are not located, prescribed, or constructed properly. Therefore, it is important to consult a qualified hydrologist or engineering geologist when locating, designing, and constructing these structures.

14.3. Selection and Accessibility

Many types of structures can be used for a watercourse crossing. Some of the simplest and most effective structures are open rock culverts, step through culverts, and stepping-stones, but these do not meet accessibility standards. Whenever possible, the drainage structure should not present a barrier to users with a mobility impairment. Even if the trail is not designated as an "accessible trail," every attempt should be made to avoid or eliminate barriers created by drainage structures.

14.4. Drainage Structure Construction

Installation of a drainage structure should occur during the time of year that water flow is lowest. Sediment control devices, such as silt fences or straw waddles, are installed downslope of the excavated area to prevent sediment from entering the watershed. (See Photo 14.1.)

Photo 14.1 - Sediment Control Devices

If the stream is running, a small cofferdam comprised of sand bags can be installed above the excavation to capture the stream flow. The water is then diverted around the excavated area and back into the stream below the worksite through a flexible plastic pipe to reduce turbidity and prevent saturation of the crossing fill during excavation. (See Figure 14.5.)

Excavated material must be exported to a stable location far enough away from the crossing site that it cannot re-enter the watercourse. Additional silt fences should be installed between the crossing and the excavated material, if there is any chance of the material migrating into the crossing.

Once the drainage structure is complete, excess excavated soil or any soil trapped in the silt fence or waddle is hauled away from the influence of the watercourse and used as backfill on trail structures or sidecast on appropriate slopes. All sediment retention structures, piping, and cofferdams are removed and disturbed areas are rehabilitated. (See Chapter 27, *Site Restoration*.)

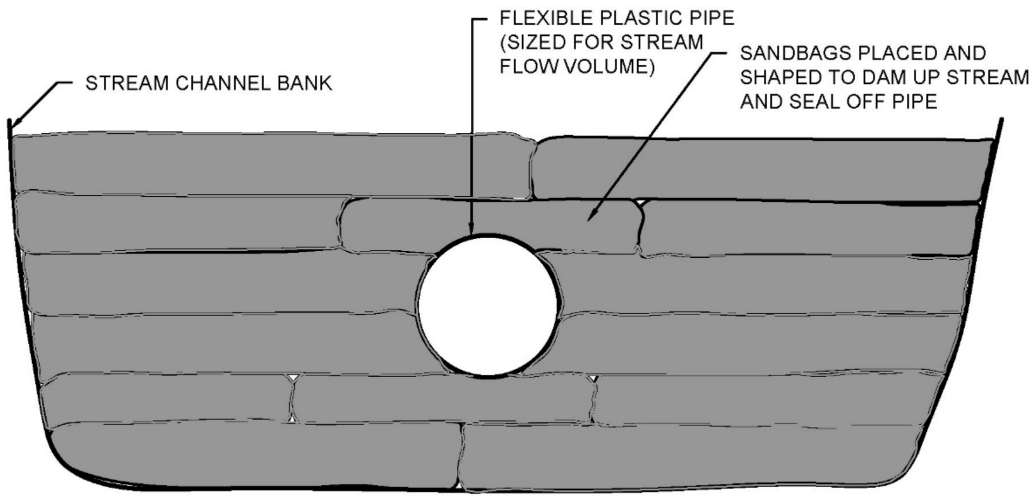
14.5. Drainage Without Structures

The most effective method of facilitating overland sheet flow is to design and layout the trail to follow curvilinear alignment. (See Chapter 5, *Principles of Trail Layout and Design.*) Design and construct the trail bed with a full bench and an outslope on a side slope with greater than 20% gradient. (See Chapter 11, *Principles of Trail Construction.*) By employing these methods, the trail will be nearly perpendicular to the overland sheet flow and the sheet flow will not be captured or re-directed. Instead, it will continue on its normal path.

Photo 14.2 - Outsloped Trail

To “outslope” a trail, grade the trail so that the outside edge is lower than the inside edge. (See Photo 14.2.) Outsloping allows sheet flow to follow its natural course across the trail and down the slope. Proper outsloping, combined with curvilinear alignment and full bench construction on a side slope with greater than 20% gradient, will prevent water from being captured by the trail and the trail becoming a watercourse. Ideally, all trail tread should be outsloped, but due to certain physical restraints (e.g., long or multiple seeps emanating from the cut bank or draining the upper leg of a climbing turn or switchback), it is not always possible. Outsloping can be the quickest and most immediate form of drainage control. If the linear grade is within the maximum sustainable grade, the trail surface is durable, and the back slope is stable, an outsloped tread is easy to maintain. Even existing trails that were not laid out or constructed properly and that perform badly can be improved by installing a proper outslope to the trail tread.

COFFER DAM (END VIEW)



COFFER DAM SETUP (PLAN VIEW)

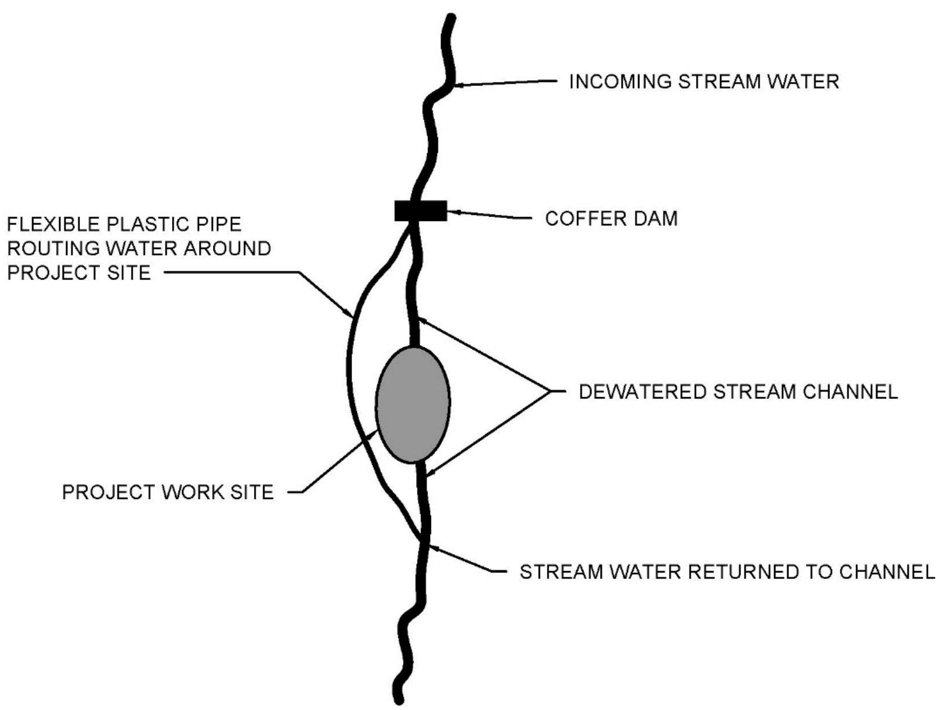


Figure 14.5 - Cofferdam

COFFER DAM

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The percentage of outslope needed to facilitate sheet flow across the trail tread depends on the linear grade of the trail; strength and durability of the soil; amount and magnitude of rainfall; amount of surface area (watershed) above the trail; percent gradient of the hillslope the trail is traversing; amount of canopy cover above the trail; the anticipated mechanical wear associated with user types; and the volume of traffic. These factors mean the required percentage of outslope can vary significantly. A common mistake is to construct trails with too little outslope based on the belief that a steep outslope will be uncomfortable for users and make the trail difficult to use. However, a 5% outslope is so gradual that it meets accessibility standards and an outslope of 8 to 12% is imperceptible to most users. If a trail has an 8% linear grade with an outslope of 5%, sheet flow intercepted by the trail will be pulled down the trail rather than across it. If the outslope is 12%, water will be pulled across the trail and not down the trail. The outslope on a trail should be equal to or greater than 1.5 times the linear grade. The ratio of outslope to linear grade may need to be increased on trails with high mechanical wear. This basic law of physics cannot be ignored when prescribing the amount of outslope required to facilitate sheet flow across a trail.

Outsloped trail tread requires cyclical maintenance to remove cut bank slough, outside berms, tread deformation, woody debris accumulation, and vegetation build-up along the inboard and outboard hinges. The frequency of maintenance varies. (See Chapter 25, *Trail Tread Maintenance.*)

14.6. Simple Open Structures

14.6.1. Applications

The next order of drainage treatment possibilities is a simple open structure. These structures will maintain an existing watercourse pattern or facilitate use of the trail within a watercourse. Most often a simple open structure is designed to be constructed from native materials. It should be noted that most simple open structures create some level of barrier to the accessibility of the trail.

Drain swales should be used on almost all trails. This structure is essential for separating the trail from the ephemeral micro-watercourses a trail will bisect. If the parent soil is too weak or has a tendency to become saturated, an unarmored drain swale may not be suitable. In these cases, the structure may have to be armored or a different drainage structure installed.

Armored drain swales have the same applications as drain swales, but can also accommodate equestrian, mountain bike, and accessible trail uses. To qualify as accessible, the armored drain swale must meet standards for open drainages and tread obstacles. (See Chapter 8, *Accessible Trail Design*)

The application of armored stream crossings depend on the amount of water the trail user will encounter when using this structure. If the crossing is dry most of the year and only receives water during storm events, it may be suitable for pedestrian, equestrian, and mountain bike trails. Users requiring mobility assistive devices may not be able to use this stream crossing structure even during the dry season, as loose aggregate, sand, and soil can be deposited on the stones during storm events. These deposits may not meet the firmness and stability requirements for accessible trail tread. If water is encountered year round, this type of crossing may not be suitable for hikers and mountain bikers on a Class I trail. User expectations in the frontcountry usually do not include wading across streams. However, this type of crossing is appropriate in backcountry or wilderness settings. Some shod horses could experience difficulty when walking over this structure if the rock surface is too smooth and uniform. Slipping becomes less likely when the stones have a layer of aggregate, sand, or soil, or a rough and uneven surface.

Drainage ditches have limited application and with proper trail planning, design, and layout, the need for these structures can be reduced. Unfortunately, most trail program managers inherit their trail systems and often have to make the best of what they were given, and, thus, drainage ditches become a necessity.

14.6.2. Drain Swales

A drain swale is an appropriate structure for maintaining natural drainage patterns. (See Photo 14.3.) It is installed where a trail bisects an ephemeral swale or crenulation with a flow that is insufficient to justify use of a more developed structure. A drain swale can be a minor control point and trail designers should follow the same methods for selecting the appropriate location. (See Chapter 5, *Principles of Trail Layout and Design.*) Identifying these topographic features and laying out a trail in a fashion that prevents water from the swales being diverted onto the approaching trail leg is an important element of curvilinear alignment. A drain swale mimics the slope coming into and out of a watercourse, so the trail dips down into the center of the swale and then pulls back out, preventing water in the swale from flowing down the trail. (See Figure 14.6.)

Photo 14.3 - Drain Swale

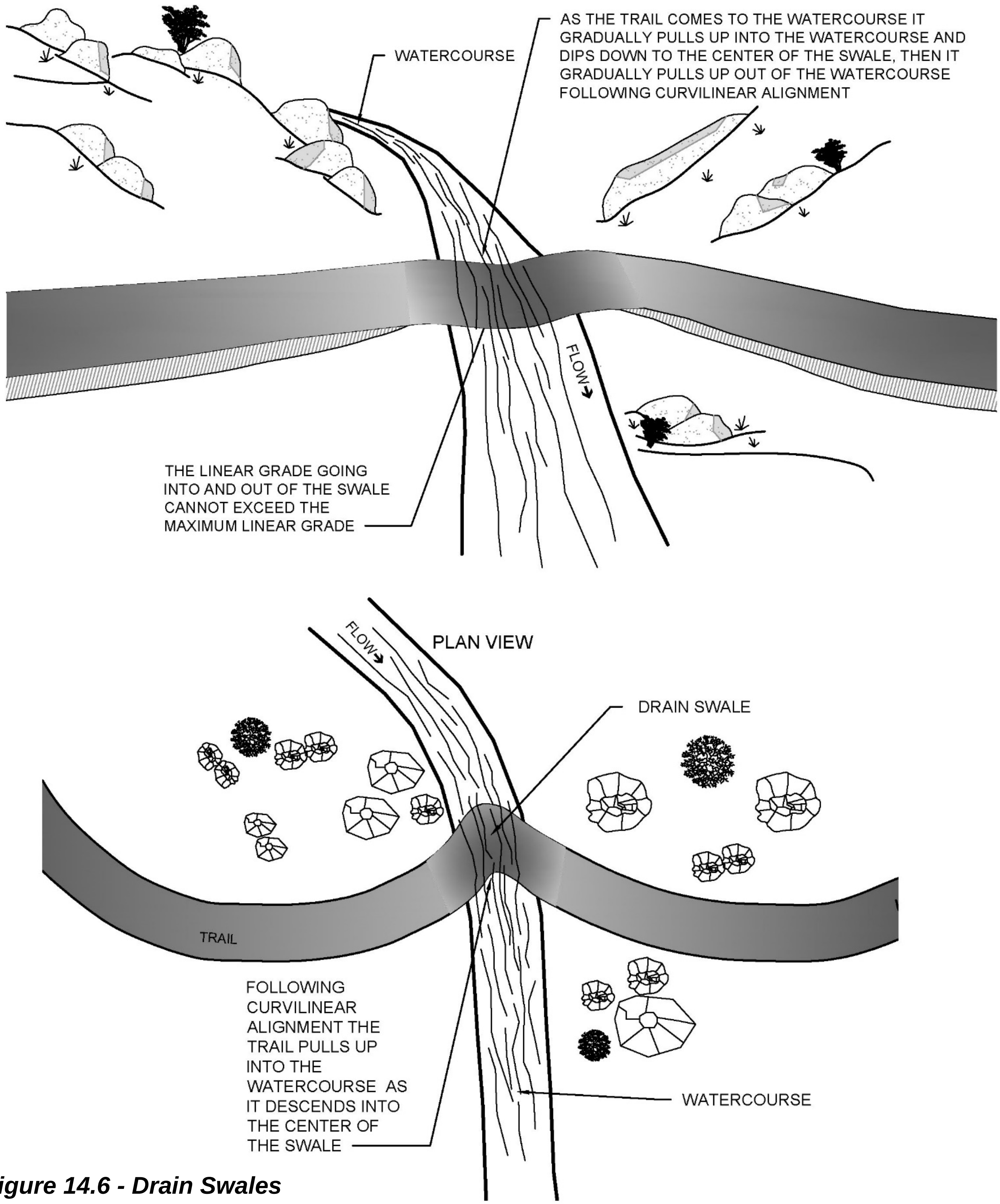

Figure 14.6 - Drain Swales

DRAIN SWALES

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Construction of a drain swale is part of trail tread construction, since it requires no additional soil excavation or materials. The method for constructing the trail into and out of a swale is the same as explained in Chapter 11, *Principles of Trail Construction*. However, the soil excavated from the swale or its influence must be exported to a location outside of the swale, so that it cannot re-enter the watercourse and introduce sediment into the lower watershed. Instead of side casting excavated soil, it is loaded into a wheelbarrow or motorized toter and exported to an appropriate site. This work can be performed by hand crews or with the aid of a mini-excavator.

14.6.3. Armored Drain Swales

Sometimes a drain swale receives high flows that warrant the hardening of the trail tread within the crossing. (See Photo 14.4.) In addition, the soil in the bottom of the watercourse may become saturated to the extent that it loses its structure and becomes a quagmire. This situation often results when equestrians use a trail and the horses' hooves penetrate the saturated soil and begin breaking up and pumping the soil. During the layout and design process, the potential for these conditions must be recognized and a prescription for armoring the swale crossing identified. The location of an armored drain swale is a minor control point and must be selected carefully. (See Chapter 5, *Principles of Trail Layout and Design.*)

Photo 14.4 - Armored Drain Swale

A drain swale is armored by installing a rock tray within the crossing and the adjacent banks. A rock tray is a method of armoring or hardening the trail tread by installing large rocks tightly together, so the finished tread surface resembles a cobblestone walkway. (See Figure 14.7.) When armoring is installed, it is laid on grade to stabilize a surface and/or to control drainage, while providing good footing. Used as a surfacing material, rock armoring is relatively flat and has a rough texture. These attributes make it an ideal surfacing material for watercourse crossings.

An armored swale crossing is installed by first excavating the crossing and adjacent banks to a minimum depth of 1 foot. The excavation must match the slope (gradient) of the watercourse crossing so that the finished elevation will match the channel's elevation. (See Figure 14.7.) If the top of the armoring structure does not match the existing channel grade, this structure will alter the watercourse morphology, which could result in lateral scour, head cutting, scour, deposition, or any combination of these problems. The width of excavation should extend a minimum of 1 foot beyond the tread width of the trail. The distance of excavation into the adjacent banks will vary depending on the watercourse's high water mark, bank stability, soil strength and cohesion, trail user type, and the steepness of the grades in and out of the crossing. (See Figure 14.7.) At a minimum, the armoring should be installed above any perceptible high water mark. In addition, the top of the rocks armoring the approaching banks must match the elevation of the banks. Again, all soil generated during excavation should be exported from the influence of the watercourse.

Once the excavation is completed, the stones are placed. The stones used in an armored drain swale should be a minimum of 1 foot in depth and width. (See Chapter 13, *Retaining Structures.*) The initial keystones are laid at the lowest point of the structure. These stones should be the largest stones in the structure, and, if possible, anchored into existing bedrock to further lock-in the structure. The keystones must be well-secured, as they serve as a buttress for the rest of the structure. Stones are placed so that the tops match the existing channel elevation. To achieve this elevation, it may be necessary to further excavate into the channel bed or place crushed rock underneath the stones to raise them to the desired elevation. Orient the stones so the flattest surface is on top. (See Figure 14.7.) The next set of stones are selected and placed to achieve a tight fit against the first layer. Stone shaping tools, such as hand chisels, hand points, and spauling hammers, will help obtain a close fit between the rocks. Gaps between the rocks should not exceed 1/2 inch, and the surface elevation of the rocks should match each other and conform to the channel gradient. (See Figure 14.7.) Once the stones are laid, it may be necessary to drive rock wedges along the outside edge of the structure to fill any voids and further tighten the rocks against each other. The final step in installing rock armoring is to chink the spaces between the rocks by pounding crushed rock into the voids until the surface is uniform and smooth.

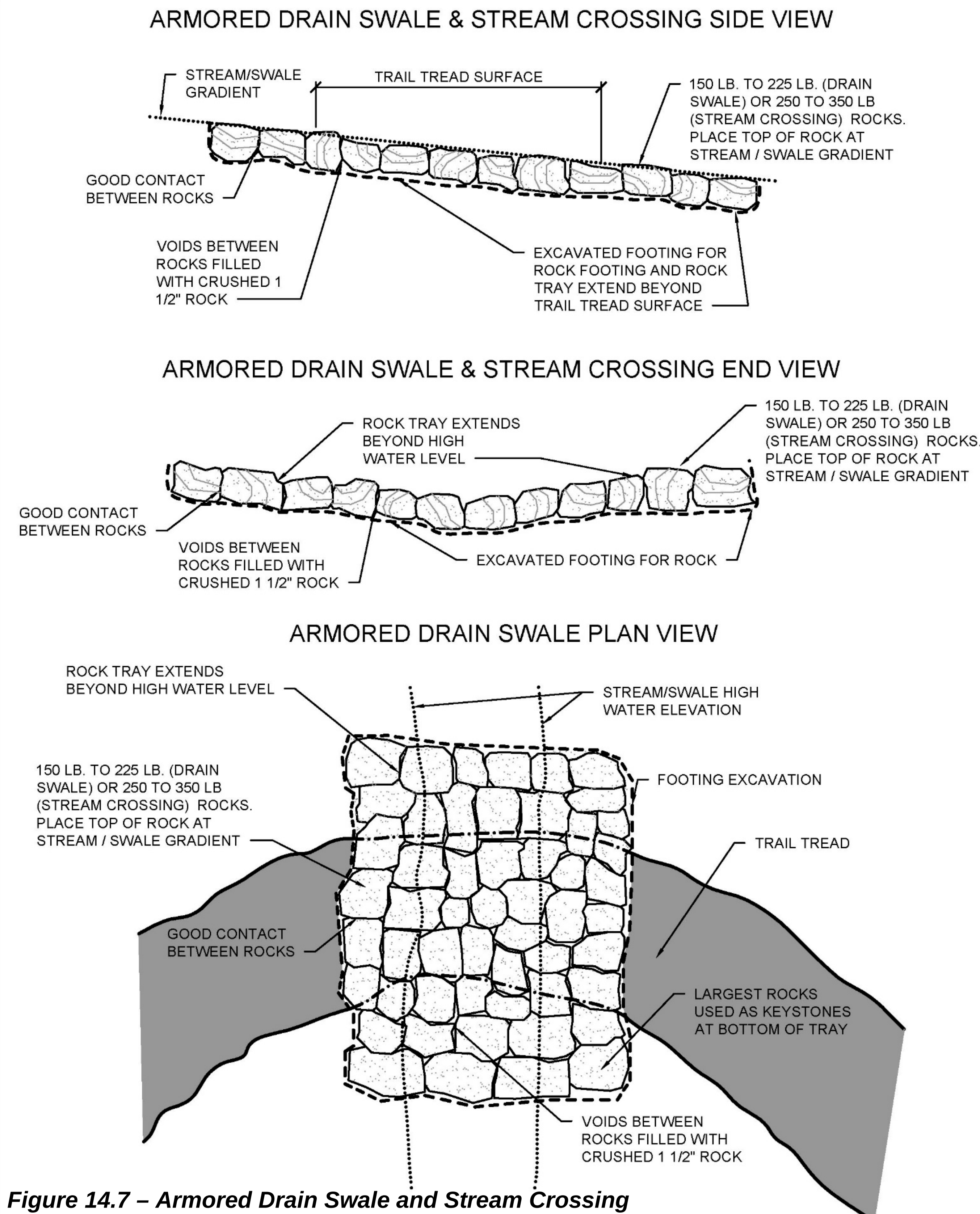

Figure 14.7 – Armored Drain Swale and Stream Crossing

ARMORED DRAIN SWALE AND STREAM CROSSING

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14.6.4. Armored Stream Crossings

Armored stream crossings are similar to armored drain swales, except they are placed in watercourses that are more defined, have perennial or year-round flows, or receive large volumes of water during storm events. (See Photo 14.5.) However, these watercourses are still smaller enough that they can be safely crossed during the intended use periods. The location of a crossing is a minor control point that should be identified during the design and layout process. (See Chapter 5, *Principles of Trail Layout and Design.*)

Because large watercourses receive more water, an armored stream crossing requires a deeper excavation and larger rocks. The excavation should be a minimum of 1 1/2 feet below the lowest point (thalweg) of the existing stream channel. The installation of an armored structure is the same as for a drain swale except in excavation depth and stone size. The stones must be a minimum of 1.5 feet deep and 1 foot wide. Streams that are more dynamic may require that the stone size be increased to 2 feet deep and 1.5 feet wide. (See Figure 14.7.)

Photo 14.5 - Armored Stream Crossing

14.6.5. Drainage Ditches

Drainage ditches are open drainage structures that must be used judiciously. Any structure that collects and concentrates overland sheet flow or shallow subsurface flow that is not associated with a natural watercourse has the potential to alter the drainage patterns of the landform. Such alterations may lead to the coupling of watercourses, inter-basin water transfer, impacts to plant and animal communities, slope instability, soil erosion, and mass wasting. There are very few circumstances where a drainage ditch should be prescribed.

The most common use of a drainage ditch is when a trail bisects a large spring or a series of springs not associated with a swale or a crenulation. (See Photo 14.6.) If the spring has a low flow volume and is confined to a small area or a single location, then a drain lens could be prescribed. (See the section **"**Drainage Lens".) Otherwise, an inboard ditch is necessary to collect the water emanating from the cut bank and carry it to where it can be drained across the trail via a culvert or simple open structure. (See the sections "Culverts" and "Simple Open Structures".) In addition, since ditches are used where ground saturation is common, the trail tread is usually hardened and elevated to maintain its structural integrity. For this reason, causeways, turnpikes, armoring, and gravel hardening techniques are often prescribed with inboard ditches. (See the section "Other Trail Drainage Structures".) In addition, inboard drainage ditches must be used in conjunction with a drainage structure to carry the water across or under the trail.

Photo 14.6 - Drainage Ditch

Another location where a drainage ditch can be appropriate is where the trail traverses through a low, flat area that accumulates water. These locations are control points and should be avoided during the layout and design process. Sometimes trail conditions are inherited or unavoidable because of other planning, design, or layout constraints. A drainage ditch applied in this situation can be a single inboard ditch or two parallel ditches on either side of the trail. The trail tread is elevated and hardened through the use of turnpikes or causeways, and cross-drained with culverts, armored swales, or drain lenses. (See the section “Other Trail Drainage Structures”.)

When constructing a drainage ditch, it must be adequately sized to carry the maximum anticipated volume of water, including anticipated overland sheet flow as well as shallow groundwater flow. The size of the ditch must also accommodate the loss of ditch capacity related to vegetation growth. The most effective ditches are lined with vegetation to help trap fine sediment, reduce water velocity, and stabilize cut banks. Excavation of the inboard ditch must not encroach upon, undermine, or destabilize the base of the cut bank in any way. (See Figure 14.8.) The material from any excavation must be incorporated into the elevated trail tread or exported away from the saturated area to a location where it won’t re-enter the watershed. Once the ditch has been excavated to the proper depth and width, the banks of the ditch are laid back to the maximum angle at which they will retain their position without sliding down the slope and even further if needed for stability and revegetation. The slope of the ditch should be nearly equal to the trail grade. When approaching a cross drain structure, the ditch grade gradually increases to match the elevation of the cross drain.

A well-designed trail grade is moderate enough that the velocity of ditch water will not be erosive, especially if the ditch is lined with vegetation. If the ditch gradient is steep enough to increase water flow velocity, the water can scour the ditch and mobilize soil. It may be necessary to armor the bottom and/or sides of the ditch with rock placed similarly to an armored crossing, so the surface is rough and reduces the velocity of water. Stones used in this application should have irregular surfaces that project 1 to 3 inches into the current. If the ditch gradient is too gentle, sediment will drop out of suspension and accumulate in the bottom of the ditch. This condition reduces the capacity of the ditch and can result in ditch water flowing onto the trail.

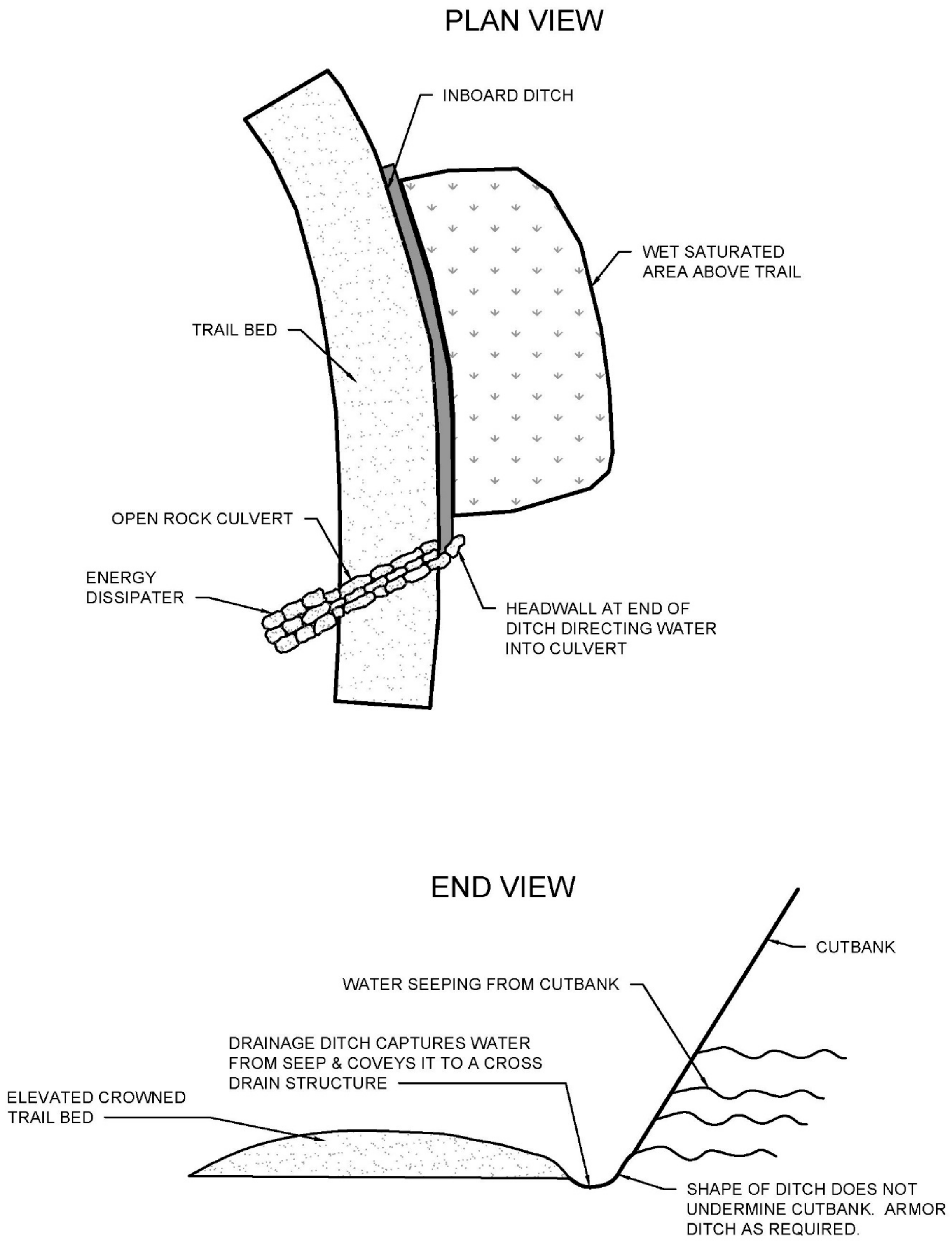

Figure 14.8 - Drainage Ditches

DRAINAGE DITCHES

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14.7. Culverts

14.7.1. Applications

Open culverts and step through culverts armor both the channel and the banks of a small watercourse. They differ from closed culverts in that they have no top, only a bottom and two sides. They are used to protect a small seasonal stream channel flowing across the trail, or to convey spring water collected in an inboard ditch across the trail. Open culverts are more accommodating of water and debris that normally can cause problems with closed culverts. Open culverts are easier to maintain and involve less excavation and fill to construct. The most common open culverts are constructed of rock.

The applications for open culverts and step through culverts are limited. These structures do not meet accessibility requirements and represent a barrier to trail users with mobility impairments. Mountain bikers prefer not to use these structures, because the majority of users have to dismount and carry their bikes across them. Equestrians prefer not to cross over an open rock culvert, but if it has a wide rock tray, the horse can step in and out of it. Open wooden culverts are not durable enough for equestrian use, and horses do not like low structures because they cannot see them well. (See Chapter 7, *Equestrian Trail Design.*) Equestrians do not like step through culverts, because horses cannot negotiate the structures very well and doing so puts them at risk. Hikers have no trouble with these structures, which makes them suitable for pedestrian only trails in backcountry settings. Wooden culverts also have a limited life span as they are subject to rot.

Closed culverts are used to convey water under the trail. They can be constructed of wood, rock, plastic, or metal. Plastic and metal culverts come in a variety of shapes and sizes. Located under the trail, closed culverts do not disrupt the trail surface or grade and facilitate meeting accessibility requirements. They provide all trail users the safest and most user friendly type of watercourse crossing. They are most commonly used on Class I trails where users expect a high level of trail development. Closed culverts must be properly sized and installed to prevent plugging, channel scour, head cutting, being overwhelmed by high flows, and impacts to aquatic species. Even when properly sized and installed they require periodic monitoring and cleaning.

14.7.2. Open and Closed Rock Culverts

The size of a culvert is determined by the anticipated runoff volume and debris load for the watercourse. (See the section “Understanding Drainage Patterns and Volumes”.) An open culvert typically has a width of 24 inches and a depth of 8 inches to enable trail users to step over or into and out of it. (See Photo 14.7 and Figure 14.9.) If used on equestrian trails, it should have a minimum width of 3 feet to allow horses to step into and out of it. If additional capacity is needed based on watershed runoff and debris calculations, then a step through culvert should be used. (See Photo 14.8.) Step through culverts are constructed the same as open culverts, but extra volume is added to the culvert opening by installing graduated steps into the structure. (See Figure 14.10.) These steps have an 8-inch rise and an 18 inch landing. The overall depth of a step through culvert should not exceed 24 inches or three steps. Any watercourse with greater depth is unsafe to cross during peak runoff, so a closed watercourse crossing or bridging structure should be employed. (See Photo 14.9 and Figure 14.9.)

Photo 14.7 - Open Rock Culvert

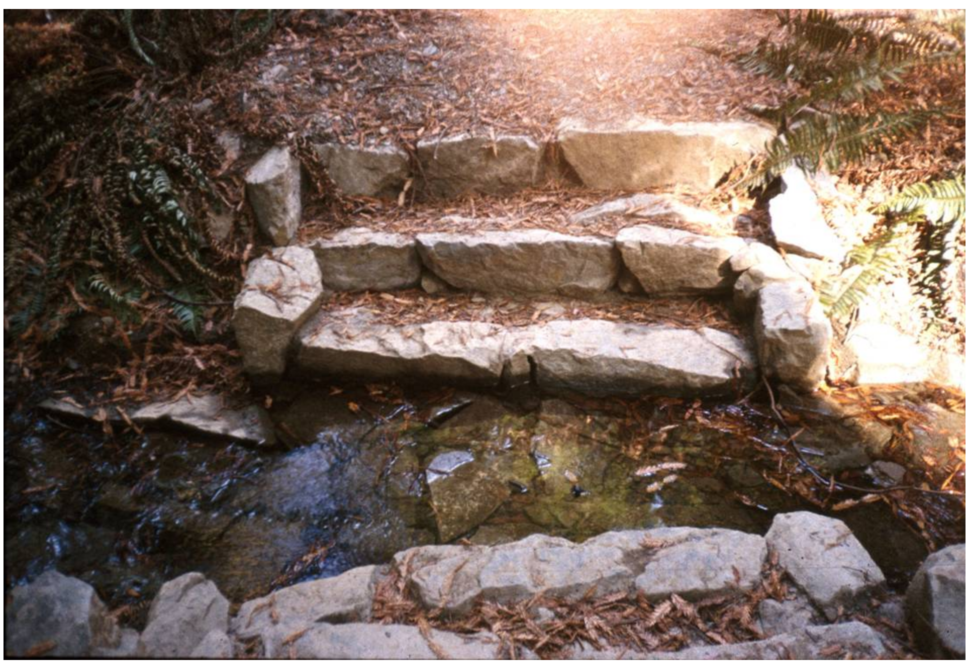

Photo 14.8 - Step Through Culvert

Photo 14.9 - Closed Rock Culvert

An open culvert used to convey a stream across a trail is installed so that the stream does not deviate from its natural alignment. If the stream gradient is steeper than the cross slope of the trail bed, the culvert gradient is installed to match the trail bed cross slope, and an energy dissipater is installed at the culvert outlet to prevent scouring and head cutting. (See Figure 14.11.) An energy dissipater is installed with a collection basin large enough to accept the maximum discharge of the watercourse and not deflect water onto the surrounding slope. An open rock culvert that collects and conveys inboard ditch water across a trail also requires an energy dissipater. This water is discharged onto the slope below the trail and can erode the hillslope if its energy is not reduced.

Construction of an open rock or step through culvert begins with excavation of the culvert opening. The depth of excavation corresponds to the dimensions calculated for the maximum water flow in a 100-year storm event. In addition, the excavation depth must include the thickness of the rock to be used for the bottom tray of the culvert, as well as the rock used for the sides. If additional steps are planned, the thickness of the rocks must be accounted. The bottom and sides of the trench are constructed in stable native soil that is free of organics, rotten wood, or fill material. Once the trench is excavated, the bottom tray of the culvert is laid. This tray is considered armoring and is installed as discussed earlier. (See the section "Armored Drain Swales".)

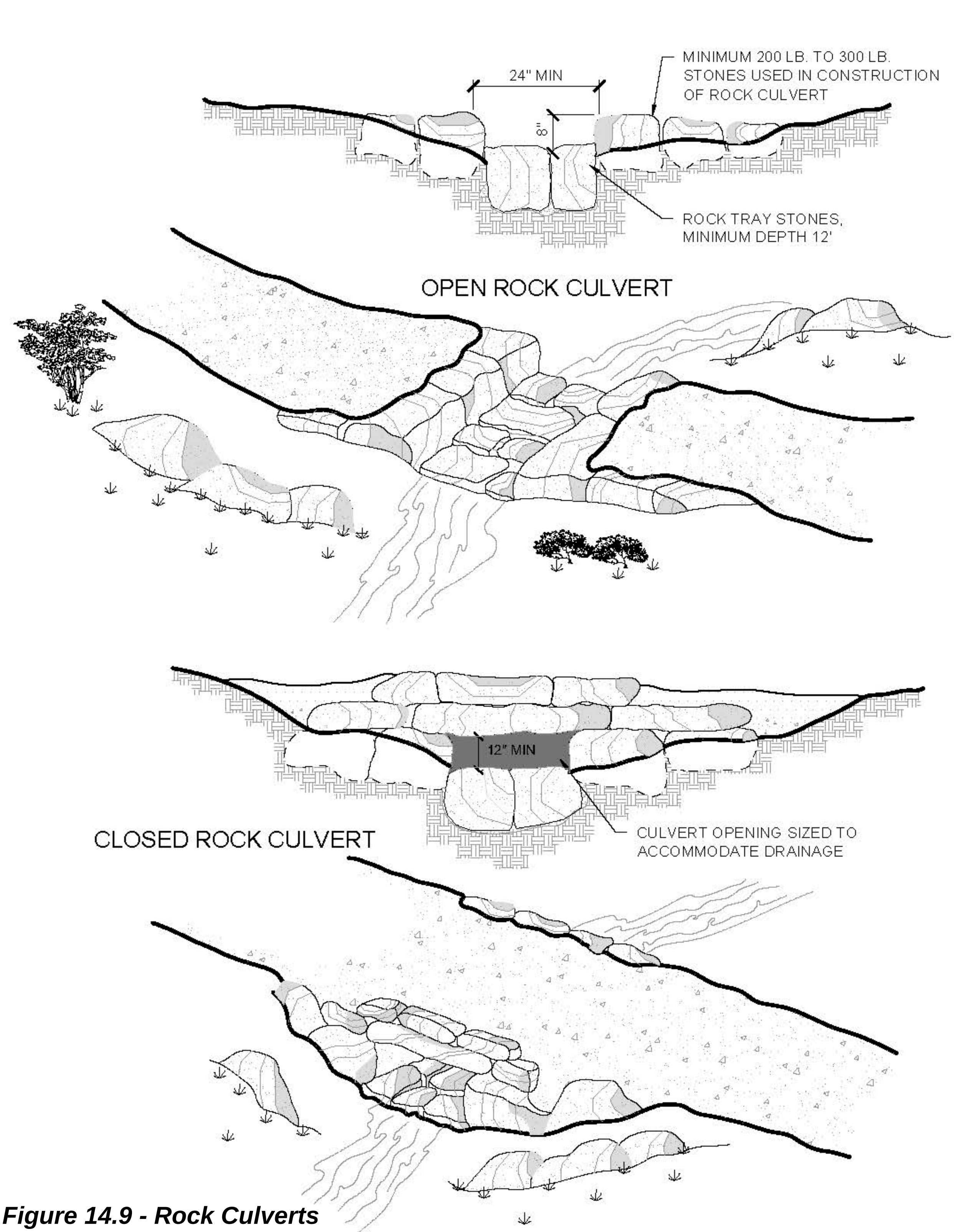

Figure 14.9 - Rock Culverts

ROCK CULVERTS

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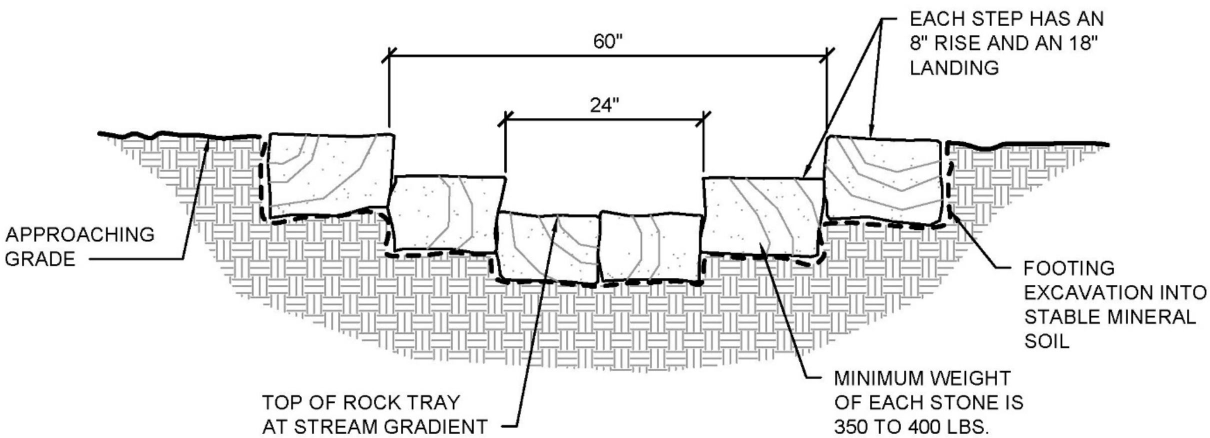
END VIEW



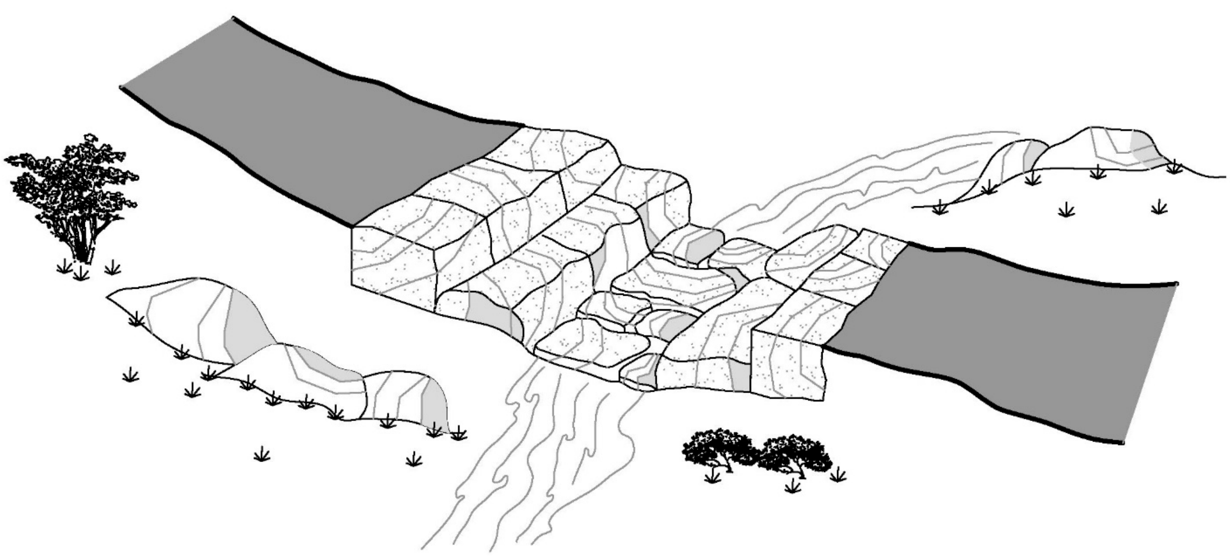


Figure 14.10 - Step Through Culverts

STEP THROUGH CULVERTS

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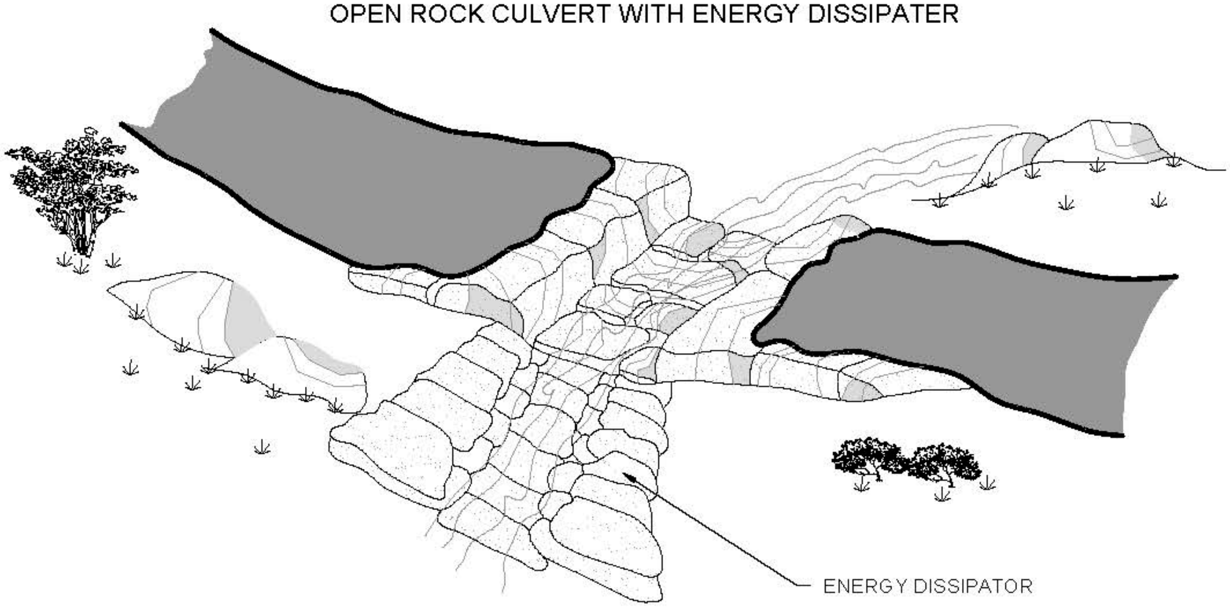
OPEN ROCK CULVERT WITH ENERGY DISSIPATER



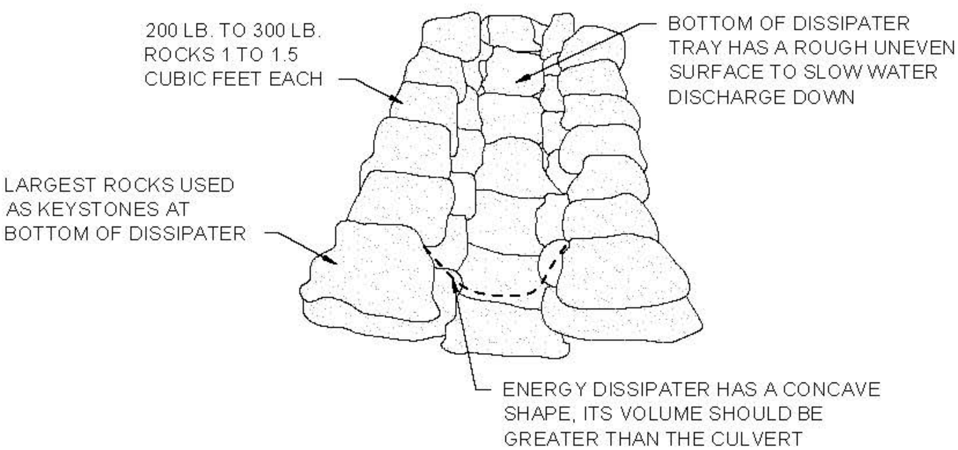


Figure 14.11 - Open Rock Culvert with Energy Dissipater

OPEN ROCK CULVERT WITH ENERGY DISSIPATER

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Once the tray is installed, the sides of the rock culvert are laid. Side wall rock (step rocks) has at least three flat sides, one for the landing surface and two to adjoin the step rocks on either side of it. The bottom of the step rock is a minimum of 6 inches below the top of the bottom rock tray to help lock the structure together. The height of the rock must be sufficient to provide the 6-inch depth below the top of the bottom tray and the 8 inch rise of the step. (See Figure 14.9.) The width of the rock needs to provide an 18-inch landing for the trail user to step off and on when crossing. The selected rocks should fit together snugly and be placed firmly against adjacent stones. Spalls (smaller pieces of rock) are used as needed to fill voids. The voids behind the sidewalls are filled with crushed rock and firmly compacted. (See Figure 14.9.)

For additional steps, the height of the side wall rock is factored into the thickness of the next step that will be constructed. Again, the height of the rock must be sufficient to provide the 6-inch depth below the top first step rock and the 8-inch rise of the step. (See Figure 14.10.) The second step starts on the outside edge of the first and extends 18 inches into the hillslope. To complete the installation of the step through culvert, similar rock steps are constructed on the other side of the open rock culvert. The same construction techniques are used to install the steps on the other side of the culvert. Any additional rock trays and steps are installed in the same fashion.

The difference between open and closed rock culverts is the addition of a top to complete the enclosure. Construction of a closed rock culvert is the same as an open culvert except for this top. Stones used to form the culvert top have a minimum thickness of 4 inch, are flat, and of sufficient dimension to bridge from one side wall to the other. They sit firmly against the side wall stones and form a base for the trail tread. The top stones are fitted tightly to eliminate any gaps large enough to allow gravel and soil to fall into the culvert. Additional chinking with rock spalls will eliminate gaps. The top of the culvert can serve as the trail tread or be buried under the trail surface. If buried, geotextile fabric is used to seal the top of the culvert before it is covered with minimum of 6 inches of soil. In addition, single tier rock walls are installed along the outside edges of the culvert to contain the soil covering the top stone or stones. (See Figure 14.9.)

14.7.3. Open and Closed Wooden Culverts

Open culverts constructed of wood are sized and installed in the same way as rock culverts. (See Photo 14.10.) However, given the limited size of planking material, this style of culvert is used primarily on small, ephemeral watercourses or seeps. The main difference between wooden and rock culverts is that wooden planks are used instead of rock, which simplifies assembly. (See Photo 14.11.) When selecting wood, use a species that is resistant to rot, such as cedar or redwood. Pressure treated wood is not acceptable because preservatives will leach into the water the culvert is designed to convey. The planks can be purchased at a lumber store, manufactured on-site by splitting them out of downed trees, or using a portable (Alaskan) chainsaw mill.

Photo 14.10 - Open Wooden Culvert

Photo 14.11 - Wooden Culvert

Planks that are split out of downed logs require additional shaping to join them together, but with the right woodworking tools, such as slicks, draw knifes, chisels, and mallets, can be accomplished with little difficulty. The minimum dimension for planks should be 3 inches thick by 12 inches wide. The length will vary depending on site conditions. The culvert is assembled by joining the two outside wall planks to the tray plank so that the bottoms of the outside planks are flush with the top of the tray plank. (See Figure14.12.) A simple butt joint can be used to join the wall planks, which can then be secured with wood screws, nails, or wooden dowels.

Closed wooden culverts have a cap plank that seals the top of the culvert. The cap plank is fastened to the wall planks in the same manner as the tray plank. Closed culverts are installed at stream gradient and backfilled with crushed rock. A rock headwall is required to seal the culvert inlet and support the crushed backfill. (See Figure14.13.) The use of wooden planks is limited to open and closed culverts. This material is not durable or strong enough to be used in a step through culvert.

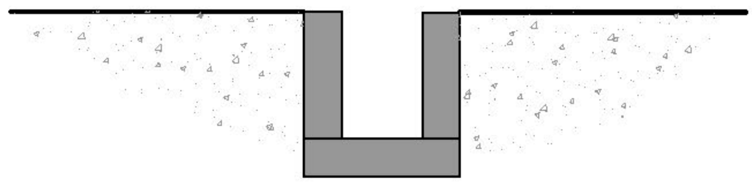
14.7.4. Metal and Plastic Culverts

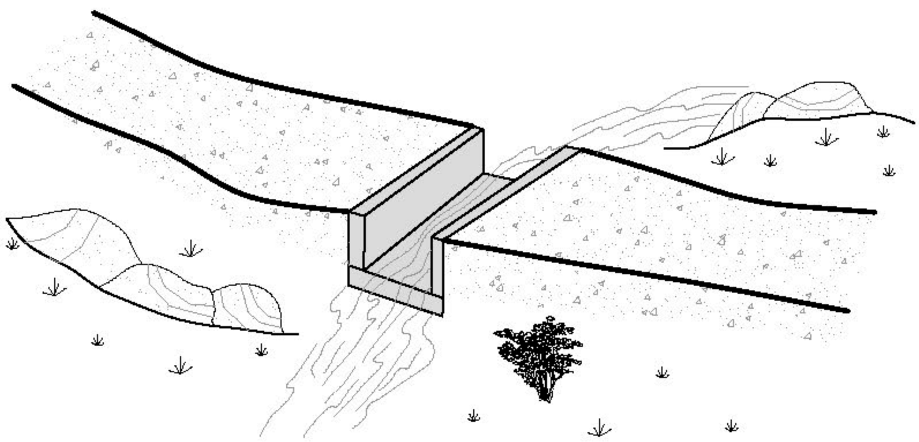
Sometimes it is necessary for a trail to cross a watercourse in a fashion that provides for an uninterrupted tread surface to reduce the impact on resources and improve user safety, trail tread stability, linear grades, and accessibility.

The most common underground closed drainage structure is the culvert. (See Photos 14.12.) This structure has a high probability for failure if not properly located, sized, and constructed. Culverts should only be used on small, low-flow perennial or ephemeral watercourses or drainage ditches. Culverts are used to carry water in a watercourse underneath the trail or in conjunction with ditches. The latter is referred to as a ditch relief culvert.

Photo 14.12 - Metal Culvert (left), Plastic Culvert (right)

END VIEW





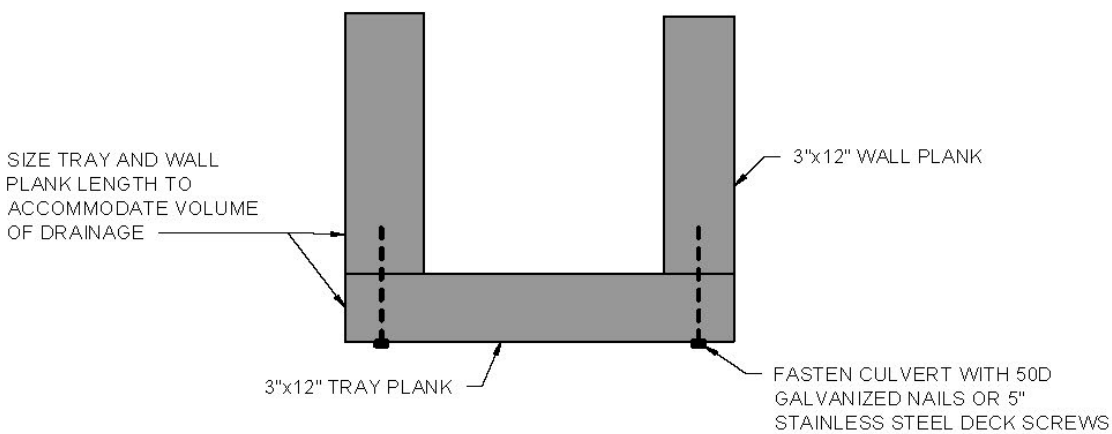


Figure 14.12 - Open Wooden Culvert

OPEN WOODEN CULVERTS

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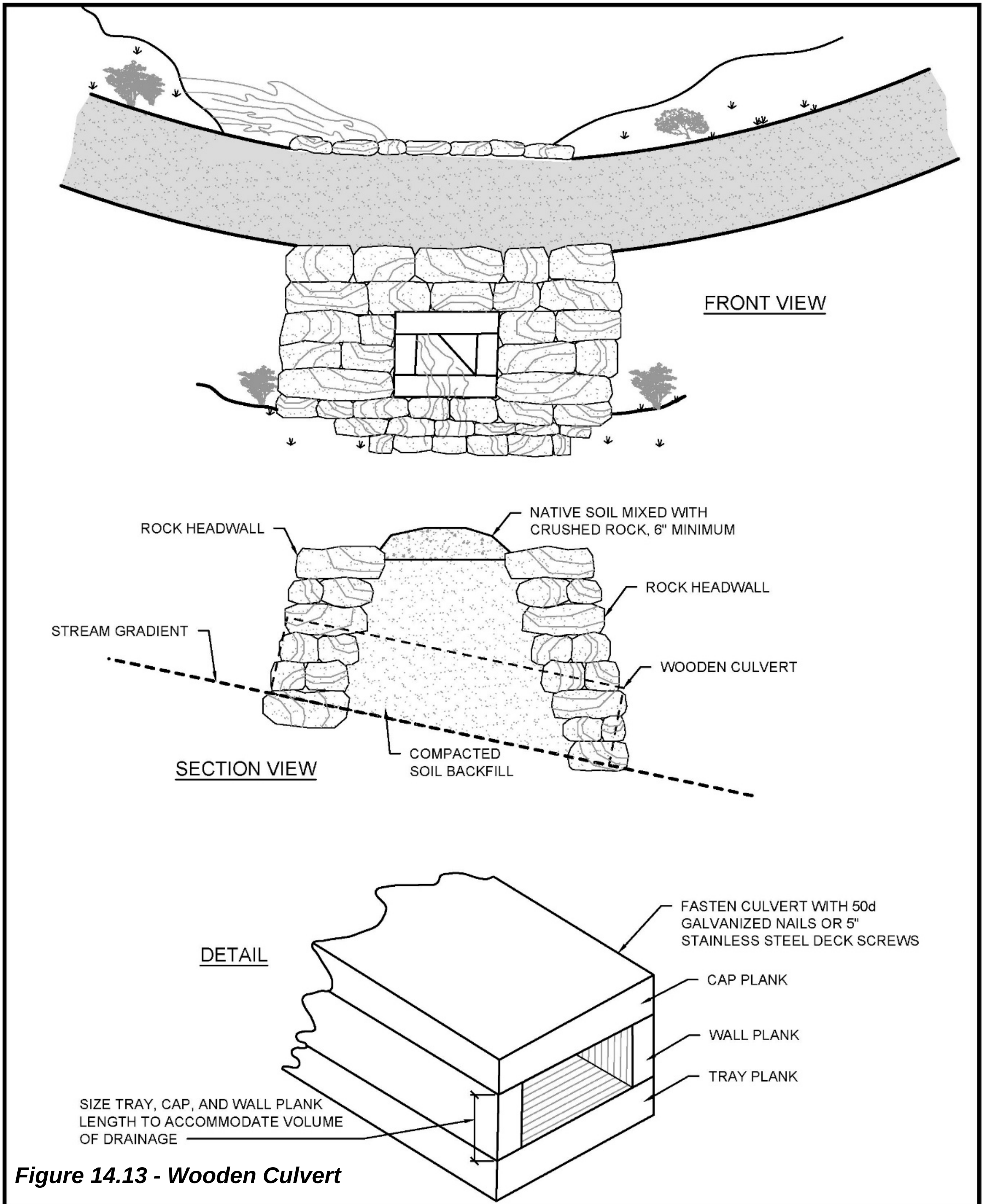

Figure 14.13 - Wooden Culvert

WOODEN CULVERTS

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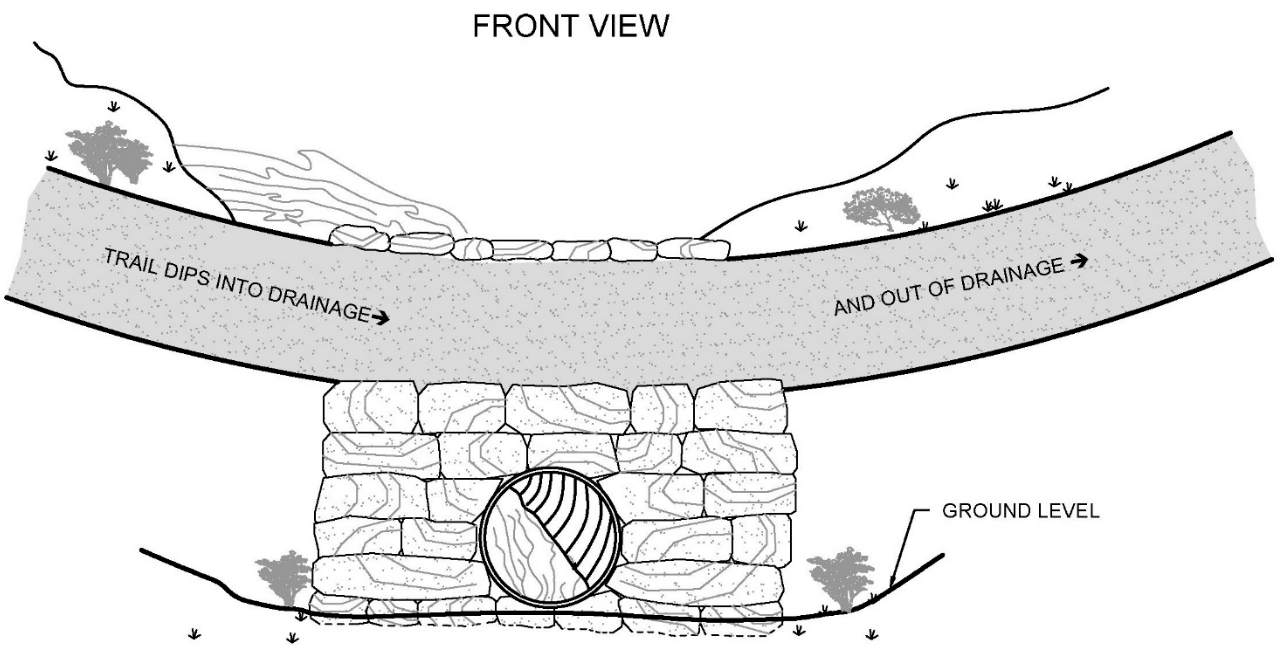
Culverts should not be used to cross a watercourse that is a habitat for fish or sensitive listed aquatic species without proper evaluation and analysis from a qualified fishery biologist and hydrologist. Spanning structures, such as puncheons or bridges, are more appropriate in these situations.

To convey a watercourse under a trail, the culvert must be properly sized using the Triple Bankfull or Double Peak Flow field methods discussed above. Since it is rare that during a storm event a trail can be patrolled to clear and clean culverts, a culvert must be able to perform without being overwhelmed by water or plugged by debris. Studies have shown that nearly 90% of culvert failures in Northwest California are caused by debris that plugs the culvert. Excessive water flow does not contribute to these failures. Careful evaluation of the stream channel above the inlet to identify the presence and quantity of aggregate, sediment, branches, or large woody debris is required to size a culvert properly. If a significant quantity of aggregate or woody debris is in the channel, the culvert's size needs to be increased to accommodate the passage of that material. In the absence of a headwall at the outflow end of a culvert, the length of the culvert must be sufficient to extend beyond the fill slope by an amount equal to the culvert's diameter while staying on the stream gradient. (See Figure 14.14.) If these guidelines are followed, a culvert is an effective and cheap method of crossing a watercourse. See Chapter 20, *Materials*, for additional information on metal and plastic culverts.

Culverts are installed by first removing the vegetation within the excavation limits. This clearing extends a minimum of 2 feet beyond the inlet and outlet of the culvert. Hand crews perform this work using methods similar to those used for clearing a new trail alignment. However, a mini excavator with a thumb attached to the bucket can also perform this task if trail standards, local policies, and site conditions permit.

Once the vegetation is removed and de-watering and erosion prevention devices are in place, excavation begins at the downstream end of the crossing to prevent water from accumulating and saturating the soil. Even if a cofferdam is installed, some water will flow through or underneath the dam and be encountered during excavation. If the excavation begins at the upstream end of the crossing, soil below the excavation will dam the water seeping into the excavation turning the crossing site into a quagmire. Excavation can be performed by a trail crew using hand tools, such as picks, mattocks, and shovels, or by mini excavator.

Given that culverts are only recommended for low-flow watercourses, the excavated trench will usually be less than 5 feet deep. OSHA requires that any trench with vertical banks and a depth of 5 feet or more has shoring to protect people working in the trench. If the sides of the trench are laid at an angle where the parent soil is stable and will not sluff or cave in, shoring can be avoided.



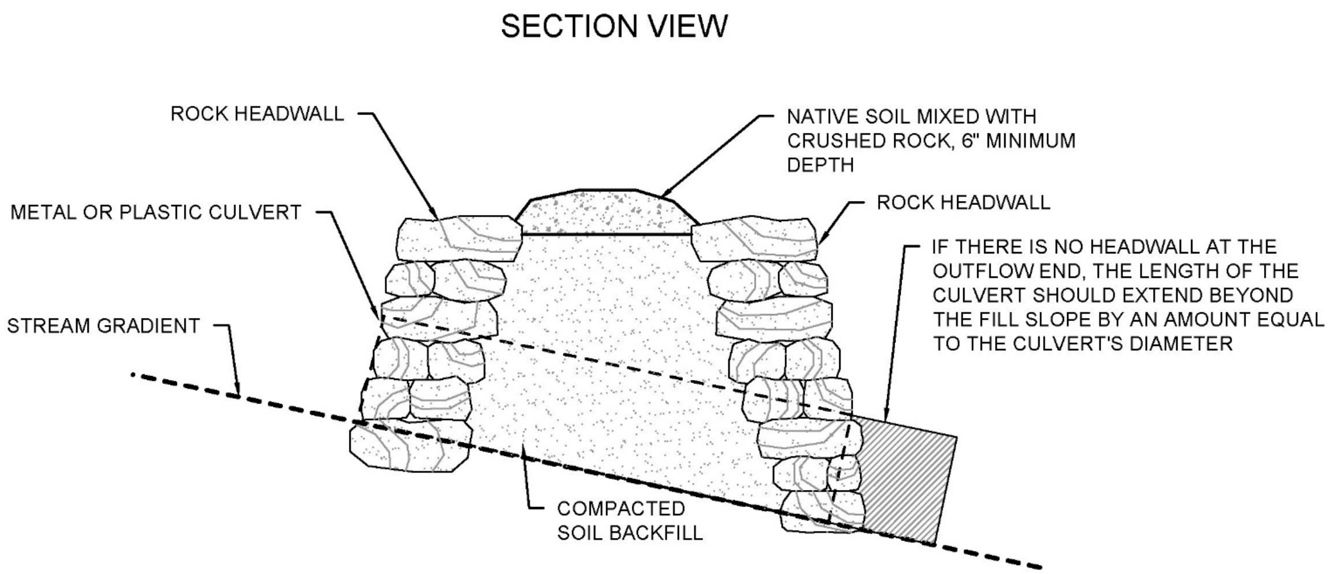


Figure 14.14 - Metal and Plastic Culverts

METAL AND PLASTIC CULVERTS

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The depth of the culvert trench could also be reduced by using an elliptical or oval culvert. This style of culvert has a lower height and a greater width than a round culvert, which reduces the needed depth of the trench. An oval culvert may also better accommodate a stream channel that is shallow and wide. Its lower profile can reduce the amount of trenching and fill material needed to ramp over a culvert that projects above the adjacent streambank.

The trench is excavated so that the bottom of the inside of the culvert is at the same gradient as the stream's natural gradient to prevent deposition or scour from occurring at the culvert's inlet and deposition or head cutting at the outlet. (See Figure 14.14.) The trench should also be aligned with the stream's natural channel flow to prevent lateral scour at the inlet and outlet and enhance the flow of water and debris through the culvert. The bottom of the trench should be uniformly smooth, well compacted, and comprised of soil that is free of large or sharp rocks, roots, or woody debris. These conditions ensure that the bottom of the culvert is uniformly supported, tightly sealed, and will not be punctured or deformed by underlying rocks or wood. If the bottom of the trench is comprised of saturated soil or coarse material, it may be necessary to install a layer of crushed aggregate or place one or two layers of non-woven geotextile fabric underneath the culvert to obtain better support and a tighter seal.

Culverts generally come in 20-foot lengths. Most culvert installations require less than 20 feet. In this case, cut the culvert to the required length before transport to the site. Plastic culverts are cut with a chainsaw or wood saw. Metal culverts are cut with an oxyacetylene torch or a power saw with a composite metal cutting blade or disc.

If the culvert is small in diameter and short in length, and the trench is shallow and the banks are laid back, place the culvert into the trench with hand crews once the bottom of the trench is prepared. If the culvert is long enough to require two or more sections, those sections are coupled after they are placed in the trench, using appropriate band couplers. When installing band couplers, wrap non-woven geotextile fabric around the pipe where the two sections join before the coupler is installed. The fabric acts as a gasket and helps seal the joint.

If the trench is too narrow or the banks too steep, assemble the culvert sections above the trench and then lower them into the trench with ropes. To support the pipes, tie loops around the pipe with ropes placed at regular intervals. Workers holding the ropes then lower the pipe into the trench until it sits on the bottom. The ropes are removed by pulling the end of the rope back through the loop and pulling the rope out from under the culvert

Prior to backfilling the trench, headwalls are installed at the inlet and outlet. (See Photo 14.13.) Headwalls are needed to prevent erosion, help contain the culvert backfill material, and obscure the culvert ends from view along the trail. Headwalls used on culverts are constructed of rock, concrete, wood, or burlap bags filled with

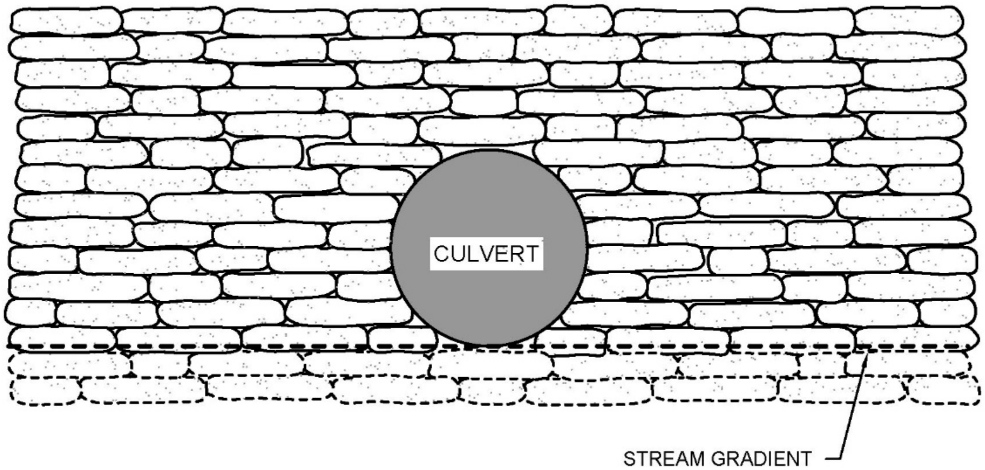
Ready-Mix. The selection of headwall material depends on local policies, architecture, historic practices, aesthetics, labor force skill, and project logistics. Rock is the most commonly used headwall material.

Photo 14.13 - Culvert Headwall

14.7.5. Culvert Headwall

To install a rock headwall, the first tier is laid under the bottom of the culvert so that the bottom of the culvert sits flush on the top of the first tier. To achieve this fit, the first tier of rocks is set into a trench excavated below the natural stream channel grade. (See Figure 14.15.) The trench must extend into the adjacent streambanks a minimum of 1 foot. The size of the rocks depends on the diameter of the culvert. One cubic foot is sufficient for most applications. The front of the headwall must protrude at least 4 inches beyond the ends of the pipe to prevent the culvert from being seen from the trail. The second tier is laid the same as any multi-tier rock wall except that the rocks butting up against the outside culvert wall are selected or shaped to conform to the shape of the culvert. (See Chapter 13, *Retaining Structures.*) The rocks must conform to the culvert to unitize and seal the headwall so that water does not flow down the outside of the culvert. (See Figure 14.15.) The ends of the headwalls are keyed into the adjacent streambank, so the stream flow cannot flank and erode the headwall. Gaps in the back of the headwalls are chinked as each course is completed. A wedge of crushed rock 1 to 2 inches thick is placed and compacted behind each headwall course to support the wall and seal off the end of the culvert. The shape of the inlet headwall is similar to a broad funnel, directing stream flow into the mouth of the culvert and improving its capacity to carry water and debris. The outlet headwall is shaped perpendicular to the stream flow. (See Figure 14.15.) The headwalls continue until they are a minimum of 6 inches above the top of the culvert. The fronts of the headwalls are chinked with rock spalls once they are constructed.

DRAINAGE CULVERT HEADWALL FRONT VIEW



DRAINAGE CULVERT HEADWALL PLAN VIEW

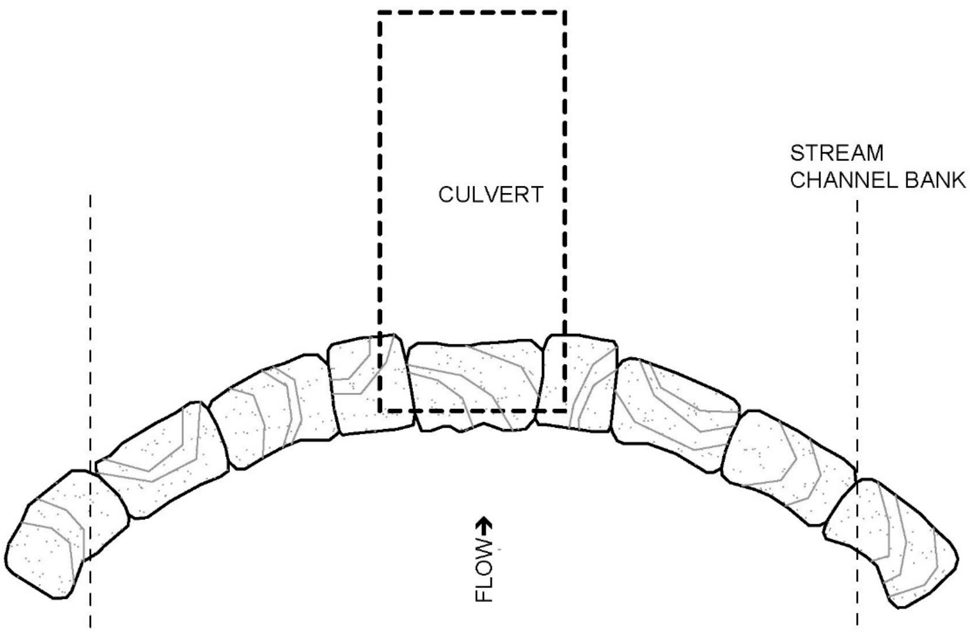


Figure 14.15 - Culvert Headwall

CULVERT HEADWALL

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After the headwalls are completed, the culvert is backfilled with soil. Fill should be free of large or sharp rocks or wood that could puncture or deform the culvert, or interfere with a tight seal between the backfill and the culvert. If a mechanical compactor is used, place and compact backfill material in maximum 6-inch lifts. If the use of a mechanical compactor is prohibited, the backfill material is placed in maximum 3 inch lifts. A hand tamper and the flat end of a digging bar are used to achieve the greatest compaction. Compaction can also be improved by using moist backfill soil. Care is taken not to disturb or compromise the headwalls while compaction is occurring. The backfill material is installed in lifts until it covers the top of the culvert by a minimum of 4 inches. Once the culvert is covered, coarse backfill material is used until the final trail grade is achieved. At final grade, the culvert should be covered with a minimum of 8 inches of soil.

Following curvilinear alignment, the completed watercourse crossing pulls into the watercourse, dips down to the center of the culvert, and climbs out of the crossing. This layout ensures that if the culvert fails, the water will not leave its natural channel and flow down the trail in either direction.

14.7.6. Culvert Dissipater

When a new culvert discharges into an unstable stream channel, an energy dissipater is required to prevent scour at the outlet. The dissipater is constructed into the streambed so that the top center is at stream level. Energy dissipaters should have a concave cross section and not displace the active stream channel. This design prevents the culvert discharge from scouring adjacent streambanks. (See Figure 14.16.)

14.7.7. Ditch Relief Culverts

A ditch relief culvert drains water from an inboard ditch. The culvert passes diagonally under the trail, discharging the water below the outboard hinge of the trail. Inboard ditches are used when collecting low volume discharge emanating from a cut bank over a wide area. With the exceptions discussed below, installing a ditch relief culvert is the same as installing a culvert in a stream channel. However, without a channel to guide the placement of these culverts, they are placed using the following criteria:

- Size and place along a ditch frequently enough to relieve maximum runoff associated with the inboard ditch.
- Place where the downhill slope is stable enough to receive water discharged from the culvert or where a small watercourse already exists.

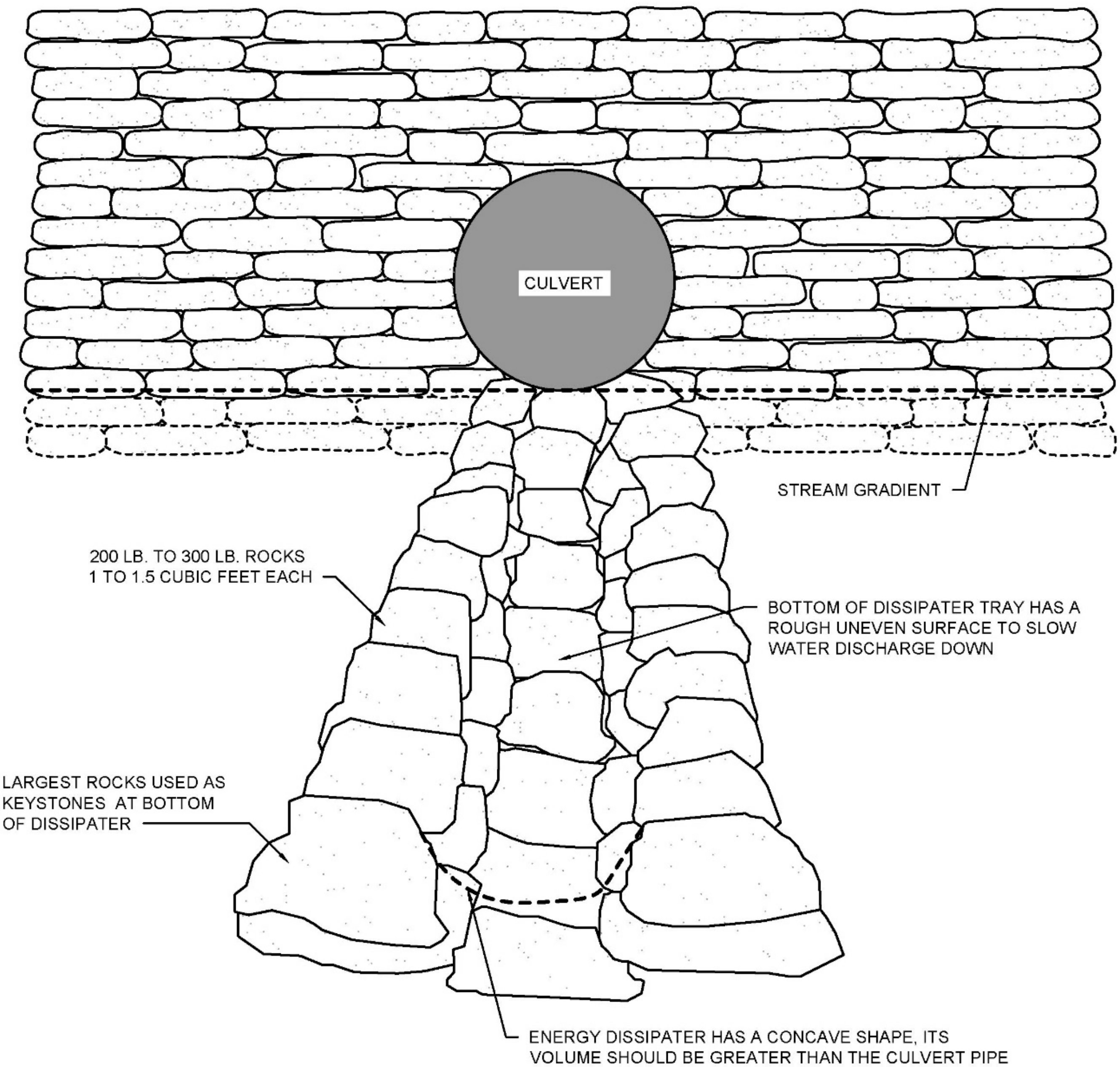

Figure 14.16 - Culvert Outlet with Dissipater

CULVERT OUTLET WITH DISSIPATER

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NOT TO SCALE

The frequency of placement along a ditch is based on, but not limited to, annual rainfall, rainfall intensity, landform coefficient of runoff, area (watershed) above the ditch, and the amount of shallow subsurface water intercepted by the ditch. The quantity of runoff is difficult to predict, even with the best hydrologic models. On-site field observation over an extended period of time is the best way to determine the size and frequency of ditch relief culverts. When constructing a new trail, this opportunity does not exist, and the designer must rely on available data. In the absence of sufficient hydrological data or field observations, placement of relief culverts should occur only where low flows are anticipated.

The best location to place a relief culvert is where a watercourse, such as a small crenulation or a drain swale, already exists. These topographic features have already been identified and designed into the trail drainage system. However, the designer can choose to use a culvert instead of a drain swale or armored swale if they know a culvert better fits the trail user type and trail tread drainage design. In the absence of a natural topographic watercourse, the water is discharged onto the slope below the trail. Collecting and draining water onto a slope where it has not been before will cause problems. Concentrated water flow can begin to erode the hillslope and establish a new watercourse. This process can trigger debris flows or landslides, if the slopes are not stable. In addition, it is likely that soil will be eroded and mobilized, and sediment delivered to natural watercourses lower in the watershed.

To minimize these effects, ditch relief culverts (in the absence of natural watercourse features) are located where the parent material below the trail is most resistant to erosion, such as a rock outcropping, slope with dense ground cover or well-developed root system, or a slope with a rocky soil matrix, especially if the soil has a fair amount of clay. In addition, ditch relief culverts must have an energy dissipater to absorb and reduce the erosive power of discharged water.

If a relief culvert is used to drain an inboard ditch, it is installed at an angle of 30 to 45 degrees from the trail alignment when the ditch is parallel to the trail alignment. This angle is necessary to direct the flow of water into the culvert from the inboard ditch. When water is turned at an angle perpendicular to its flow, the bank absorbs much of the water's energy. (See Figure 14.17.) This collision slows the flow of water into the culvert, causing sediment to drop out of suspension and reducing the velocity of water in the culvert. Culverts installed at the 30- to 45-degree angle turn the water without a major reduction in velocity, and, as a result, are more efficient at transporting water and its associated sediment and debris.

If a relief culvert is not placed at a natural watercourse, the gradient is determined by the gradient of the inboard ditch. To maintain a constant flow velocity, the gradient of the relief culvert should be approximately 3% to 5% more than the gradient of the inboard ditch. (See Figure 14.17.)

A relief culvert must have a headwall and energy dissipater. A headwall is constructed in the same manner as previously discussed, except that the inlet headwall is shaped in a sweeping arch. When the ditch water comes into contact with the culvert, the water turns gradually. The leading edge of the headwall is wider than the mouth of the culvert and gradually tapers down to make a tight seal around the mouth. Again, the headwall is funneling the water into the mouth of the culvert. (See Figure 14.18.) The energy dissipater is also constructed in the same manner previously discussed, except it is shaped like a basin. The basin must be large enough to contain the culvert discharge without splashing onto surrounding slopes. At the outlet of the basin, a rock-lined channel is constructed to direct the water down slope and further dissipate its energy. The channel is constructed at the same gradient as the hillslope and must be concave, wide enough to contain the water discharged from the culvert, have a rough, irregular surface to further slow the water, and be a minimum of 10 feet long. (See Figure 14.17.)

Relief culverts should be covered with a minimum of 8 inches of soil. The tread elevation above the culvert should be lower than that of the approaching trail grades. This elevation difference creates a dip in the trail where the culvert is located, so that if the culvert ever plugs or is overwhelmed, ditch water will flow across the trail at the same location as the culvert and off the trail onto the energy dissipater and rock channel below. (See Figure 14.17.)

14.8. Step Stone Crossings

Step stones are drainage crossing structures used on low volume streams or chronically wet areas where standing water is present. (See Photo 14.14.) The crossing location is a minor control point and must be identified during layout and design. Some important criteria to consider when deciding to use a step stone crossing include:

- The stream should have a relatively low volume and velocity so the step stones will not be inundated, washed downstream, or chronically wet and, therefore, hazardous.
- The stream crossing site should have a straight channel and low banks, so during a peak runoff event the stream can overflow its banks without undermining or eroding them.
- The site should have a nick point to provide a stable streambed so the bed load movement will not undermine the step stones. (See Photo 14.14.)
- The site should be a location in the channel that is wider than average for the stream and the gradient is low so the velocity and streambed scour are minimal.

Using step stones in an active stream requires careful evaluation of the stream. If the conditions listed above are not present, the step stones will be hazardous, washed away, or undermined. There is also the chance that the step stones will displace too much of the stream channel volume, which can create lateral scour during peak flow events. (See Figure 14.19.) Placing step stones in standing water is less problematic, but these areas are often habitat for sensitive plant and animal species.

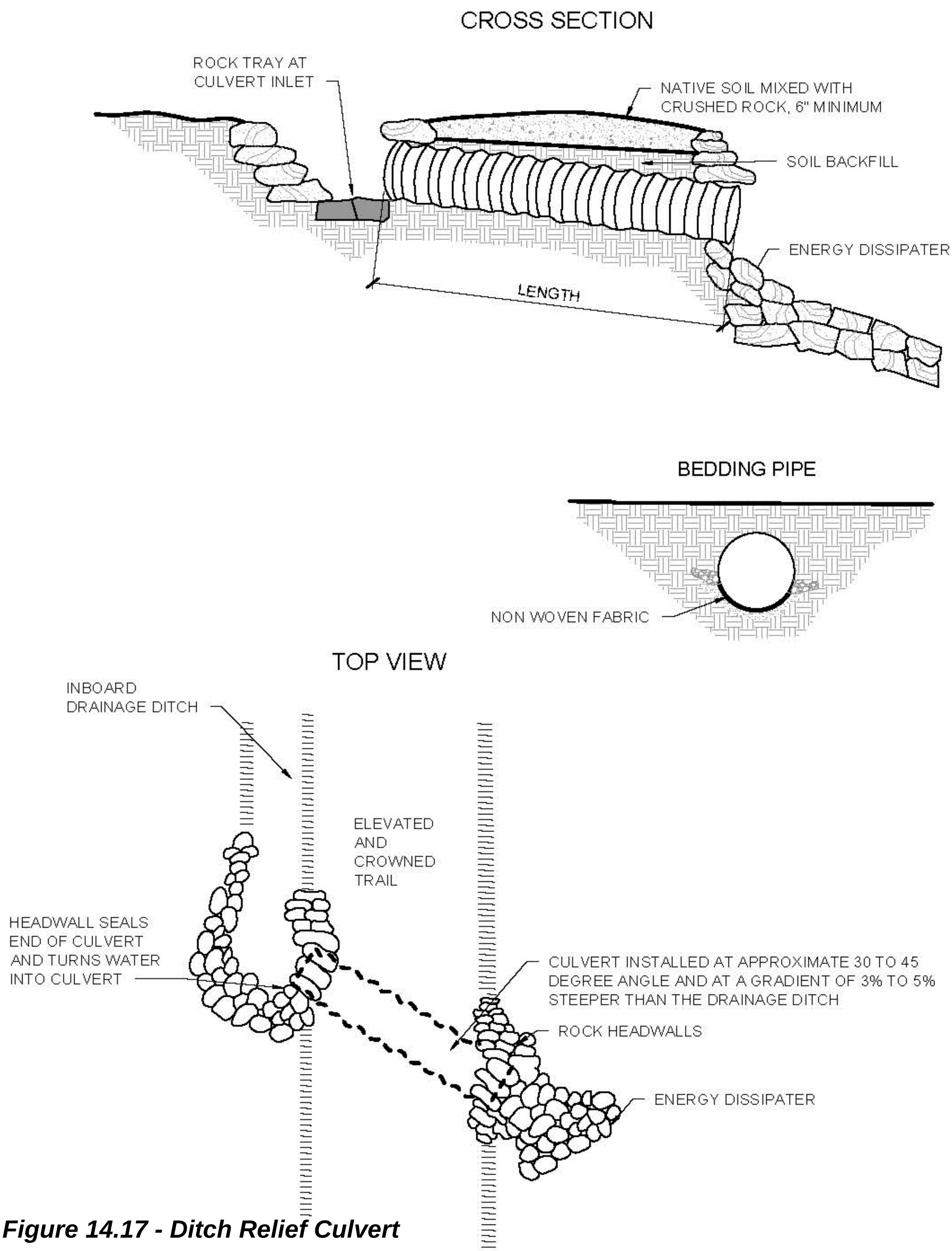

Figure 14.17 - Ditch Relief Culvert

DITCH RELIEF CULVERT

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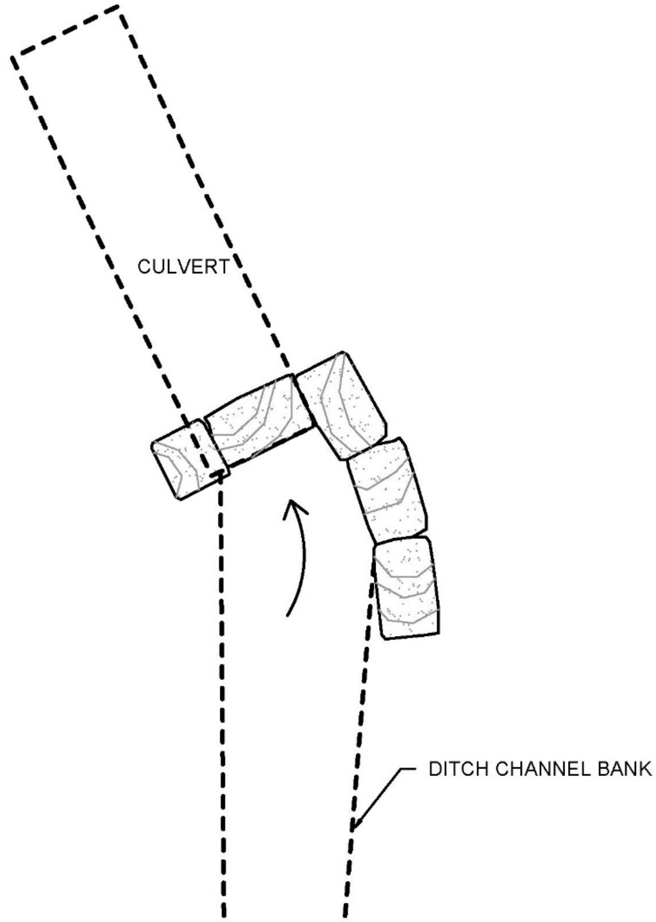
NOT TO SCALE

PLAN VIEW



CROSS DRAIN CULVERT HEADWALL END VIEW

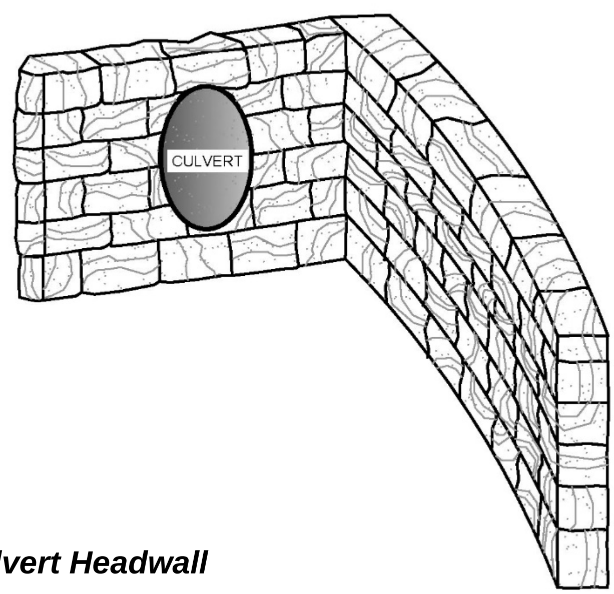


Figure 14.18 - Ditch Relief Culvert Headwall

DITCH RELIEF CULVERT HEADWALL

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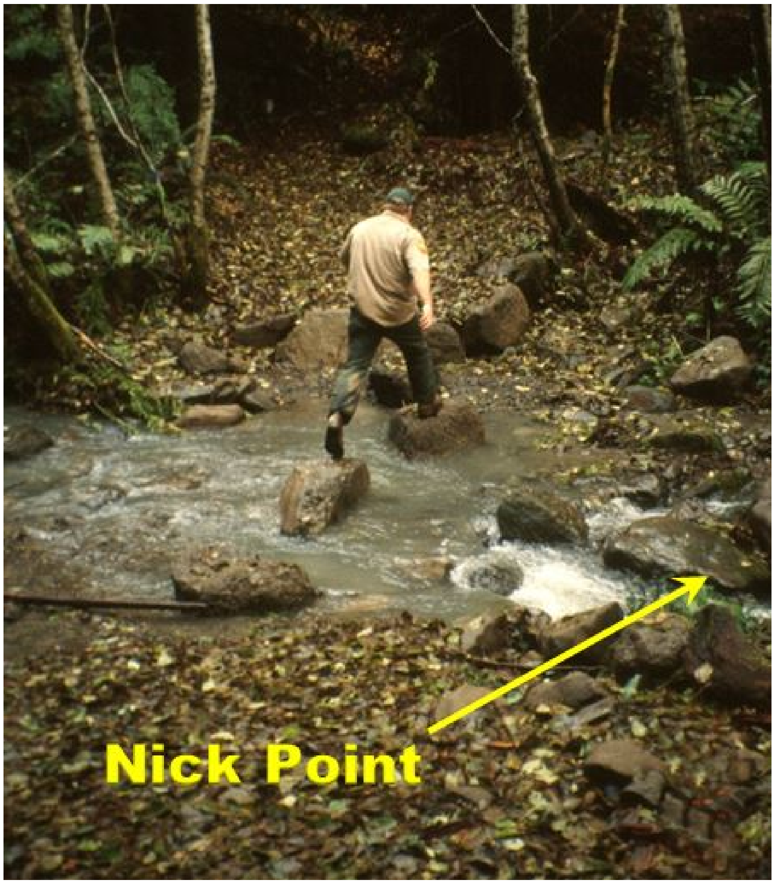

Photo 14.14 - Step Stone Crossing

Installation of step stones is performed during low flow periods in perennial streams and during dry periods in ephemeral streams. Local native stone found near the crossing site or unearthed in adjacent trail tread excavation can be the source of step stone material. (See Chapter 13, *Retaining Structures.)* The step stone must be large enough that one-third of its mass is below the streambed and it projects well above the highest stream flow anticipated during the time when the trail is used. It also must be large enough to support the weight of the heaviest hiker without tipping or rocking. The exposed surface should be relatively flat and large enough for hikers to place both feet. The surface should have some roughness, so that the hiker has good traction.

When installing a step stone crossing, layout must be performed to ensure that the stones have the proper spacing and take up the least amount of stream channel volume. The initial stones are placed at the edge of the streambank, allowing hikers to step on or off the rocks without breaking down and eroding fragile banks. The excavated footing is a minimum of 1 foot below the thalweg of the stream channel, so steps will not be undermined by future stream channel adjustments. The stones in the channel should be spaced a maximum of 3 feet apart so hikers can comfortably step from one rock to the next. Placing the stones too close together can make the crossing structure take up too much of the stream channel volume, resulting in lateral scour during peak runoff. (See Figure 14.19.)

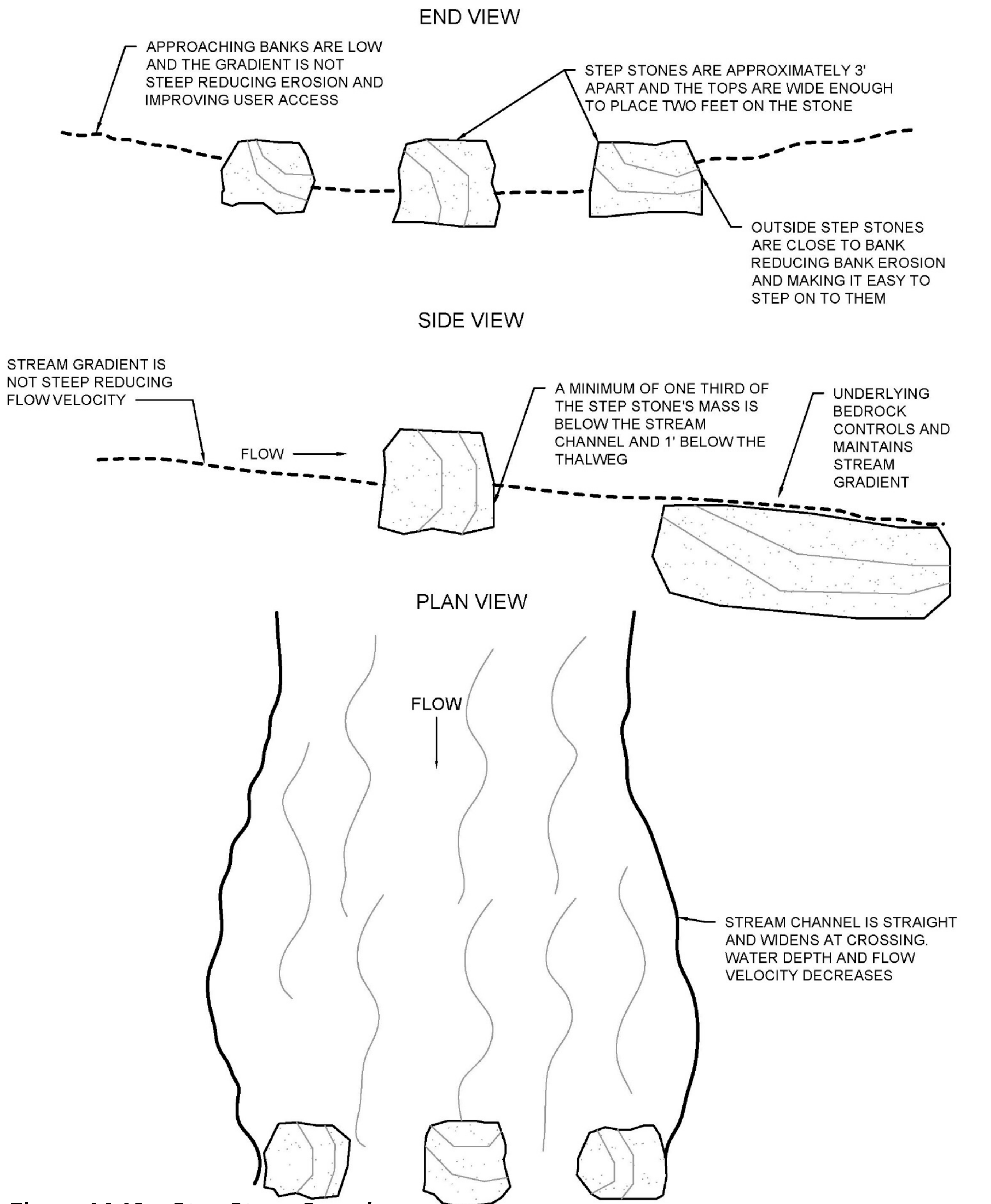

Figure 14.19 – Step Stone Crossing

STEP STONE CROSSING

CALIFORNIA STATE PARKS

NOT TO SCALE

The footing is excavated using hand tools such as rock bars, shovels, and picks. Five-gallon buckets are useful for transporting streambed aggregate out of the channel and into wheelbarrows or totes. Again, all excavated gravel and soil is exported out of the influence of the watercourse. Given the depth that the rocks are set into the streambed, the need for them to project above the high water level and the surface area necessary for secure footing, the stones must have substantial weight. Set the stones into the footings by rolling them (piss-anting or using rock bars for levers) into position, or with a skyline over the crossing, lowering the stones with a hoist. The rigging method is the safest and easiest, and has the least impact on the stream environment. Stones selected for the steps must have greater mass toward the bottom to provide a low center of gravity and greater stability. Once placed, the top of the stones should be level for easier and safer use by hikers. (See Figure 14.19.)

Step stone crossings are limited to pedestrian trails in backcountry and wilderness settings where visitor use is low. Trail users with mobility or visual impairments typically cannot use these structures. Equestrians cannot use these structures unless combined with a ford crossing (see below). Mountain bikers can use step stones but they must carry their bikes across, which is possible but not very practical.

Site requirements are the biggest limiting factor for using a step stone crossing. Finding a stream crossing location that meets all of the criteria listed above is difficult. Installing step stones in a stream channel will alter the stream morphology, and can adversely affect the stream and its corresponding watershed. This type of crossing also triggers additional control agency consultations and permitting. Altering the stream morphology should not be attempted without consulting a qualified hydrologist or an engineering geologist.

14.9. Fords

Fords are primarily intended for use by horses. They are located on streams that have low to moderate flows and are closed when high flows occur during the winter and early spring. (See Photo 14.15.) Sometimes a ford is located adjacent to a bridge crossing because equestrians often prefer using a ford. Like most watercourse crossings, fords are a control point. Depending on the circumstances, a ford can be a major or a minor control point. When designing fords into a trail alignment, select a location where the natural stream morphology provides a suitable ford rather than manipulating the stream to provide the requisite conditions.

Photo 14.15 - Ford Crossing

Good locations for fords are where the stream gradient levels off after a steep run and the channel is wide. The leveling off of the stream gradient causes small rocks and coarse aggregate to drop out of suspension and deposit on the streambed, creating a streambed that is uniformly comprised of smaller rocks and gravel, which is easy for horses to walk across. Large, smooth boulders or flat, smooth sloping rocks with voids are treacherous for horse and rider. Where the channel is wider, the water depth is lower and leveling off the stream gradient reduces the water velocity. There is usually a hardened nick point that stabilizes and controls the streambed gradient at the bottom end of these low gradient sections. These points are critical to the long-term stability of the ford crossing. Streambanks must also be stable and have moderate slopes for the construction of the trail in and out of the channel. The combination of these geomorphic and hydrologic characteristics provides a safer and more sustainable ford crossing. (See Figure 14.20.)

Sometimes it is not possible to find a site that provides all of the conditions listed above, especially in a streambed comprised of small rocks and aggregate. In these cases, it may be necessary to alter the streambed. One possible alteration is to construct a step stone crossing just below a potential ford. The site conditions for a step stone crossing and a ford are nearly identical, so combining these two crossings is logical. Also, since step stone crossings are not suitable for horses, and fords are not suitable for hikers, combining the two designs accommodates both user groups. Installing step stones just below the desired ford slows the stream current so that small rocks and aggregate fall out of suspension and are deposited on the streambed above the step stones, which provides a safer and more desirable crossing for equestrians. (See Figure 14.21.)

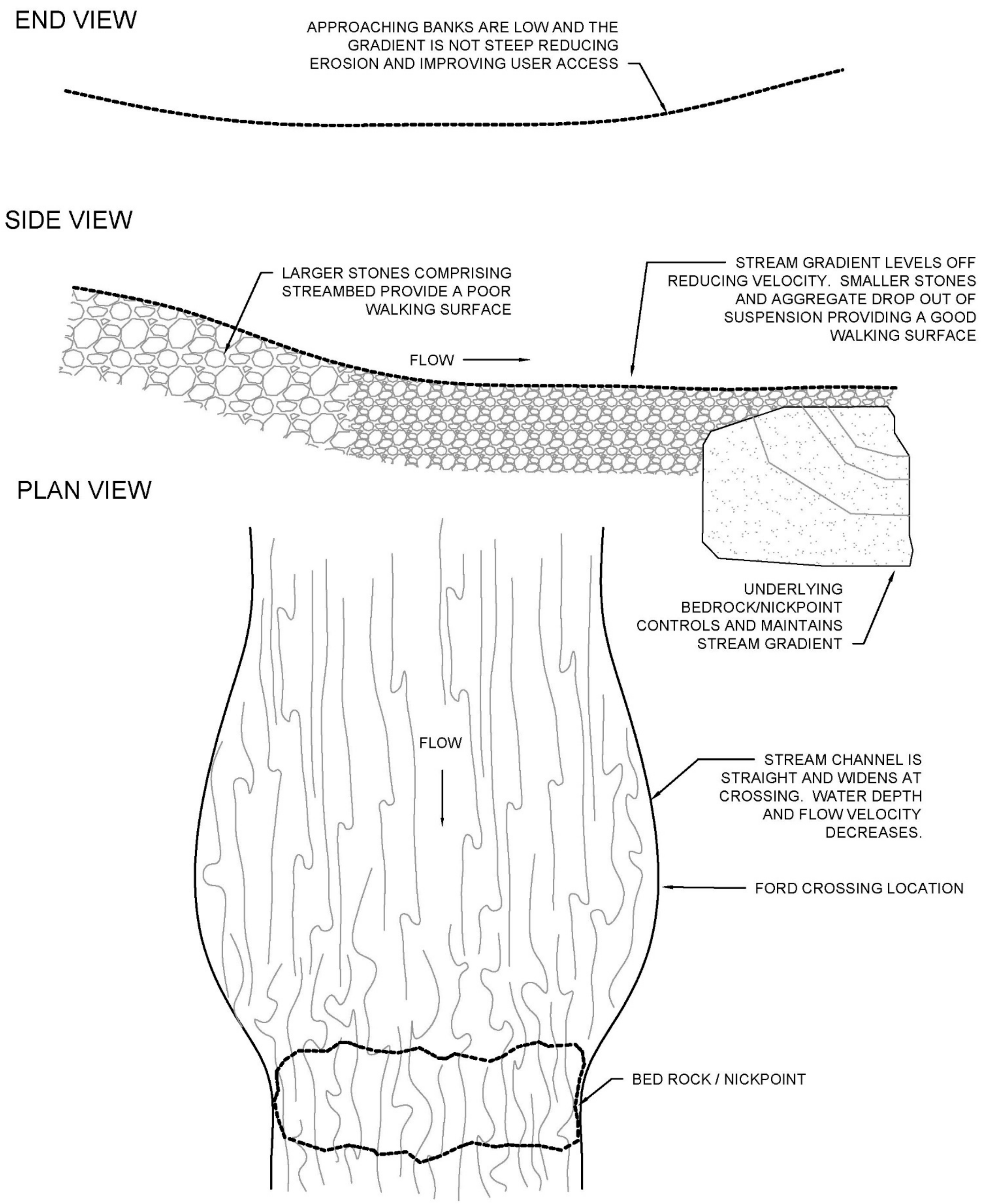

Figure 14.20 - Ford Crossing

FORD CROSSING

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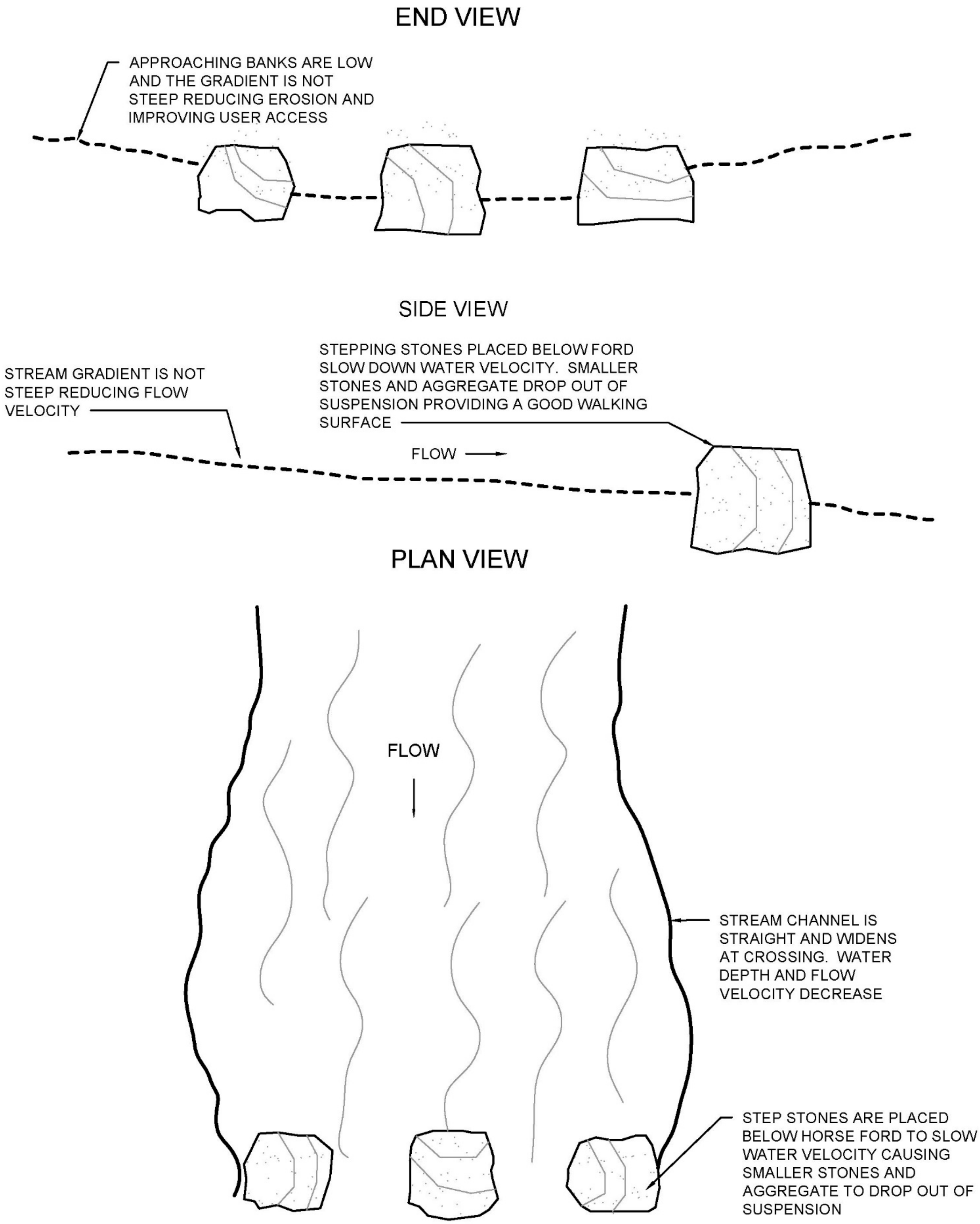

Figure 14.21 - Ford Crossing with Step Stones

FORD CROSSING WITH STEPPING STONES

CALIFORNIA STATE PARKS

NOT TO SCALE

Fords are limited to equestrian use in backcountry and wilderness settings where visitor use is low. Trail users with mobility or visual impairments cannot use these structures. Other pedestrians cannot use them without wading through water. However, both equestrians and hikers are accommodated when fords are combined with a step stone crossing. Mountain bikers can use the ford but must wade across the stream channel while carrying their bikes, which, again, is possible but not practical. Improving the ford conditions by altering the stream morphology can adversely affect the stream and thus the watershed. These modifications also trigger additional control agency consultations and permits. Altering stream morphology should not be attempted without consulting a qualified hydrologist or an engineering geologist.

14.10. Drain Lenses

14.10.1. Applications

Occasionally, a trail bisects an ephemeral spring or seep. If not accounted for, these low volume flows can saturate the base soil and create a muddy, unstable trail bed. A simple and effective solution is to install a rock drain lens. (See Photo 14.16.) The lens carries water under the trail surface, while maintaining surface flow characteristics.

The use of a drain lens for crossing ephemeral springs or seeps is restricted to low flow seeps with a narrow discharge. High volume springs or springs that cover a broad area are better served by other drainage structures, such as inboard ditches, culverts, or armored drain swales. A drain lens can also be installed in a turnpike or causeway to provide cross drainage when low flows are anticipated. When properly prescribed and installed, a drain lens is excellent for conducting water through the trail, keeping the trail tread dry and stable, and helping to maintain linear grades. For these reasons, it is a very useful drainage structure on Class I trails.

Installation begins with excavation of the trail bed to the depth of the saturated soil and beyond the trail bed width into the back slope and slope below the outboard hinge. (See Figure 14.22.) The amount of area being drained will determine the length of excavation needed. Usually, a lens is applied where the seep is confined to a single source that is less than 30 feet in length. Larger and multiple seeps longer than 30 feet are better drained by an inboard ditch and relief culvert. (See the section “Ditch Relief Culverts”.) Prior to installing the drain lens, a layer of non-woven geotextile fabric is placed over the native soil and under the first layer of drain lens rock to create a stable base for the lens and keep the rock from sinking and becoming plugged by soil infiltration from beneath. After the fabric is in place, the excavation is filled with large angular quarry rock. The bottom course of rocks consists of the largest quarry rock (usually 10 to 14 inches), with each successive layer comprised of smaller rocks. Rock is laid point to point, so that voids are left for water to pass through. Uphill and downhill sides of the lens have a maximum inward batter of 45 degrees or approximately 1 foot horizontal for every 1 foot of vertical.

Photo 14.16 - Drain Lens

As additional layers of rock are added, the rock size is gradually reduced. Care is taken to maintain voids at the bottom and gradually close the voids as the lens is built up. The trail tread surface is applied when the voids are closed. Tread surface is a minimum of 4 inches thick and compacted. If native soil is unavailable or unsuitable, imported material may be used. In applying the tread, make sure the material will not filter down and clog the rock lens. If voids cannot be closed with rock, lay another layer of woven geotextile fabric under the tread material. The fabric should not extend to the edge of the trail bed, but instead should be no closer than six inches from the edge. Tread material should be 8 inches deep if an upper layer of fabric is employed. The objective is to provide surface sustainability and avoid surface erosion that may cause the fabric to be exposed. (See Figure 14.22.)

14.10.2. <u>Drain Lens with a Culvert</u>

In certain conditions, the effectiveness of a drain lens can be improved by adding a culvert. (See Photo 14.17.) A culvert is necessary when there is a periodic increase in water flow that exceeds the capacity of the lens. A culvert may also be required when the soil encountered during excavation is high in organics and has poor cohesion. This soil is often very mobile and can migrate into the rock lens, restricting the flow of water. Adding a culvert increases the drainage capacity of the lens.

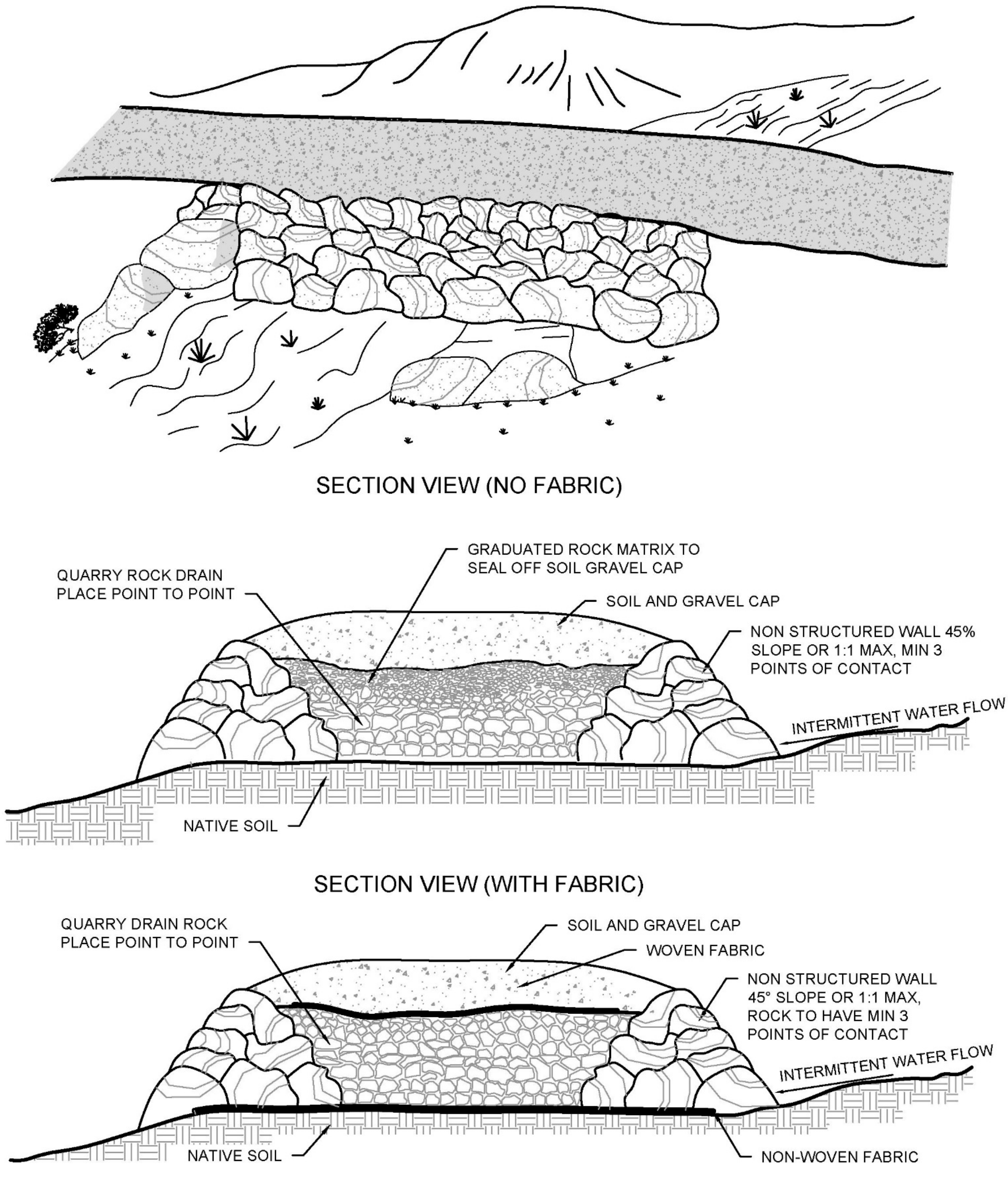

Figure 14.22 - Drain Lens

DRAIN LENS

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Depending on the size of the drain lens and the site conditions, one or more culverts may be required. Culverts are sized and installed similar to ditch relief culverts, except that the backfill material around the culvert is comprised of the rock lens instead of soil. To protect the culvert (especially an ABS culvert) from sharp rock faces, the culvert is wrapped with geotextile fabric when installed. (See Figure 14.23.)

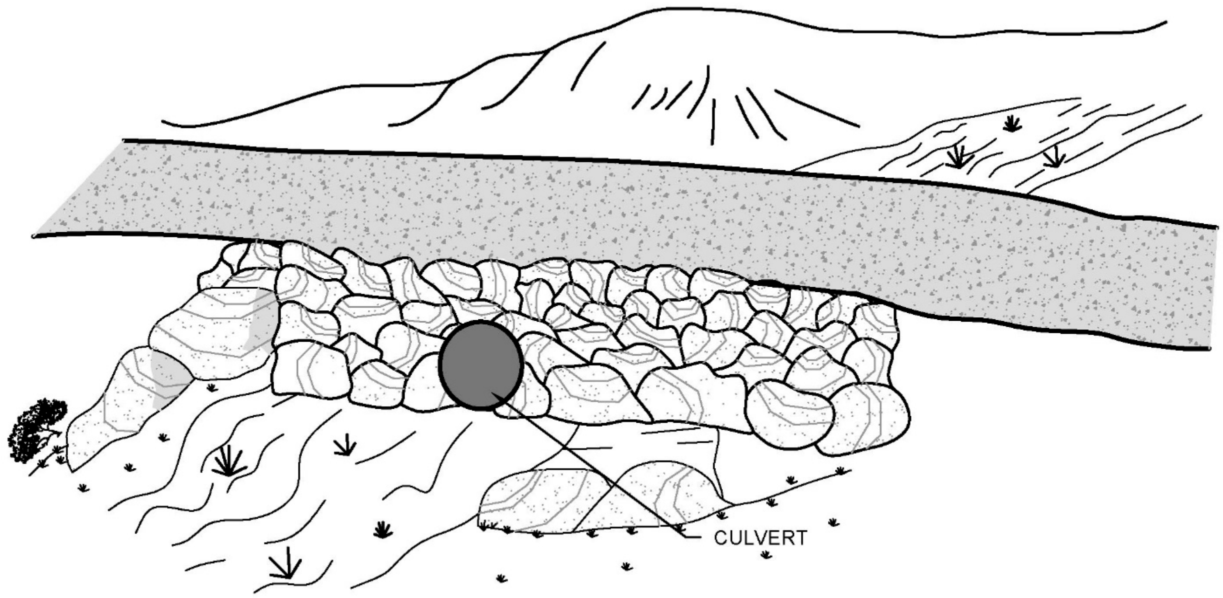
Photo 14.17 - Drain Lens with Culvert

14.11. Other Trail Drainage Structures

14.11.1. <u>Applications</u>

In some situations, trails are located in flat low-lying areas where drainage is inherently poor, such as river terraces, stream valleys, and meadows. When realignment of the trail is not a suitable alternative, raising the elevation of the trail is an option. While elevated trails are not drainage structures, they do provide a solution to crossing a poorly drained area, especially when combined with other drainage structures.

Turnpikes and causeways can improve trail tread in flat areas that have weak soil and/or are poorly drained. They are applicable in frontcountry and backcountry settings and are a good design tool for meeting accessibility standards and protecting resources. These structures should not be used where there is standing water for long periods of time or where site conditions meet the criteria for a wetland. In those locations, less intrusive structures such as puncheons and boardwalks are more suitable. (See Chapter 15, *Timber Planking, Puncheon, and Boardwalk Structures.*)



SECTION VIEW

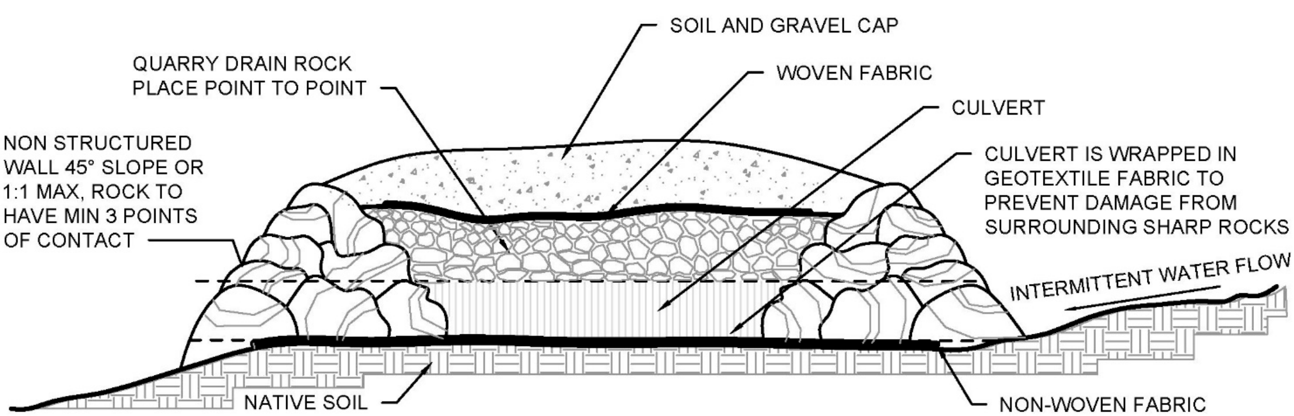


Figure 14.23 - Drain Lens with Culvert

DRAIN LENS WITH CULVERT

CALIFORNIA STATE PARKS

NOT TO SCALE

Other drainage features can be incorporated into turnpikes and causeways to help facilitate water flowing under, through, or across the trail. Make sure that the turnpike or causeway does not become a dam. If there is a potential for water to pond, the trail designer must thoroughly evaluate the land being traversed. Flat areas often have subtle depressions where water will flow to or through. These areas can be detected during large storm events. If field observation of water flow is not possible, a survey instrument such as a builder’s level, transit, or total station is used to locate low areas by shooting cross sectional elevations where the structure will be. Armored drain swales, open culverts, closed culverts, or drain lenses can be incorporated into the turnpike or causeway. Ditches can be added to accumulate and drain water to a drainage structure. These structures are installed as previously discussed.

14.11.2. Turnpikes

Turnpikes harden the trail by raising the tread surface above the soil that is subject to saturation, pumping, and deformation. (See Photos 14.18.) Turnpikes are preferable to puncheons or boardwalks due to their durability and lower long-term maintenance costs.

Photo 14.18 - Log Turnpike (left), Lumber Turnpike (right)

Turnpikes are constructed either without or with walls. A turnpike without walls or supportive sides (“wall-less”) is installed in the same manner as when hardening the trail tread with aggregate surfacing. (See Chapter 11, *Principles of Trail Construction.*) This treatment is most applicable when raising the tread level 12 inches or less with trail material that is cohesive and able to retain a solid edge on its own. If additional elevation is required, log walls are installed to frame and support the tread. A wall-less turnpike is best for locations with a vegetative canopy and air/soil moisture sufficient to maintain a compact surface (e.g., redwood forest or foggy coastal terrace). In dry, arid locations, the soil or aggregate may lack sufficient soil moisture to maintain a cohesive bond.

A walled or log turnpike consists of curb logs placed parallel to the trail and filled with rock, gravel, or soil. For log walls, a trench is excavated to provide a footing for the wall to keep the logs from rolling and spreading apart when the fill material is installed. In addition, logs can be tied together with heavy gauge galvanized wire to prevent spreading. (See Figure 14.24.) If the turnpike is longer than one log, the logs are butted together. The ends of the logs are drilled and pinned with a length of rebar. (See Figure 14.24.) Once the log wall is installed, a layer of non-woven geotextile fabric is laid down between the log walls to support the fill material, when the parent soil is too weak to support the weight of fill and surfacing material. Backfill consists of rock or mineral soil, depending on local sources and the logistics needed to import material. This material is placed and compacted in lifts. When soil is used, the lifts should not exceed 3 inches in depth. Compacting is done with a gas powered plate compactor ("vibraplate") or manual tamper. The final surface is compacted and crowned with the prescribed slope to prevent water from accumulating on the trail. (See Figure 14.24.) Depending on the amount of rainfall and the surrounding soil conditions, water draining from the surface of the turnpike is absorbed in the surrounding terrain. If the surface runoff upslope of the turnpike is sufficient to pond water above the turnpike, the water is collected by parallel ditches and channeled to culverts that carry the flow under the turnpike to escapement ditches down slope. (See Figure 14.24.)

In the absence of suitable logs, dimensioned lumber can be used to frame in turnpike material. It is also used when constructing accessible trails when a more uniform linear grade, cross slope, and tread surface are required. The lumber needs to be a minimum dimension of 4 x 6 inches but 4 x 8 inches is preferable. The 4- x 8-inch lumber provides more height for the required footing and backfill material. Larger dimension lumber may be required when the trail tread needs additional elevation.

Rot-resistant wood, such as con heart redwood or cedar or pressure treated Douglas fir, should be used for this application. Non-structural plastic lumber can also be used. This material is more expensive but may have more longevity than wood products. Climatic conditions should be a factor when considering the use of plastic lumber. Plastic lumber expands in warm temperatures and contracts in cold temperatures, which means the boards can warp and twist when the ambient temperature varies significantly. In temperatures below freezing, plastic lumber can become brittle and subject to fracturing.

When storing plastic lumber, it should be stacked flat, banded tightly, and stored out of the sun. Once plastic lumber is unbanded, it should be used as soon as possible because it may warp once unrestrained. The use of plastic lumber in a turnpike will need to compensate for this potential for warping with larger dimension lumber and tighter spaced ground anchors than would be used with natural lumber. Joint overlaps should be properly sized and anchored to ensure the plastic lumber does not break at these joints.

The construction of a lumber turnpike is similar to a log turnpike. The footing for each wall is excavated into firm and stable soil. On an accessible trail, the depths of the footings are closely monitored to ensure that they are both at the appropriate linear grade and level to each other. In most applications, the lumber used is 12 feet in length unless the curvature of the trail requires a shorter length. When more than one piece of lumber is used, the lumber is joined with a 6-inch lap joint. (See Figure 14.25.) The lap joint is cut and pre-drilled for pinning prior to being laid in the footing. Note, to avoid drilling holes through the lumber while it is lying on the floor of the footing and potentially dulling the drill bit, all the lumber cribbing for one side of the wall and the lap joints are cut and pre-drilled for pinning prior to being set in the footing. Once placed into the footing, the ends of the lumber are pinned with 5/8-inch x 3-foot rebar. (See Figure 14.25.) The span between rebar pins is typically 4 feet but should not exceed 6 feet. Additional pinning will be required for longer lumber.

When installing lumber cribbing for accessible trails, it is often easier to install one side of the wall to the required standard first and then install the second wall so it matches the first. The use of an auto level, clinometer, stadia rod, and a carpenter's level makes this installation quick and easy.

The geotextile fabric (if required) and backfill material are installed in the same manner as for log turnpikes, however, given the lower height of lumber walls, it may be necessary to excavate some soil between the two walls to ensure that there is sufficient depth to receive the required backfill material. The trail tread is crowned to the appropriate specification and its final elevation must be higher than the lumber walls to allow for drainage.

To eliminate an abrupt drop-off on the outside edge of the lumber cribbing, soil generated from the footing excavation and from between the walls is placed and compacted along the outside edge of the walls. (See Figure 14.25.)

14.11.3. <u>Rock Causeways</u>

A rock causeway is the same as a log turnpike, except the fill material is contained by rock walls. (See Photo 14.19.) This structure is most suitable in rocky environments, where materials are plentiful and aesthetic compatibility can be maintained. When trails have been routed through meadows and multiple entrenched trails develop, causeways are used to consolidate these trails and provide one elevated trail with stable and firm tread. The abandoned trails are rehabilitated and returned to their natural state.

A causeway is built to be inconspicuous. It should be the minimum height and width necessary to bridge the problem area. The height is designed to provide a dry and stable hiking surface during the wettest conditions.

Construction of the causeway wall begins with excavation of the footing where the rock will be laid. The footing should extend into stable soil that is free of organics.

The causeway wall is laid with a near level and uniform surface. If the wall cannot be leveled due to site constraints, the first rock is laid at the lowest end of the wall. This first rock should be the largest available to serve as the keystone and buttress for the rest of the wall. The rock is laid so the most aesthetically pleasing face is to the outside.   (See Figure 14.26.)

Photo 14.19 - Rock Causeway

The inside face is not as important since it will be buried with crushed rock fill and mineral soil or aggregate surfacing. Note, when constructing a causeway on an accessible trail hardened with crushed rock, the inside face needs to be nearly vertical so the crushed rock will have an even and uniform depth and to prevent differential settling. A causeway wall is laid in the same manner as a single tiered rock wall. (See Chapter 13, *Retaining Structures.*) When complete, the wall is chinked with rock on the inside and outside before backfill material is installed.

Once the rock walls are installed, a layer of geotextile fabric is laid between them to support the fill material, if the parent soil is too weak to support the weight of fill and surfacing material. If rock is abundant, the causeway is filled initially with crushed rock a maximum of 4 inches in diameter. Rock can be crushed with 10 to 12 pound sledgehammers (“double jacks”) or hauled in, logistics permitting. A 5-pound mash hammer or a 4-pound hand sledge (“single jack”) is used to make small rocks for filling the voids between large rocks. Crushed fill is installed a minimum of 4 inches from the top of the rock walls. The final fill consists of mineral soil, aggregate, or a combination thereof to act as the trail surface. The final tread surface is compacted and crowned in the same fashion as for a turnpike. (Figures 14.26 and 14.27.)

When a causeway is used to cross an ephemeral flow, it may be necessary to incorporate additional drainage structures within the causeway structure. These structures help prevent the causeway from damming the ephemeral flow. Open step-through and closed culverts work well in this application. (See Figure 14.28.)

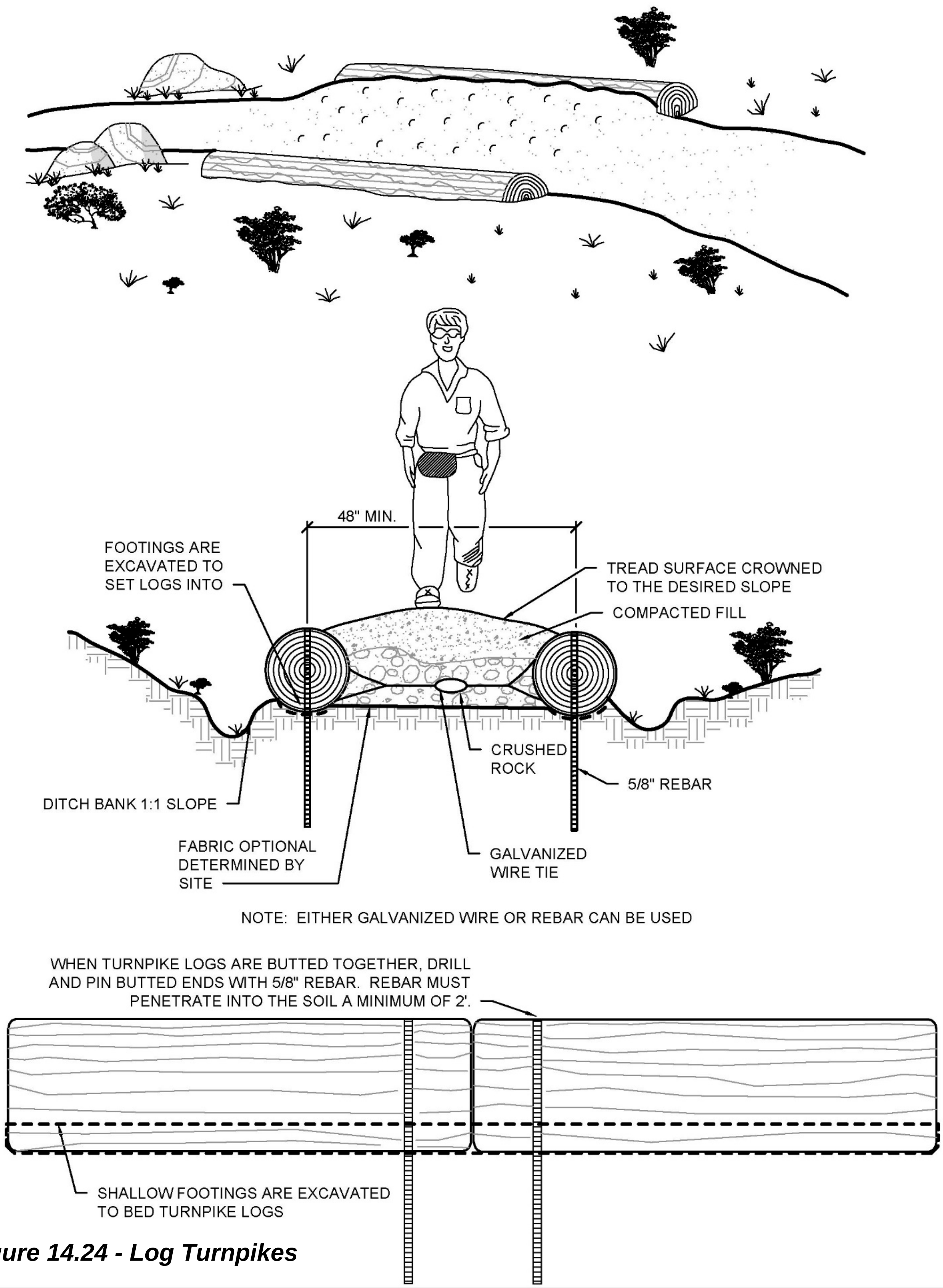


Figure 14.24 - Log Turnpikes

LOG TURNPIKES

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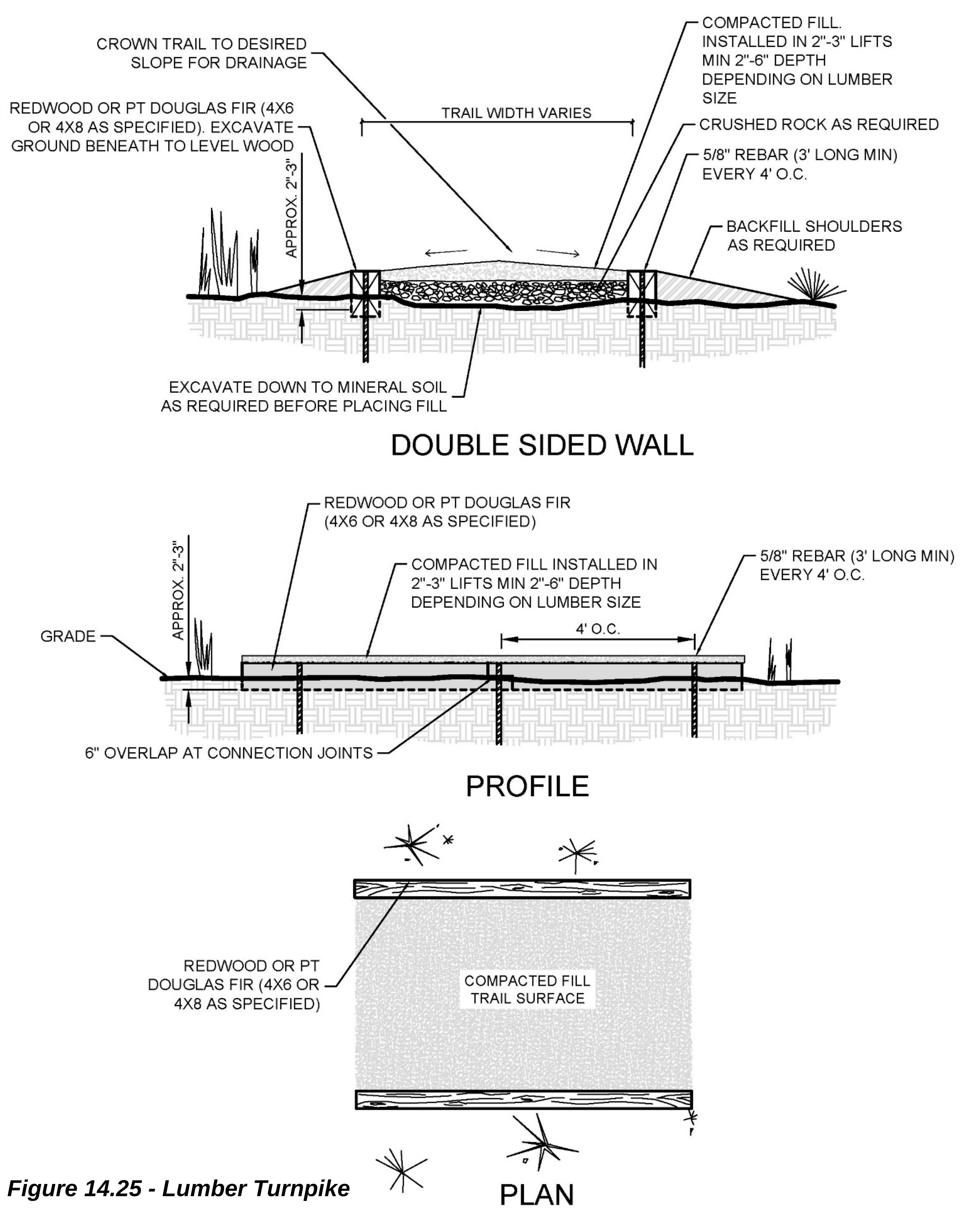

Figure 14.25 - Lumber Turnpike

LUMBER TURNPIKE

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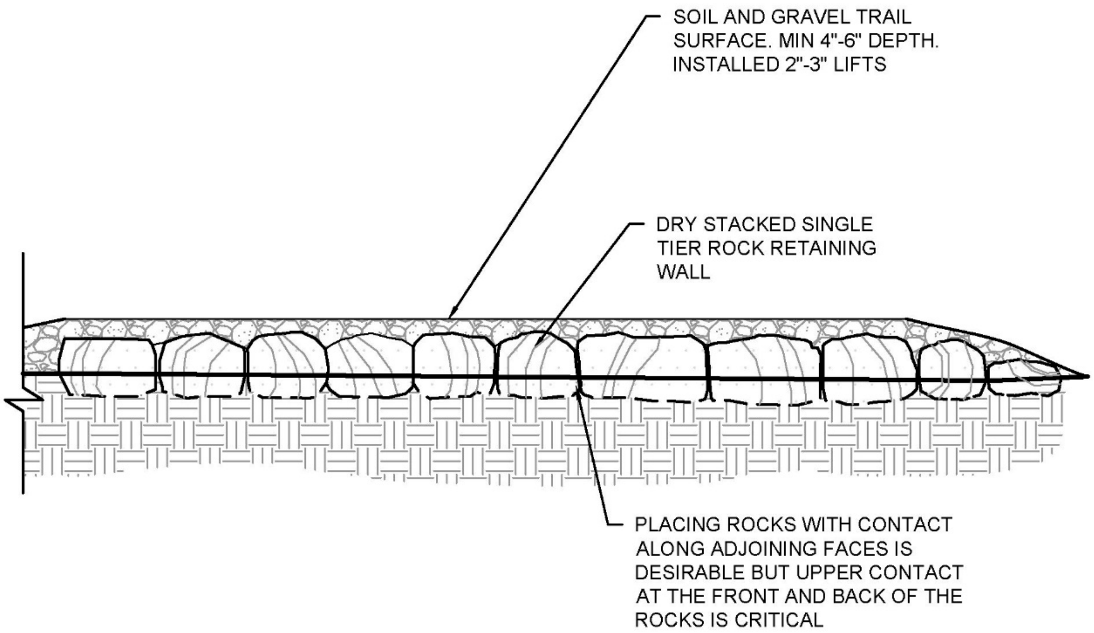

SIDE VIEW

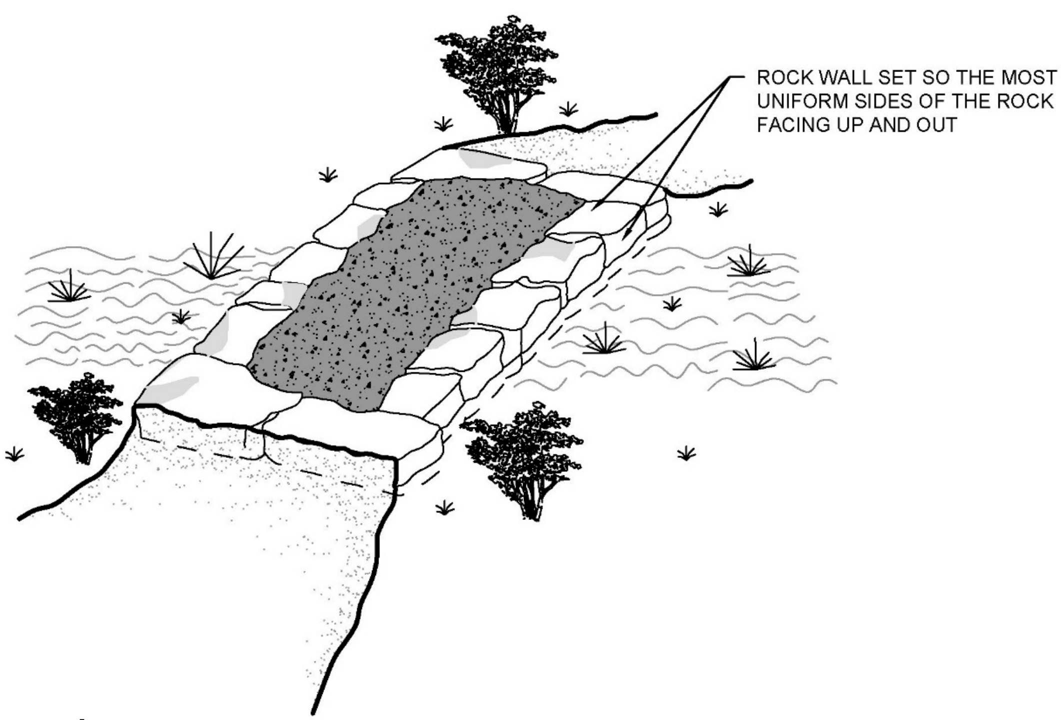

Figure 14.26 - Rock Causeway

ROCK CAUSEWAY
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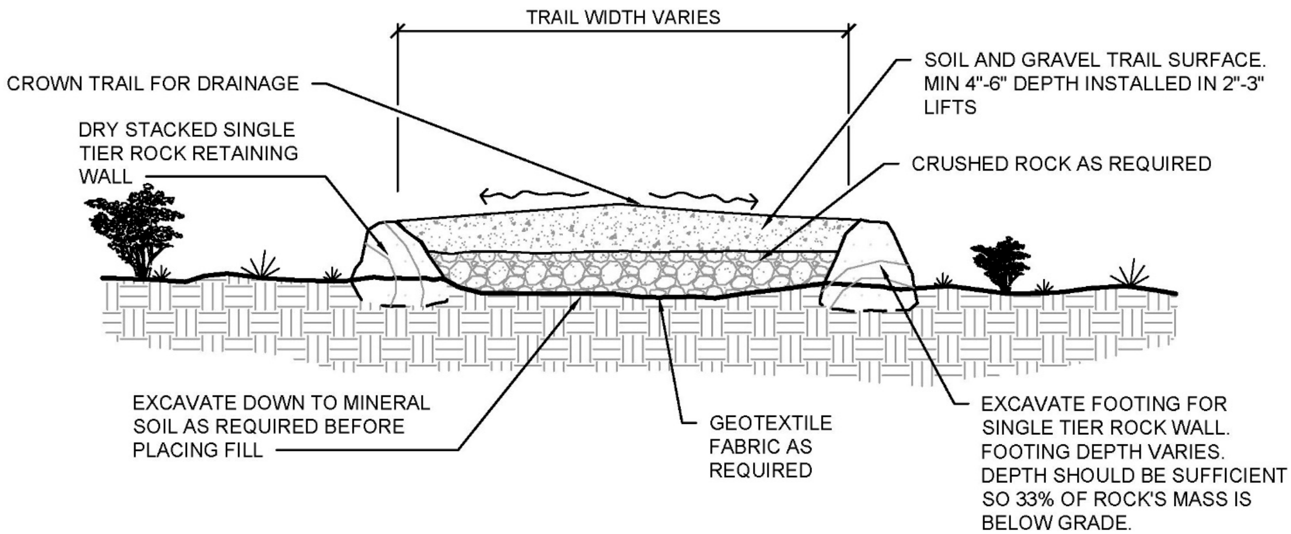
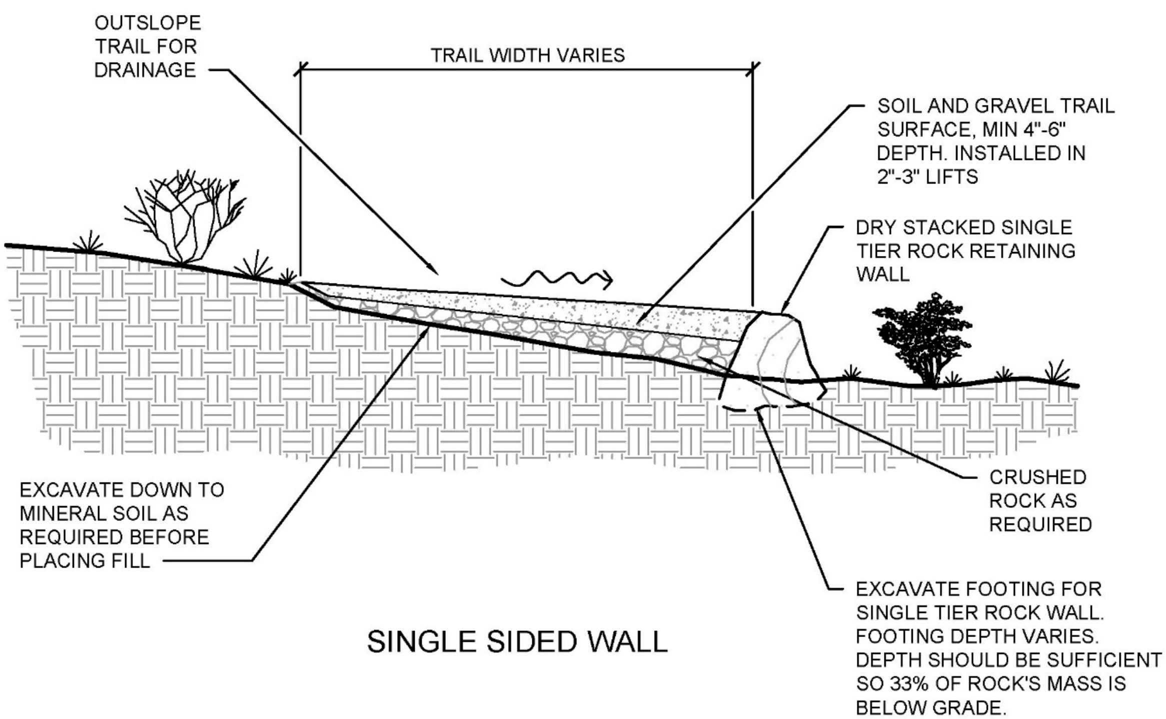


DOUBLE SIDED WALL



SINGLE SIDED WALL

SECTION

Figure 14.27 - Rock Causeway Continued

ROCK CAUSEWAY CONTINUED

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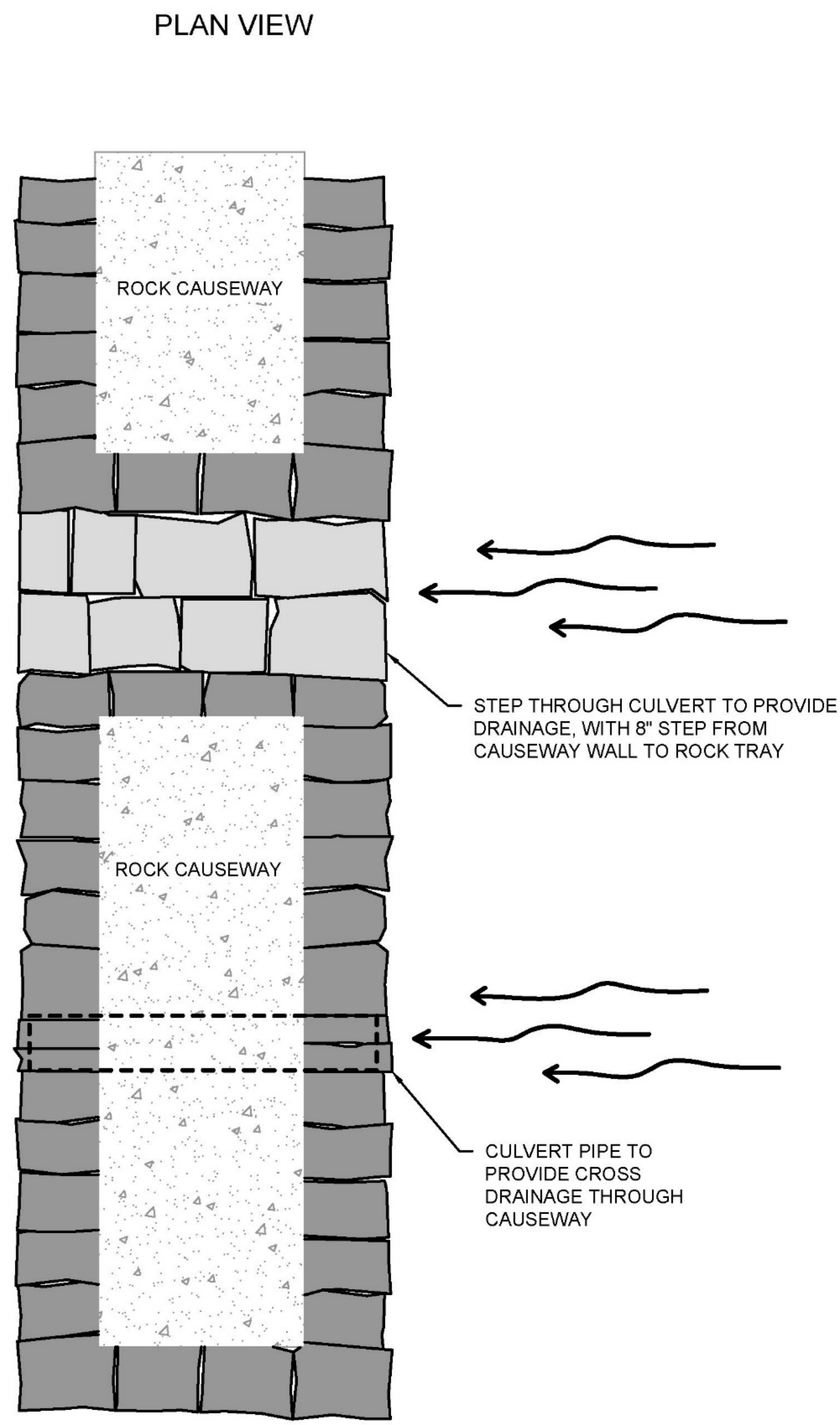

Figure 14.28 - Rock Causeway with Culvert

ROCK CAUSEWAY WITH CULVERT

CALIFORNIA STATE PARKS

NOT TO SCALE

When a causeway is constructed on sloping ground, a single wall is installed on the downhill side of the trail. The uphill side of the trail is graded to the elevation of the existing hillslope to prevent the causeway structure from damming overland sheet flow. (See Figure 14.27.)

14.12. Supplemental Drainage Structures

If a trail has been properly planned, designed, laid out, and constructed, the need for drain dips (grade reversals), rolling grade dips, and water bars should be minimal. Like inboard drainage ditches, these structures collect and concentrate overland sheet flow or shallow subsurface flow that is not associated with natural topographic watercourse. They have the potential to alter natural drainage patterns, which can lead to the coupling of watercourses, inter-basin water transfer, impacts to plant and animal communities, slope instability, soil erosion, and mass wasting.

Both water bars and drain dips collect water from the trail and divert it to the slope below. Thus, the trail becomes a conduit for water runoff. The theory is that if these structures are placed frequently enough, the water they collect is dispersed over a wide area in small concentrations. However, even when functioning properly, the trail is still being eroded, sheet flow and subsurface flow is being concentrated and diverted, and water in high volumes is drained onto slopes that have never received water of that magnitude.

14.12.1. Applications

A water bar has limited application on a new trail alignment that is planned, designed, and constructed to be sustainable. A water bar is applicable when an existing trail cannot be drained without it or when the trail is receiving such heavy mechanical wear that no other solution is viable. A backed water bar is appropriate on a heavily used equestrian trail, where it can serve as both a drainage structure and a step.

A drain dip (grade reversal) is appropriate to drain a spring that emanates from the cut bank and flows across the trail. A drain dip is also appropriate when the designer cannot avoid a long steep section of trail that is at or near the maximum sustainable grade. In this circumstance, the drain dip is installed as a back-up to outsloping of the trail tread and curvilinear design. A drain dip is also appropriate when the rate of mechanical wear exceeds the capability of sustainable trail design.

The use of water bars and drain dips should only be considered after determining that the sustainable trail design and construction practices identified in this handbook are insufficient. These solutions are “backed into” after all other sustainable options are considered. If used, the placement must be carefully chosen based on the site conditions and integrated with the sustainable design and construction concepts identified in this handbook. Using pre-determined intervals or overly simplistic formulas to determine the installation locations for these structures is a recipe for poor trail performance.

The use of rolling grade dips should be limited to trails with high mechanical wear or where the designed emphasis is the user's experience; not sustainability. If the land management agency provides the maintenance, reconstruction, and mitigation measures required for these types of structures, a rolling grade dip is a necessary and effective form of drainage control.

The only reasonable application for these structures is if: (1) they are used as back-up to an outsloped trail with an insufficient ratio of outslope to linear grade; (2) the linear grade is too close to the fall line; (3) the linear grade exceeds the maximum sustainable grade; or (4) the mechanical wear associated with the user group is more than the parent soil and outslope design can sustain. Some of these conditions can be avoided with proper trail planning, design, layout, and construction.

Unfortunately, many trails have the above characteristics that require use of these structures until the trail can be rerouted, reconstructed, or eliminated. In addition, the rate of mechanical wear associated with certain trail uses cannot be offset simply by using curvilinear alignment, staying within the maximum sustainable grade limit, employing full bench construction, providing sufficient outslope, and performing regular cyclical trail maintenance. In these cases, water bars and drain dips may help increase the maintainability of the trail.

14.12.2. Drain Dips

Drain dips (grade reversals) have been around as long as water bars, but until recently, their use has focused on draining seeps and springs that emanate from a cut bank and flow across the trail. For this purpose, they are very effective. They should not be confused with drainage structures that are located at topographic features such as drain swales or armored drain swales. Drain dips, on the other hand, are located along the trail between naturally occurring watercourse features. They require less maintenance than water bars and present less of a barrier to trail users, because they are more subtle and do not project above the trail tread. They have become popular as a simple solution to trail drainage design problems. Using drain dips in a similar fashion to water bars has proven effective for trail with high rates of mechanical wear, such as off road vehicle and downhill mountain bike trails.

The mountain bike community has popularized drain dips due to the undulating ride that it provides the biker. This roller coaster affect enhances the user's experience and, therefore, this structure has become a staple in mountain bike trail design. However, the use of drain dips alters and disrupts the natural drainage pattern of the landform. Land managers and trail designers need to recognize that these drainage structures can have adverse impacts. However, with certain trail uses, these structures may be necessary. (See Chapter 5*, Principles of Trail Layout and Design.*)

Drain dips are located where they will be most effective. Selection criteria are similar to those used to locate ditch relief culverts. Although the term “drain dip” has been around for many generations, these structures are now commonly called “grade reversals.” This name is apt as drain dips are a designed and constructed grade reversal in the trail alignment. The uphill side of the trail maintains the designed linear grade. At the upper end of the dip, the outslope begins to increase until it reaches the bottom of the dip. At the bottom of the dip, the outslope should be a minimum of one and half times the designed outslope of the trail segment. The dip is angled across the trail at approximately 30 to 45 degrees to turn the water off the trail and toward the outflow of the dip. Below the outflow, an energy dissipater is installed, as site conditions require, to slow and absorb the energy of the water. The energy dissipater is sized according to the volume of water generated by the drain dip.

From the dip the trail grade reverses and the trail begins to rise rather than descend. This rise in grade should not exceed the designed grade for the trail segment or the maximum sustainable grade. The outslope prescription for the reversal is also reversed since it begins at the minimum 1.5 times the designed outslope and ends at the top of the reversal at the designed outslope. The reversal side of the dip must be long enough that the transition in and out of the dip is gradual and not abrupt. The terrain and volume of water encountered determine the length and the degree of outslope in the dip. Steep terrain and high flows require longer drain dips with more outslope. Climbing out too rapidly over a short distance or with too much linear grade will result in substantial mechanical wear. (See Figure 14.29.)

When laying out and designing a drain dip, it is important to compensate for the loss of elevation associated with this structure. If the trail is climbing between two control points and a drain dip is located between those two points, the average linear grade between those control points will change. The reversal leg lowers the trail elevation and increases the linear grade from the bottom of the dip to the upper control point. This difference must be recognized when laying out and flagging the trail. The drain dip becomes a minor control point and the elevation is factored into the alignment. Otherwise the grade climbing out of the dip is likely to exceed the designed maximum linear grade. (See Figure 14.29.)

The increased grade becomes an issue when a drain dip is added to an existing trail, especially if the trail already has a steep linear grade. This situation often results in short reversal legs and an increased liner grade climbing out of the dip. The net result is a substantial increase in mechanical wear, trail saturation and deformation, and increased soil erosion. Careful evaluation of the current and potential linear grade, soil characteristics, location in the watershed, hillslope grade, rainfall, canopy cover, trail user group, and the amount of anticipated use must be performed when adding this structure to an existing trail. (See Figure 14.29.)

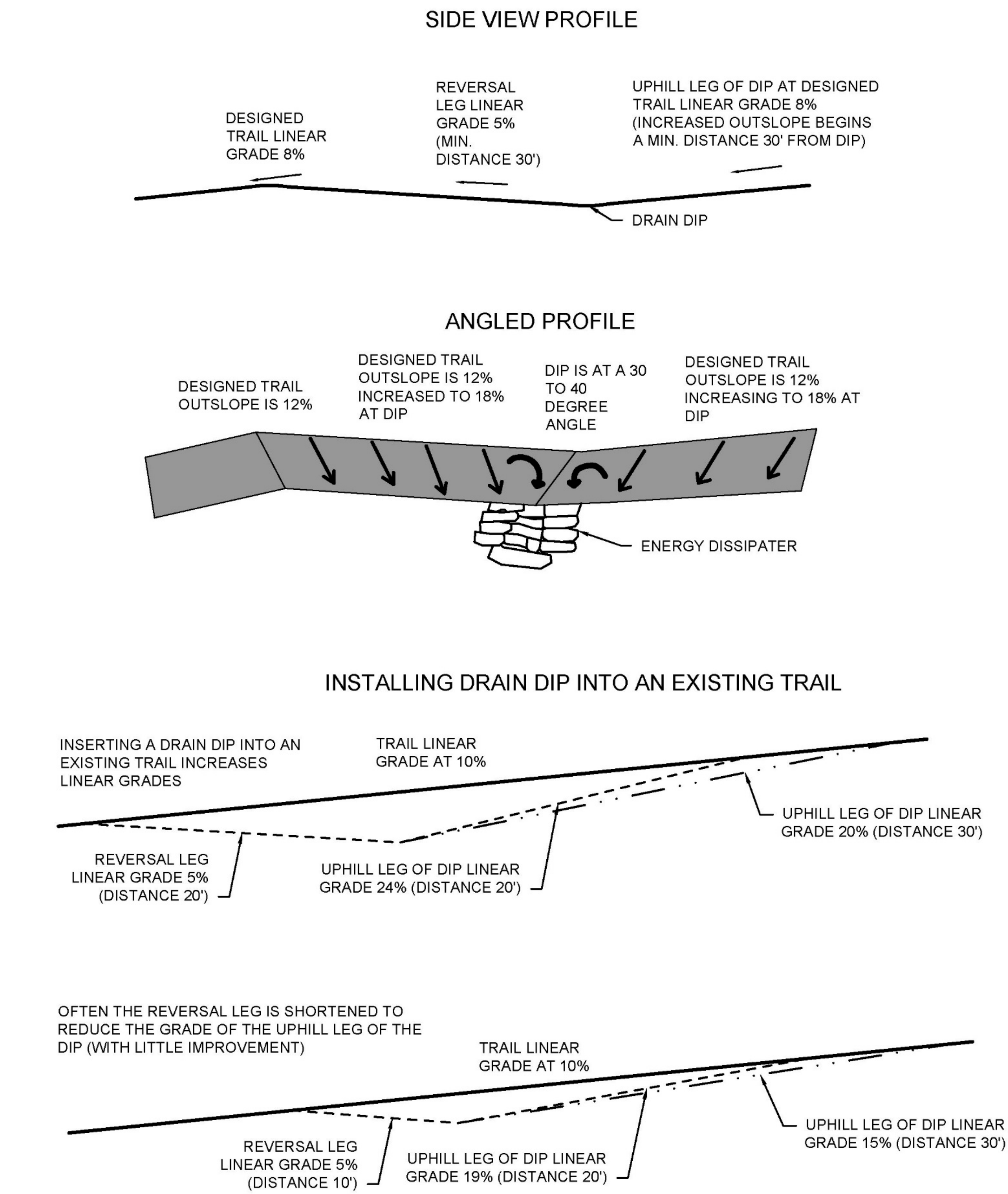

Figure 14.29 - Drain Dip/Grade Reversals

DRAIN DIPS / GRADE REVERSALS

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14.12.1. Rolling Grade Dips

This drainage structure, also known as a rolling dip or tank trap, is an exaggerated drain dip that is used on trails that receive a high rate of mechanical wear or where the user's desired trail experience precludes the use of more sustainable trail design concepts. A rolling grade dip is used primarily on off-highway vehicle trails, downhill mountain bike trails, or equestrian trails used for competitive endurance riding. With a high rate of mechanical wear or the use of a "fall line" alignment, this drainage structure is often liberally installed throughout the trail alignment.

The design of a rolling grade dip is similar to a drain dip but the linear grade in and out of the structure is steeper and the reversal legs are shorter in length. (See Figure 14.30.) When designing a trail with a rolling grade dip, account for the steep linear grade created by this structure. Installing a rolling dip on an existing trail can be challenging as it can increase substantially the linear grade between control points substantially. (See Figure 14.30.)

Because of the steep grade and short reversal legs, a rolling grade dip is often deformed rapidly and requires frequent maintenance. However, given the fall line alignment and/or high rate of mechanical wear associated with the type of trail that requires this structure, it is often the most affective form of drainage control.

14.12.2. Water Bars

A water bar is a trail structure that turns and directs water on a trail to the downhill side of the trail. Water bars are constructed of wood, rock, plastic wood, wood/ plastic composites, or rubber. In most instances, a water bar should only be used as a short-term solution to erosion and drainage problems. However, sometimes a water bar may be the only practical solution to certain erosion and drainage issues. A good example is a trail with weak parent soils, located above timber line, and receiving high usage from horse and pack stock. The inherent poor quality of the soil, lack of canopy cover, and high rate of mechanical wear render standard sustainable drainage solutions futile. Water bars combined with backed water bars, steps, and rip rap may be the only successful method of keeping the trail from washing down the hillside. Such solutions require a substantial investment in construction and maintenance. If a water bar must be used, it needs to be constructed properly to be effective.

Water bars have been the mainstay of trail design for decades. Most designers and workers know that water bars are difficult to maintain, as they are prone to filling with sediment from the first big storm. Once filled, they no longer divert water from the trail and, instead, become head cutting check dams. Only recently has the sustainability and impact on resources of these drainage structures been recognized. Water bars are no longer uniformly prescribed and their use has diminished. Water bars have been replaced with another structure, the drain dip discussed above.

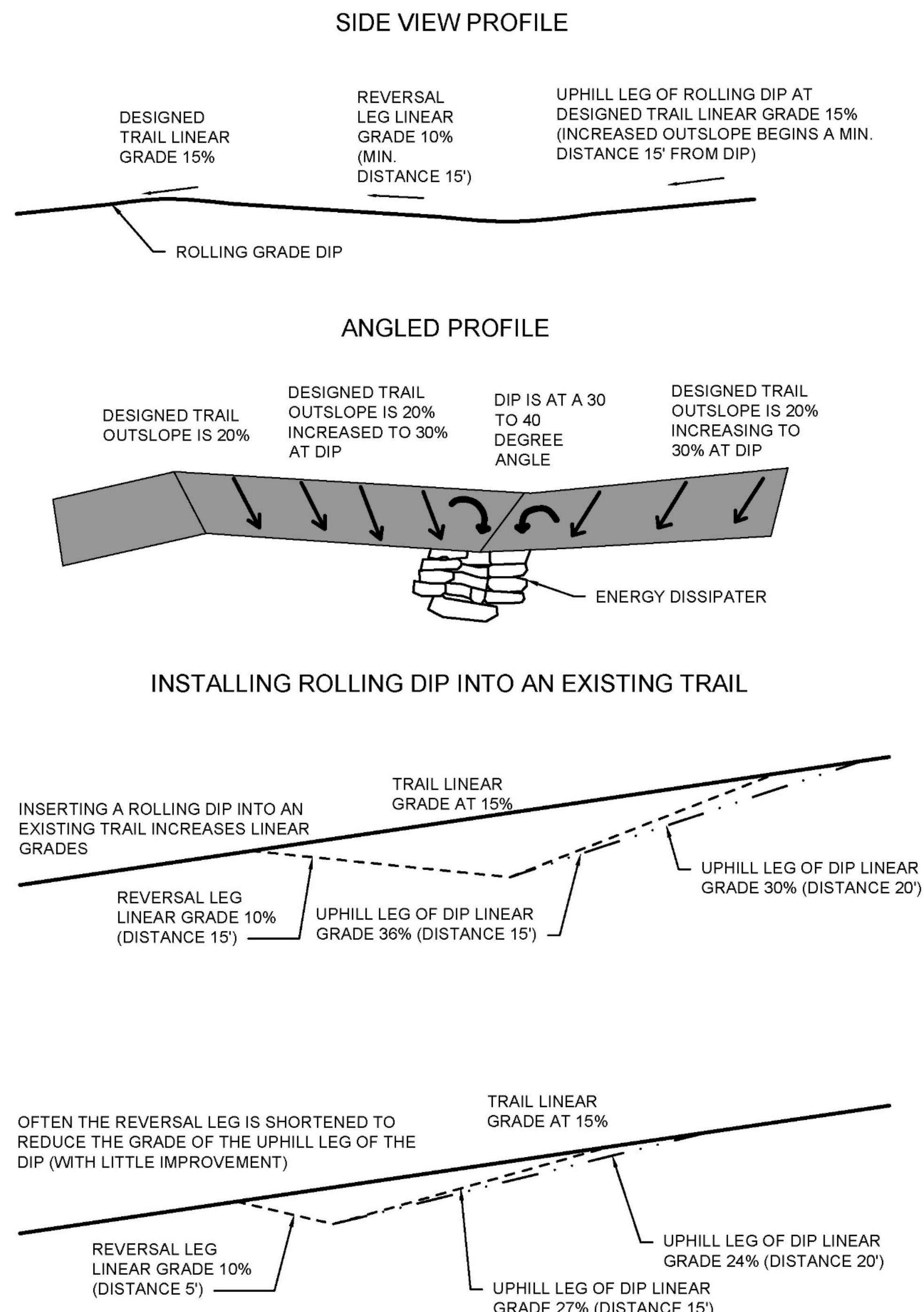

Figure 14.30 – Rolling Grade Dips

ROLLING GRADE DIPS

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The angle of a water bar across the trail depends on the gradient of the trail, the volume of water being drained onto the trail, and the surrounding terrain. The angle is 20 to 40 degrees from a perpendicular line across the trail. A water bar at less than 20 degrees may dam water flow and require frequent maintenance. A water bar at more than 40 degrees can promote erosion that undercuts the structure. The ideal angle is somewhere in between 20 and 40 degrees, at a point where the flow of the water keeps the water bar clear of sand, soil, and debris. (See Figure 14.31.) A self-maintaining water bar is the objective, but is rarely achieved.

To determine the angle of a water bar across the trail, begin with 20 degrees and add a degree for each percent of grade of the trail section up to a maximum of 40 degrees. For example, a trail with a 15% grade requires a water bar at an angle of approximately 35 degrees. Observe how the trail and surrounding landform drains to determine the appropriate placement of the bar. Viewing the trail with water on it during spring runoff or a cloudburst will make the drainage pattern apparent. Locate water bars where they can most effectively intercept surface runoff captured by the trail and divert it onto the hill slope below. At these locations, the hillslope below the trail must be durable and stable enough to withstand the increased runoff without eroding or creating a slope failure. The frequency or spacing of the water bars is dependent on the volume of water captured by the trail and the number of suitable locations for placement.

To determine the location for a water bar, also look for natural anchor points, especially large rocks embedded alongside the trail, which make excellent keystones for water bars. Trees may also be used when well located.

14.12.3. Water Bar Construction

A water bar is constructed to a height that can accommodate the amount of water it will receive in a cloudburst or seasonal runoff, yet not high enough to interfere with travel by hikers and stock. Usually a water bar can be lower than expected. The uphill side of a water bar projects above the trail tread approximately 7 to 8 inches and functions as a step. During construction, the bar must fully cross the trail to prevent water and trail users from traveling around the water bar.

Regardless of the material used, the water bar needs to be placed in a trench to provide a stable foundation. The trench also ensures that the bottom of the bar is below trail grade and will not be undermined by flowing water.

14.12.4. Wood and Plastic Water Bars

Wood, plastic, and wood plastic composite material should be a minimum dimension of 4 x 10 inches. Install the bar by pre-drilling two to three holes through the ends and center of the bar, placing it in the trench, pinning it with a length of 5/8-inch rebar through the holes, and shaping and compacting the soil around it. When finished, the downhill side of the water bar is at trail grade and the uphill side is 7 to 8 inches above trail grade. (See Figure 14.31.)

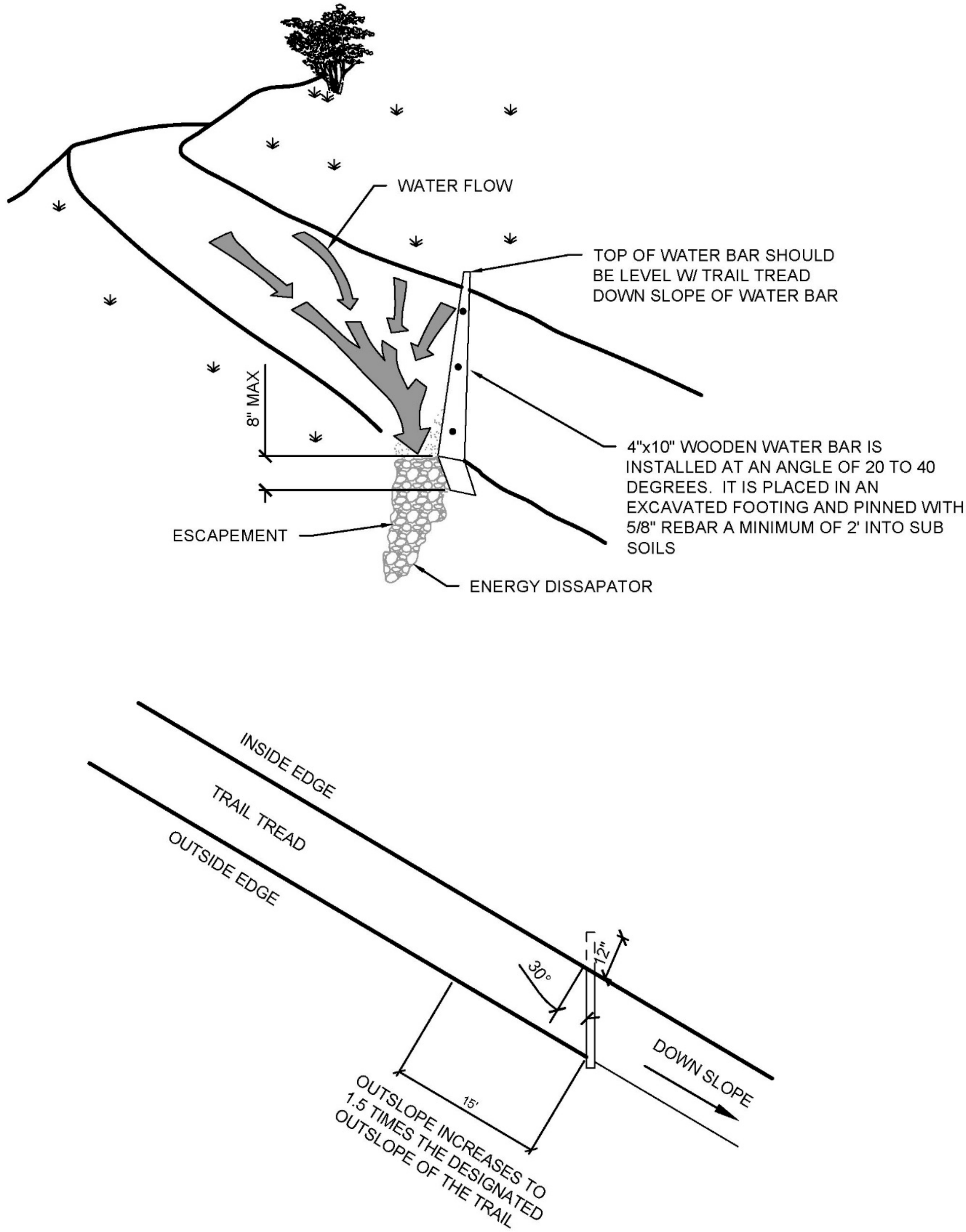

Figure 14.31 - Water Bars

WATER BARS

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14.12.5. Rock Water Bars

When selecting rocks for a water bar, rocks should have a uniform surface and at least one surface at a 90-degree angle. (See Photo 14.20.) Lay the rocks in the most stable position, with the majority of the weight down and in the trench. It is better to lay a rock with the weight low rather than high, where it may be kicked out. The lower portion of the rock is buried and chinked tightly. Lay the rocks so they have as much contact with each other as possible. Take care that the contact between rocks is sufficient to prevent water from flowing between them and eroding the water bar and the trail below. (See Figure 14.32.)

Fill behind the water bar and chink it tightly. Supplemental materials, such as crushed rock fill, provide additional stability to the water bar in an unstable area or on a steep gradient. Lay a rock tray if required in front of the water bar to provide a non-eroding surface for the water to pass.

On trail sections of more than 10% grade, heavily used trails, or sections that take a lot of runoff, construct a "backed" water bar. A backed water bar is a step installed across the trail less than 2 feet below (or downhill of) the trail from the water bar. Between the water bar and the step, crushed rock fill and trail tread material are filled to the level of both the water bar and the step. (See Figure 14.33.)

Installing a step and tread behind a water bar provides additional strength and stability to the water bar. Adding a rock tray in front of the water bar prevents erosion to this area and maintains the designed step height.

Photo 14.20 - Rock Water Bar

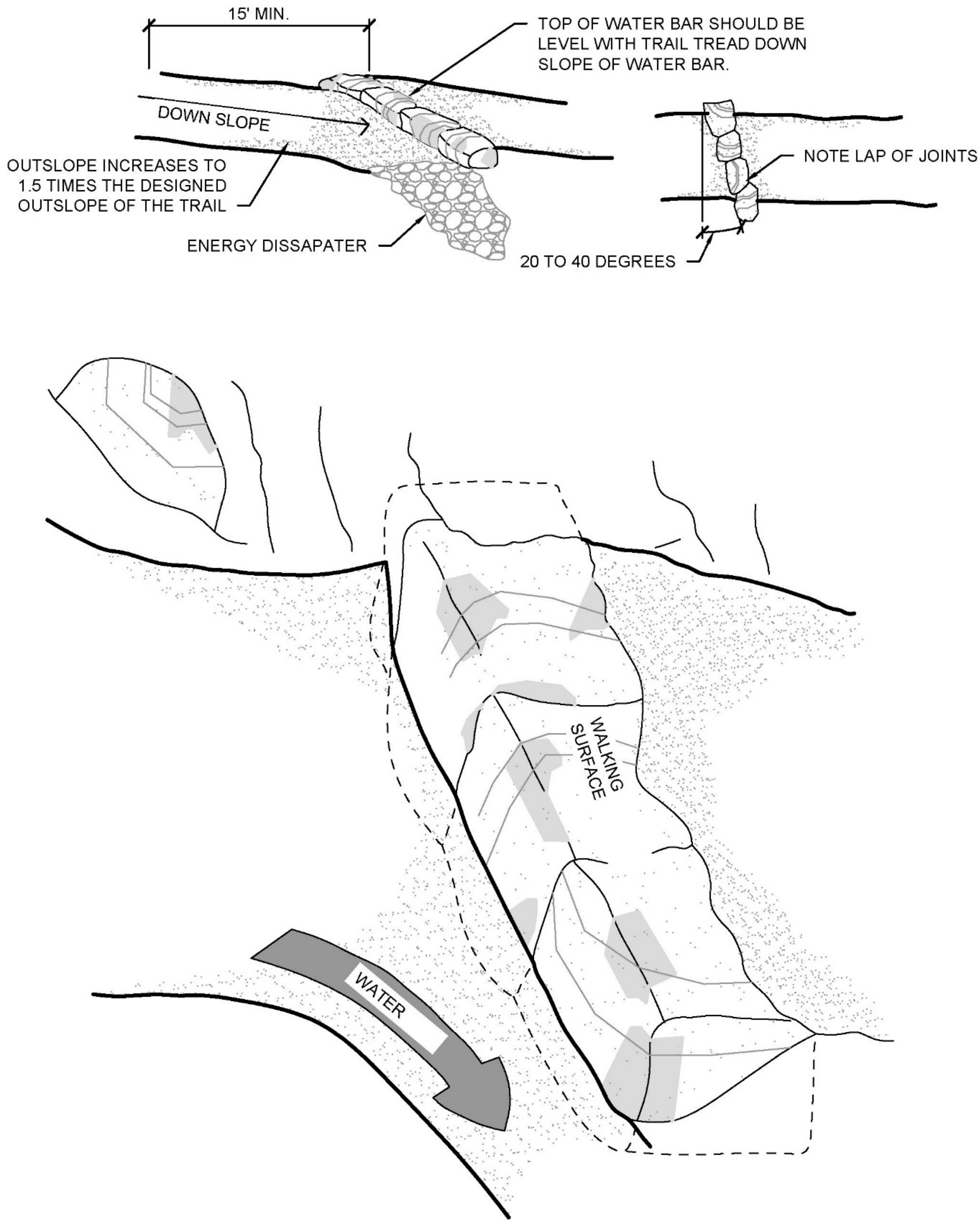

Figure 14.32 - Rock Water Bars

ROCK WATER BARS

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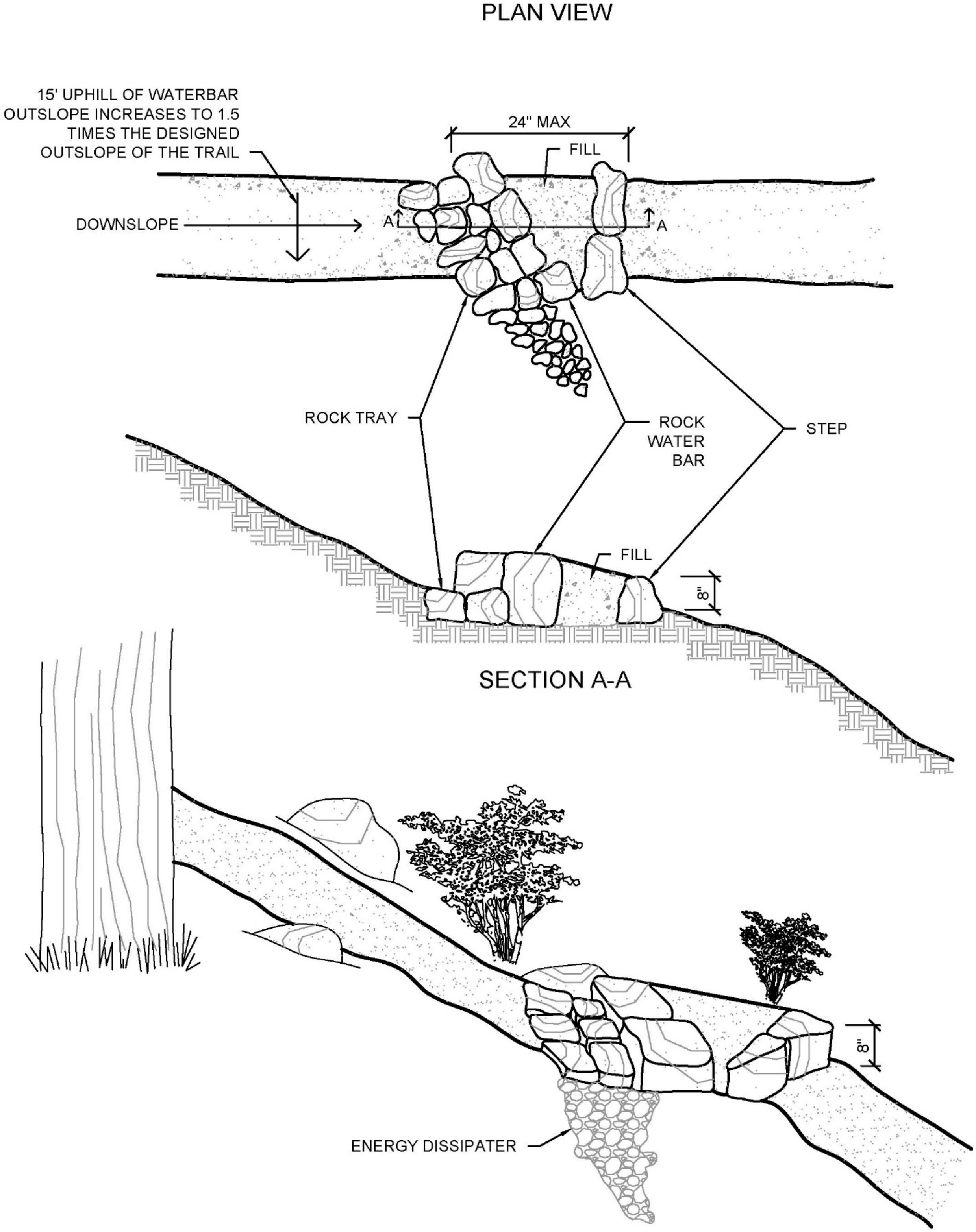

Figure 14.33 - Backed Rock Water Bar

BACKED ROCK WATER BAR

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