**Chapter 11. Principles of Trail Construction ........ 11-1**

**11.1. Trail Construction ........ 11-1**
11.1.1. Clearing and Brushing ........ 11-1
11.1.2. Reflagging the Alignment........ 11-9
11.1.3. Tread Construction ........ 11-9

**11.2. Hand Crew Construction ........ 11-11**

**11.3. Construction in Watercourses ........ 11-16**

**11.4. Use of Mechanized Equipment ........ 11-17**

**11.5. Role of the Trail Crew Leader........ 11-20**

**11.6. Trail Curing ........ 11-21**

**11.7. Trail Hardening........ 11-22**
11.7.1. Aggregate Surfacing ........ 11-22
11.7.2. Aggregate Material ........ 11-24
11.7.3. Aggregate Surface Installation........ 11-25
11.7.4. Stone Pitching ........ 11-27
11.7.5. Rip Rap........ 11-30

**11.8. Road-To-Trail Conversion ........ 11-35**
11.8.1. The Conversion Process ........ 11-36
11.8.1. Shaping and Mulching the Trail ........ 11-41
11.8.2. Watercourse Crossings ........ 11-44

**Figures**

Figure 11.1 - Logging Out Clearing Limits........ 11-2
Figure 11.2 - Clearing and Brushing Travelway ........ 11-3
Figure 11.3 - Clearing and Brushing Limits ........ 11-4
Figure 11.4 - Clearing and Brushing Limits Continued........ 11-5
Figure 11.5 - Down Tree Removal and Placement ........ 11-8
Figure 11.6 - Inslope/Outslope/Crowned........ 11-10
Figure 11.7 - Volume Comparisons by Trail Width and Percent of Hillslope ........ 11-17
Figure 11.8 - 3/4 in. Minus and 1 1/2 in. Minus Aggregate Grading Specifications .. 11-25
Figure 11.9 - Aggregate Surfacing Outslope/Flatground........ 11-28
Figure 11.10 - Stone Pitching........ 11-31
Figure 11.11 - Rip Rap........ 11-34
Figure 11.12 - Road to Trail Conversion Layout........ 11-37
Figure 11.13 - Edge of Native Road Bench........ 11-39
Figure 11.14 - Fill Notch ........ 11-42

**Pictures**

Photo 11.1 - Repositioning Logs ... 11-7
Photo 11.2 - Lead Worker Begins First Cut ... 11-11
Photo 11.3 - Workers Sidecasting Soil ... 11-12
Photo 11.4 - Stagger Line to Reduce Worker Movement ... 11-13
Photo 11.5 - Using McLeods for the Final Shaping ... 11-14
Photo 11.6 - Compacting the Trail Tread with Hand Tamper and Plate Compactor. 11-15
Photo 11.7 - Dispersing Sidecast Soils ... 11-15
Photo 11.8 - Finished Trail Tread with an 8% Linear Grade and a 16% Outslope ... 11-16
Photo 11.9 - Exporting Excavated Soil ... 11-16
Photo 11.10 - Insufficient Trail Curing Resulting in Damaged Trail Surface ... 11-21
Photo 11.11 - Aggregate Surface ... 11-23
Photo 11.12 - Applications of Stone Pitching ... 11-29
Photo 11.13 - Rip Rap Armoring ... 11-32
Photo 11.14 - Rip Rap Used with Rock Framed Steps ... 11-32
Photo 11.15 - Blue Line is Original Road Profile; Yellow Line is Native Bench ... 11-38
Photo 11.16 - Inspector Marking the Trail Bench ... 11-38
Photo 11.17 - Dozer Ripping Road Bed ... 11-40
Photo 11.18 - Sequence of Heavy Equipment Trail Construction ... 11-41
Photo 11.19 - Small Dozer Trail Construction ... 11-43
Photo 11.20 - Hand Crews Performing Final Trail Construction ... 11-43
Photo 11.21 - Completed Road to Trail Conversions ... 11-44
Photo 11.22 - Drainage Crossing Structures ... 11-45
Photo 11.23 - Watercourse Crossing Removal During and After ... 11-47

# Chapter 11. Principles of Trail Construction

## 11.1. Trail Construction

### 11.1.1. Clearing and Brushing

Trail construction begins once the initial flagging of the trail alignment is complete and the required environmental compliance and permitting are approved. Clearing and brushing the alignment, including removing all trees, downed logs, and brush within the travelway (a minimum of 2 feet above the top of cut bank to a minimum of 2 feet below the outboard hinge of the trail), must be done first. The overhead clearance is 10 feet for equestrian and multi-use trails and 8 feet for pedestrian and mountain bike trails. (See Figures 11.1 and 11.2.) The clearing limits vary depending on the size of the trail bench and the intended user group. The wider the trail bench, the wider the clearing limits. The dimensions also depend on the steepness of the hillslope and the maximum angle at which the soil will retain its position without sliding down the slope. Generally, the steeper the hillslope, the wider the clearing limits. In addition, the limits vary as measured from the centerline of the trail, depending on the steepness of the hillslope. In most cases, as the hillslope becomes steeper, a larger area of ground above the trail centerline will need to be cleared because the steeper the hillslope, the further into the hill the trail is constructed. (See Figure 11.3 and 11.4.) The distance cleared and brushed on the uphill side of the trail is also influenced by the steepness of the cut bank, which varies based on the soil's ability to retain its position on the hillslope without sloughing.

Flags can be placed to indicate the upper and lower clearing limits. Often an experienced crew leader and trail crew can visualize these limits without flagging them by using the trail grade flags as a reference. Either way, adjustments in clearing widths and their relationship to the trail's centerline must be made.

**Note, unless otherwise specified the trail bench flag line always represents the outside edge of the trail and the trail is always constructed with a full bench.** A full bench is excavated into the hillslope, is comprised solely of consolidated mineral soil, and no fill material is used to develop the trail bench. The trail bench is cut to the proper width, linear grade, and cross slope without using loose soil to fill low areas or depressions. These requirements influence the clearing and brushing limits. It is important not to clear and brush too little or too much area. Not clearing and brushing enough means additional clearing and brushing will be required during trail construction, which will slow production. Clearing and brushing too much will unnecessarily increase clearing costs, the trail's footprint, and environmental impact. Too much clearing and brushing also requires more time for the alignment to heal and soften in appearance. If a new trail alignment is replacing an existing trail, plants suitable for transplanting should be salvaged from the new alignment. These plants have the same genetic characteristics as those adjacent to the old trail alignment and will flourish if proper transplanting procedures are followed.

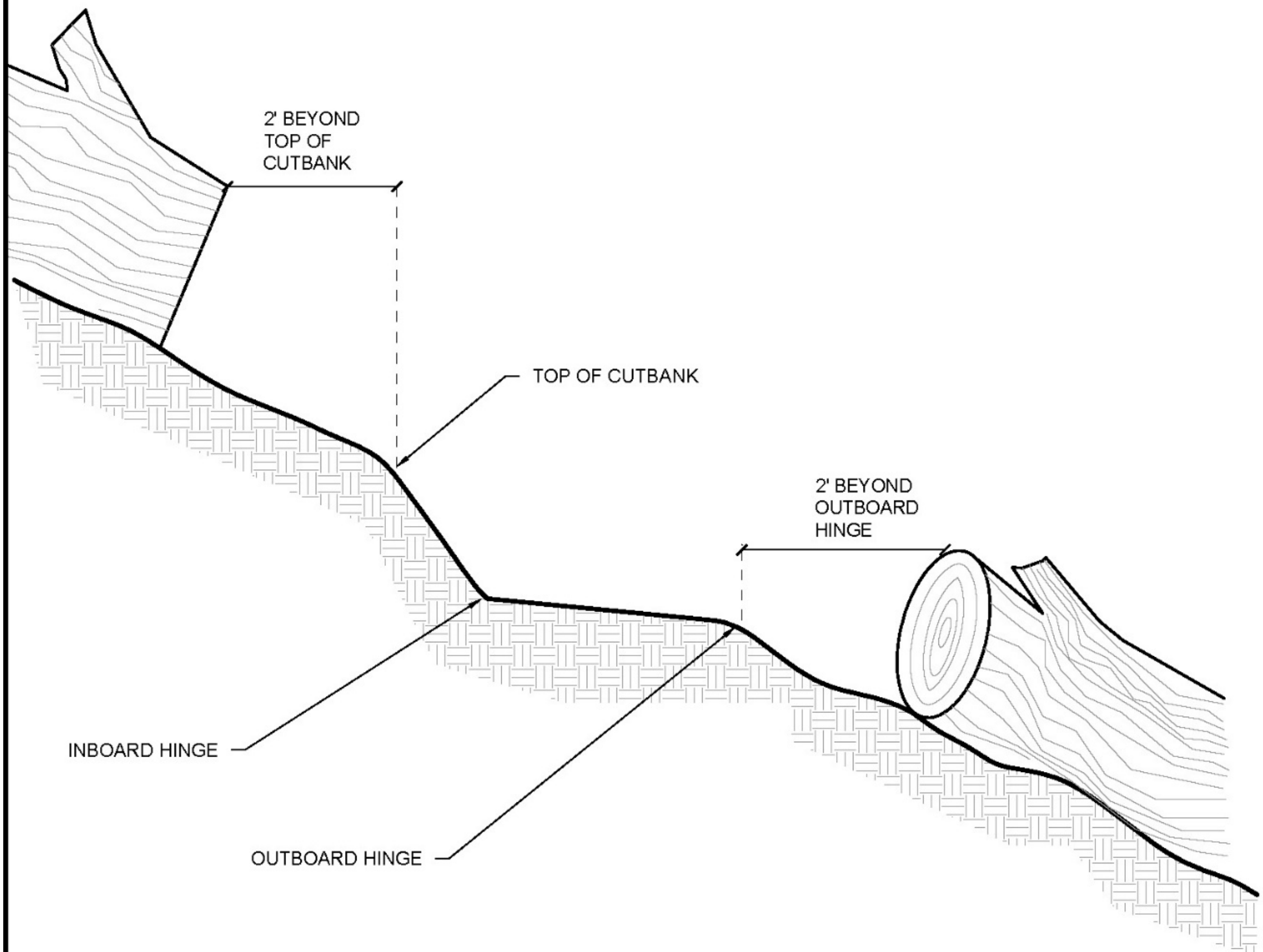


***Figure 11.1 - Logging Out Clearing Limits***

LOGGING OUT CLEARING LIMITS

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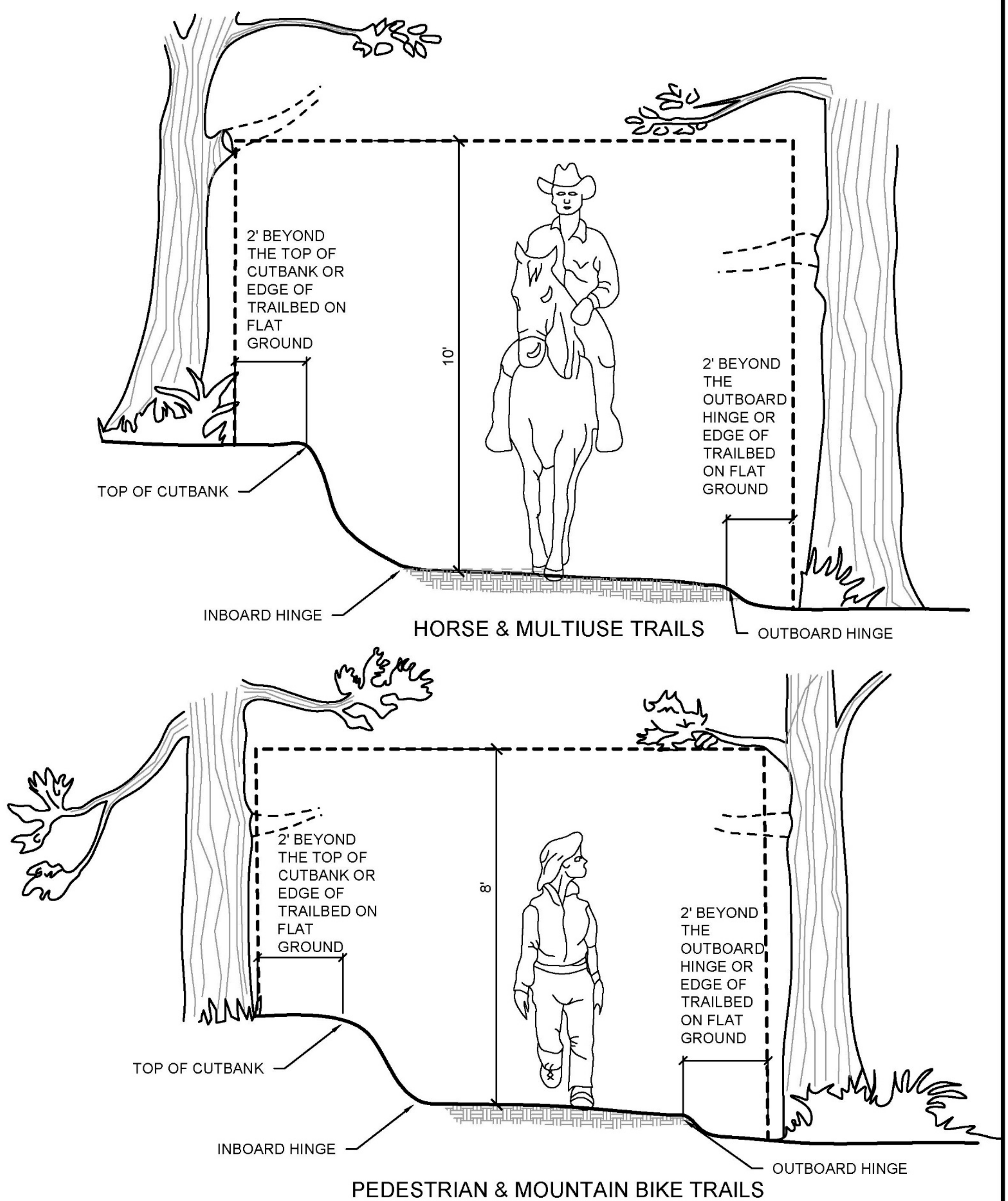


*Figure 11.2 - Clearing and Brushing Travelway*

CLEARING AND BRUSHING TRAVELWAY

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NOTE, DRAWINGS ARE BASED ON CLEARING AND BRUSHING STANDARD OF 2' BEYOND THE OUTBOARD HINGE AND THE TOP OF THE CUTBANK. CUTBANKS ARE SHOWN AT 45 DEGREE ANGLES BUT MAY BE LESS DEPENDING ON THE PARENT SOILS. FOR ILLUSTRATION PURPOSES ONLY.

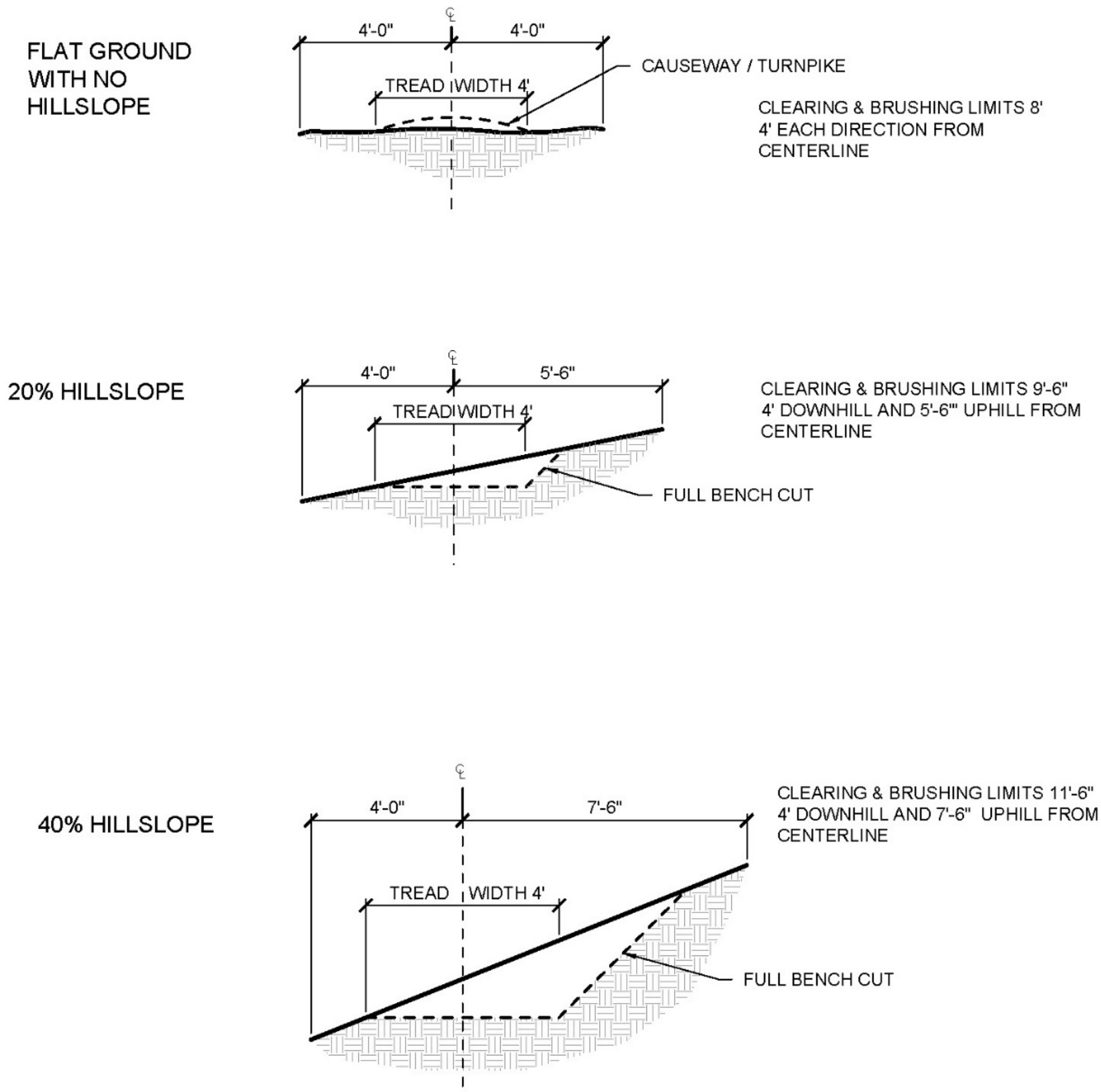


*Figure 11.3 - Clearing and Brushing Limits*

CLEARING AND BRUSHING LIMITS

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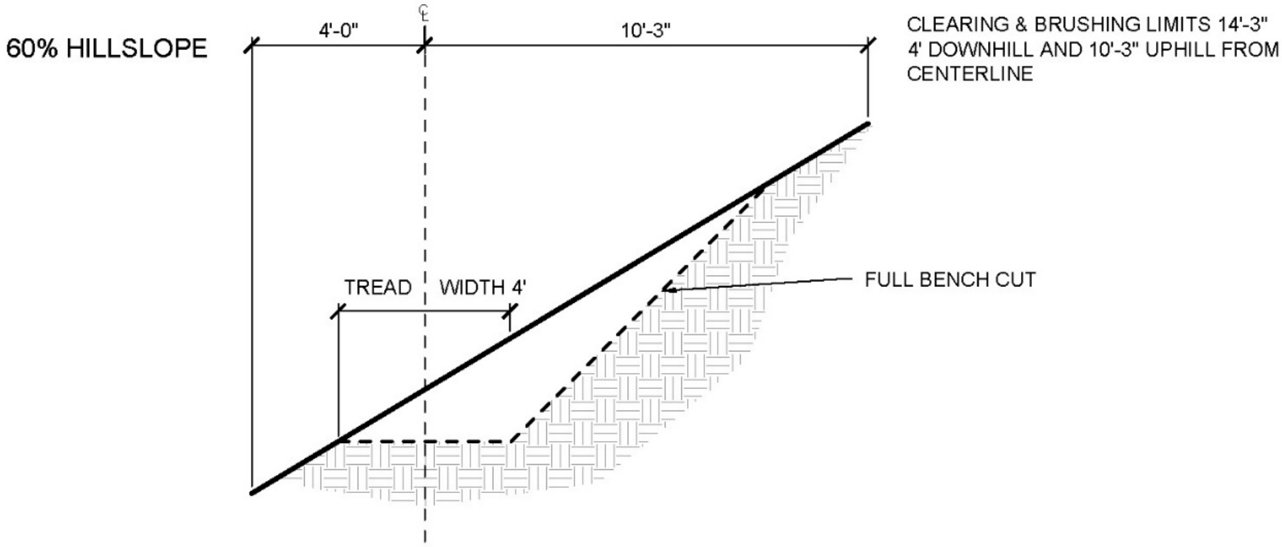


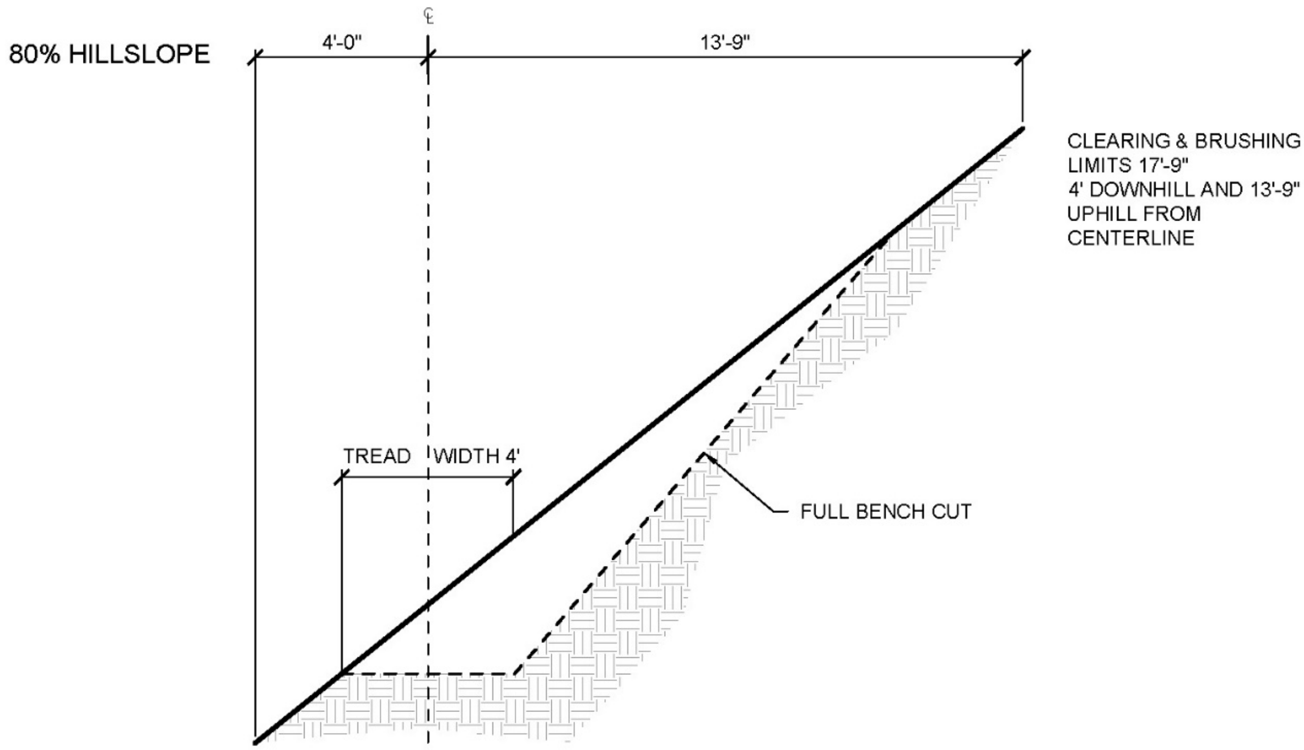


***Figure 11.4 - Clearing and Brushing Limits Continued***

CLEARING AND BRUSHING LIMITS CONTINUED

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Trail crews perform clearing and brushing with a combination of hand and power tools. In some locations, due to a wilderness designation or noise restriction to protect specific wildlife, only hand tools can be used. When constructing a new trail with hand tools, it is important to have a crew large enough to achieve the ideal level of operational efficiency. Clearing and brushing crews are organized in different ways, but the most effective way is to send a group of brushers out in front of the sawyers. The brushers remove all brush within the clearing limits of the trail, and skip over downed trees and standing trees greater than 2 inches in diameter. The brush is cut as close to the ground as possible without dulling the tools. Sawyers follow the brushers and cut down standing trees as well as buck downed logs and trees. Generally, only small standing trees are removed from a trail alignment. Large trees or those with special significance are avoided during the reconnaissance and flagging process.

Small trees should be cut off as high as the sawyer can safely reach, leaving a stem or trunk that can be used as a lever to pull the tree and its roots out of the ground. The rest of the tree is bucked into pieces that can be removed by hand or by mechanical hoist. Downed trees within the trail clearing limits are logged out with saw cuts made to facilitate rolling the cut log out of the way. A skilled trail crew should be able to perform this task so that the removed log remains in one piece, eliminating unnecessary movements as well as the unsightly remnants of log rounds scattered above or below the trail. If approved in the project's environmental documents, suitable downed trees within the travelway should be identified as construction material, then cut in workable lengths and staged for later use.

Periodically, cut brush and bucked trees need to be removed from the trail alignment. If the brush is thick, it must be removed before the trees are pulled and the cut logs are repositioned. In areas with light brush, it may not be necessary to stash cut brush until after the trees are removed and logs repositioned. Stash cut brush and tree limbs out of sight using a "human chain" to minimize worker movement, reduce resource impacts, and improve efficiency. An experienced crew leader will break the monotony of clearing and brushing by changing crew assignments. Changing assignments also works different muscle groups, which reduces worker fatigue.

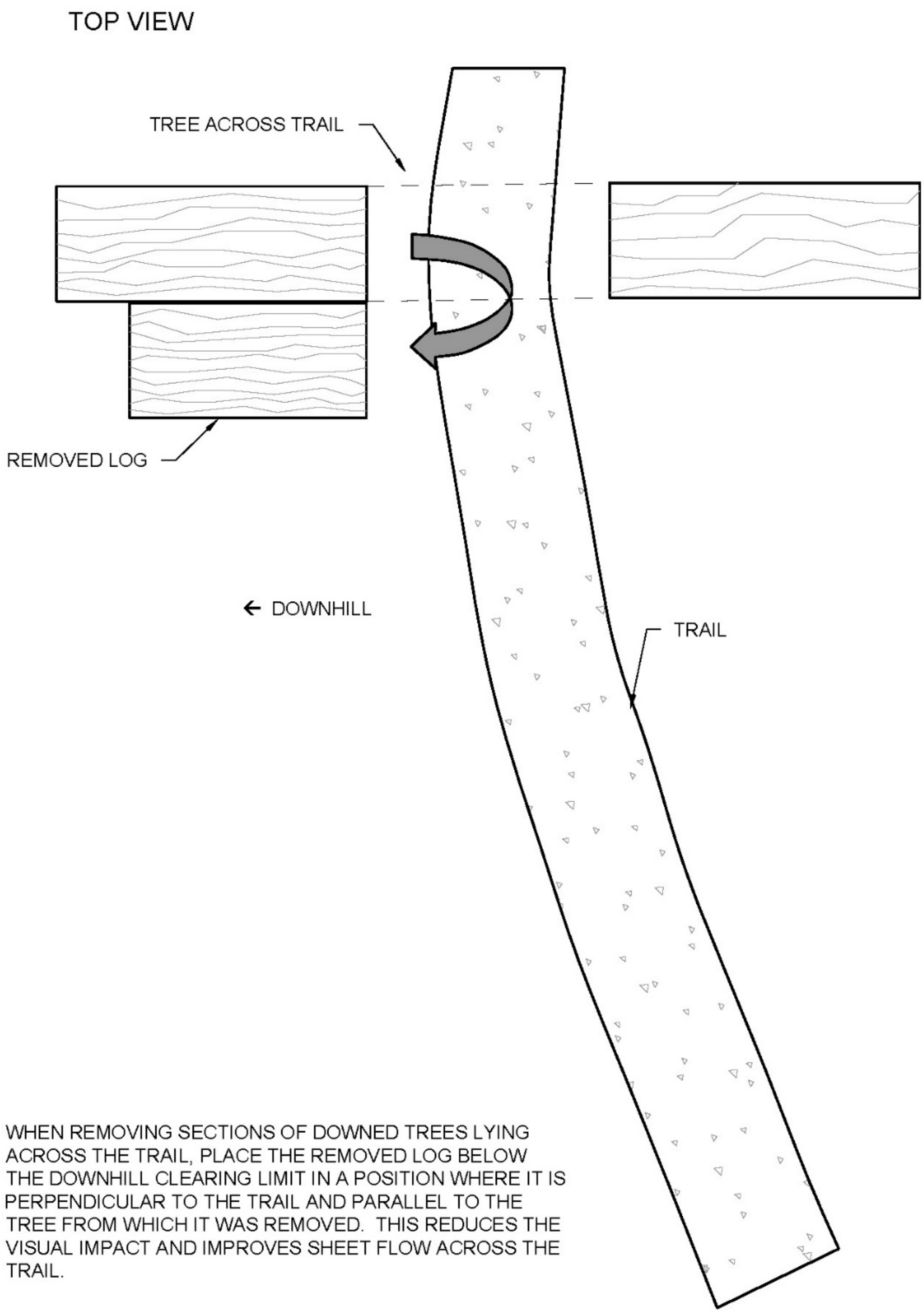
The next phase of clearing is pulling tree stumps, repositioning bucked downed trees, grubbing out brush roots, and removing duff and organics from the travelway. These tasks are best completed with a combination of mechanical hoist, rigging, and hand tools. (See Photo 11.1.) By setting up rigging with teams of two to three workers, the teams are positioned along the cleared alignment to pull tree stumps and reposition logs from various locations; they can anchor a manual wire rope hoist and reach as many trees and logs as possible with a minimum number of set-ups. By leaving a high trunk or stem on a felled tree, a high choker set can use the trunk as a lever. This technique makes it easier to efficiently remove stumps. Large trees that were approved for removal in the project's environmental documents are more efficiently removed not by felling, but setting a choker high in the tree and pulling it over with a manual wire rope hoist. This method uses the height and weight of the tree to pull it over and pull its roots out of the ground.



***Photo 11.1 - Repositioning Logs***

Mechanized equipment, such as trail dozers with winches, can be used to remove stumps; however, this equipment can be unstable on side slopes so it must be operated from a constructed trail bench as it moves down the alignment. Winches have a faster take-up speed than a hand-powered hoist, but have limited mobility. They are not suited for lifting and require a minimum of two people to operate efficiently. When removing trees and logs lying across the alignment, the cut out log is placed below the clearing limit in a position where it is perpendicular to the trail and parallel to the downed tree from which it was removed so it presents minimal disruption to overland sheet flow and the least amount of visual impact. (See Figure 11.5.)

Crew members not involved in the removal of tree stumps and logs can grub out the roots of the brush cut at ground level during brushing, and rake the duff from the intended travelway. Organic material should be raked down slope below the clearing limits where it can be used as a wattle to filter sediment coming off the trail, as a source of duff to be placed later on the finished trail tread, or scattered evenly across the slope. It is critical that all brush, trees, and downed logs and their associated roots be removed from the trail's clearing limits prior to trail bed construction. Organic material left in or beneath the trail bench or fillslope will make it difficult to shape and compact these surfaces and eventually these organics will rot and leave depressions or sink holes in the trail.




WHEN REMOVING SECTIONS OF DOWNED TREES LYING ACROSS THE TRAIL, PLACE THE REMOVED LOG BELOW THE DOWNHILL CLEARING LIMIT IN A POSITION WHERE IT IS PERPENDICULAR TO THE TRAIL AND PARALLEL TO THE TREE FROM WHICH IT WAS REMOVED. THIS REDUCES THE VISUAL IMPACT AND IMPROVES SHEET FLOW ACROSS THE TRAIL.

***Figure 11.5 - Down Tree Removal and Placement***

DOWN TREE REMOVAL AND PLACEMENT

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### 11.1.2. Reflagging the Alignment

Once the trail alignment has been cleared and brushed, the flag line is re-established. This process was previously discussed under the section addressing the second flagging of the alignment in Chapter 5, *Principles of Trail Layout and Design*. Prior to excavating the trail bench, the trail crew or equipment operator must have the trail alignment clearly identified, which requires very detailed flagging, including subtle adjustments for small swales and crenulations. In addition, flags should be placed to identify soil export and fill areas, trail structures, and native material sources. Trail bench construction is accomplished by using hand crews or a combination of hand crews and mechanized equipment.

### 11.1.3. Tread Construction

Depending on the trail's design and construction, the surface of the tread will be outsloped, insloped, or crowned. An outsloped trail is shaped so that surface runoff from the cut bank flows quickly and freely across the trail tread and continues unimpeded down slope. In other words, the inboard hinge of the tread is higher than the outboard hinge, and the trail tread slants down and out toward the slope below the tread. (See Figure 11.6.) An outsloped tread surface is the most sustainable, as it facilitates the natural drainage pattern of the landform. (See Chapter 5, *Principles of Trail Layout and Design*, and Chapter 16, *Drainage Structures.*)

When the trail tread surface is insloped, the tread is higher on the outboard hinge and lower on the inboard hinge. The tread slopes away from the outboard hinge and into the hillside or inboard ditch. This design is usually used on the upper leg of a climbing turn or switchback so that water can drain away from the turn and lower leg. This design may also be used with an inboard ditch, to collect water from a spring or seep and drain it away from the tread. (See Figure 11.6 and See Chapter 12, *Topographical Turn, Switchback, and Climbing Turn Construction,* and Chapter 14, *Drainage Structures.)*

With trails in flat or poorly drained areas, the tread is built up or elevated to keep it dry and free from standing water. (See Chapter 14, *Drainage Structures.*) The tread surface is crowned so the center of the tread is higher than the inboard and outboard edges. Rainfall on the surface of the trail will drain to the inside or outside edge where it can be captured by a parallel ditch or flow onto the surrounding land. (See Figure 11.6.)

The percent grade of outslope, inslope, or crown varies according to the designated use, linear grade, soil conditions, weather conditions, canopy conditions, percent of hillslope, and location of trail on the hillslope. When the trail alignment is on a side slope, the trail bench should be constructed with a "full bench," in mineral soil, and free of topsoil and organic material.

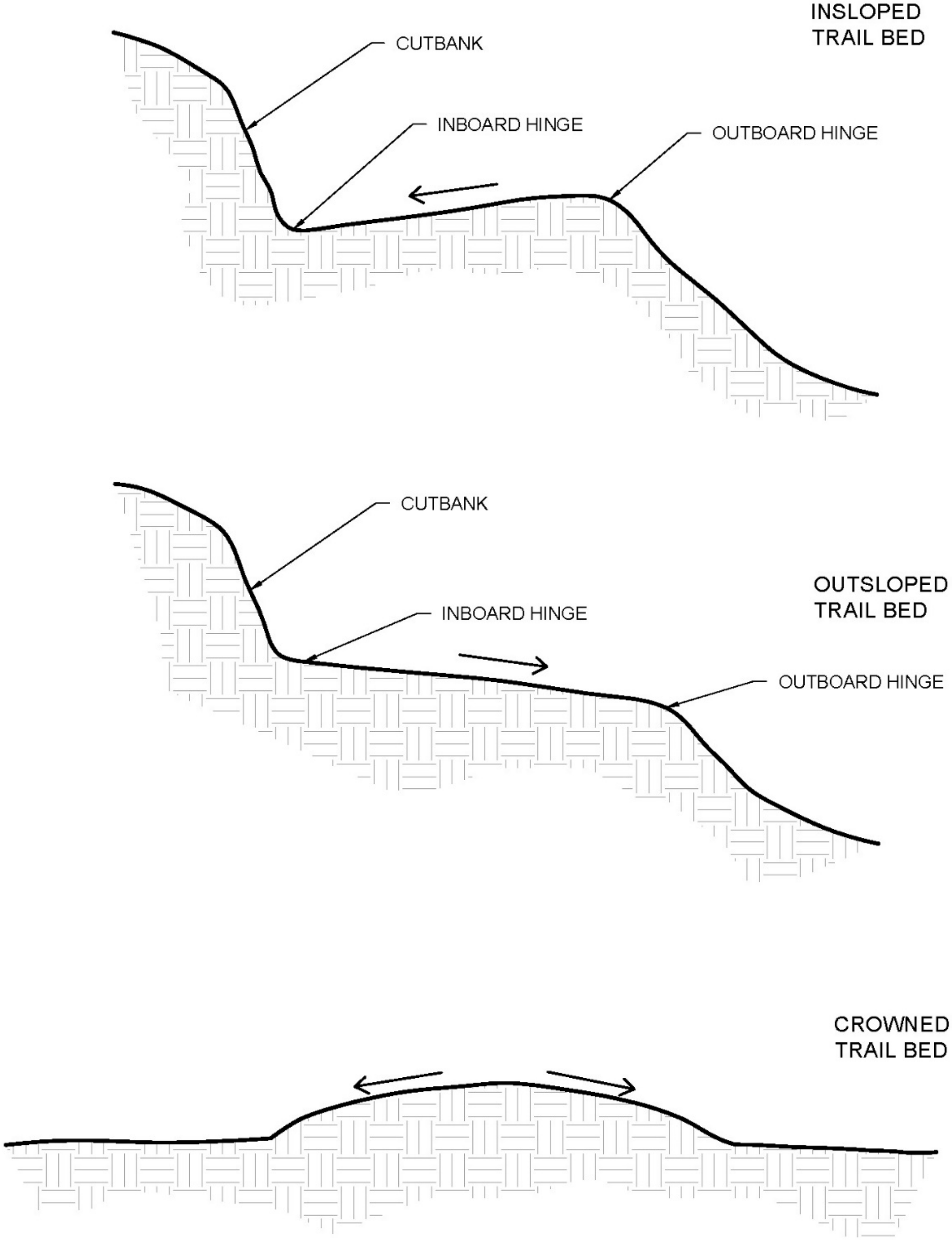


***Figure 11.6 - Inslope/Outslope/Crowned***

INSLOPE / OUTSLOPE / CROWNED

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## 11.2. Hand Crew Construction

A proven and highly effective method of trail construction utilizes hand crews organized into a "hook line." In a hook line, each member of the crew constructs only a portion of the trail and leaves the remaining work for the people working behind. The people at the end of the line perform the final shaping and compaction. Experience has shown that a hook line with a large crew (i.e., 12 or more) will increase individual productivity as well as project efficiency. Having many people in the hook line also allows the crew leader to space the workers so that excavated material is moved off the trail without the workers having to reposition their bodies or move the same material two or three times. (See Photos 11.2, 11.3, and 11.4.) Large crews also feed off each other's energy and sustain a high level of effort. With large crews, crew leaders switch workers' positions in the construction line, allowing them to work with different tools and use different muscle groups, which keeps the workers fresher and more interested in the trail construction activities.

Trail construction with a hand crew begins with the front of the construction line using heavy grubbing tools such as picks, pick mattocks, or axe (cutter) mattocks for excavation. The type and number of tools in the line depend on the resistance of the parent material. The lead person reaches up to the top of the cut bank and cuts into the hillslope. This cut represents the top of the excavation, and its location depends on the steepness of the hillslope and the desired width of the trail. The steeper the hillslope and wider the trail, the further up the slope the cut is made. The cut is flagged or an experienced crew leader and trail crew can locate the point from experience. The first cut goes into the hillslope a few inches at the top and gets progressively deeper into the hillslope as it descends toward the desired trail grade. The lead person takes a dozen or so swings with a tool, and then moves forward to repeat the process. The next person in the line continues the cut further down the hillslope toward trail grade and moves to the location that the lead person just occupied. (See Photo 11.2.)

***Photo 11.2 - Lead Worker Begins First Cut***

This progression continues for several workers until it is necessary to insert into the line a clearing tool, such as a hazel hoe, McLeod, or shovel. These tools remove the loose soil that has accumulated from work with the heavy excavation tools. For a wide trail bench, it may be necessary to place two workers with clearing tools together, with the second one behind and down slope of the first one. Staggering allows the first worker to pull the loose soil across the slope in one motion to where the second worker moves it further down slope and below the location of the outboard hinge without either worker needing to reposition themselves. (See Photo 11.3.)

***Photo 11.3 - Workers Sidecasting Soil***

Once the soil is less difficult to excavate, lighter excavation tools such as Pulaskis and hazel hoes are worked into the line. Tools with the widest blades are usually more efficient at moving soil, but soil conditions ultimately dictate which tools are most effective. Pulaskis are also used to chop out feeder roots that are protruding through the cut bank and trail bed. Large structural roots should never be cut unless otherwise specified in the project documents because it can compromise the health and stability of the tree. During the layout and design process, the trail should be routed above trees or a retaining structure should be prescribed below trees to prevent damage or removal of structural roots. When structural roots are encountered during trail construction, the crew leader determines if the uncut roots represents a hazard or obstruction to the trail user and either leaves the roots in place or bridges over them with compacted aggregate or mineral soil.

To effectively remove rocks from the trail prism, tools such as double jacks, rock bars and slide hammers are often added into the project tools. Small rocks projecting from the surface of the trail can either be removed with rock bars or driven into the soil below grade with a double jack. Large rocks deeply embedded in the soil can be lowered to trail grade by breaking off the extruding surface with a double jack or slide hammer. Gas powered jack hammers may be required to excavate the extruding surface of large, hard rocks. Rocks embedded in or below the trail surface should be left in place as they add structural strength to the trail bed and excavating them leaves a large hole in the trail bed. Even when filled with compacted aggregate, this hole will not have the same load bearing strength as the embedded rock.

To the extent possible, the trail bed should be constructed so that it is comprised of solely undisturbed mineral soil. Any excavation into the trail bed to remove protruding roots or rocks must be filled with maximum 2 inch lifts of aggregate or a mineral soil/ aggregate mix and then fully compacted.

Because conditions can change throughout the trail alignment, a variety of tools are kept with the crew and bumped forward as the crew moves along the alignment. Extra tools are placed above the cut bank where they will not interfere with the excavation of the trail. The crew leader monitors the movement of these tools so they are always within close proximity to the crew.

Once the line is comprised of mostly broad blade soil excavation and shaping tools, such as hazel hoes and McLeods, workers can be staggered so that one person works the trail from the inboard hinge to the center, and the next person works from the center to the outboard hinge. This organization minimizes repositioning of workers and reduces their movements. (See Photo 11.4.) Toward the end of the line, a worker rakes the accumulated loose soil off the outboard hinge and onto the hillslope below.

***Photo 11.4 - Stagger Line to Reduce Worker Movement***

The next worker in the line uses a McLeod for the final shaping of the trail tread, ensuring that the surface is uniformly smooth, has the prescribed linear grade and cross slope, and is free of depressions or bulges. (See Photo 11.5.)

***Photo 11.5 - Using McLeods for the Final Shaping***

The back slope must be laid back to the maximum angle at which it will retain its position without sliding down the slope and even further if needed for stability and eventual re-vegetation. As the trail bench is constructed, make sure that the inboard hinge is not over-excavated, which will leave a depression that will trap water. The finished trail tread is cut (not filled) to its final linear grade and cross slope and should be mineral soil, free of organics, uniformly smooth, compacted, and without holes, rock/root protrusions, or concave depressions that can trap water. The cross slope on trails with native tread is a minimum of 1.5 times the linear grade of the trail and may be increased as required (e.g., an 8% linear grade has a minimum 12% cross slope). See Figure 11.6 for an example of an outsloped trail.

The final workers in the line perform the compaction of the trail bench using a vibrating plate compactor (“vibraplate”). A vibraplate compactor can be used to achieve compaction, but if regulations prohibit the use of a vibraplate compactor, hand tampers can be used to compact the trail tread. The bottom of a hand tamper is flat and smooth, and usually weighs about 10 to 15 pounds. It can achieve a moderate level of compaction, but is not as effective as a vibraplate. It is important that soil moisture is suitable to achieve the proper amount of compaction. Typically, a minimum of three passes with the vibraplate compactor over the entire width of the trail bench is required to achieve the desired level of compaction, but can vary according to the soil type and moisture content. (See Photo 11.6.)

***Photo 11.6 - Compacting the Trail Tread with Hand Tamper and Plate Compactor***

In addition to the trail tread, the soil sidecast down slope is dispersed and compacted by a worker using a McLeod or hand tamper to keep the soil consolidated and minimize sloughing and raveling. (See Photo 11.7.) If no stabilizing material is placed on top of the trail bed, then the final step is to scatter duff over the trail cut bank, trail bed, and the slope below the outboard hinge. The duff should be available below the outboard hinge from previous construction activities. Placing duff on the trail helps protect the soil from rainfall, mechanical wear, and loss of soil moisture. The duff is also rich in humus and native plant seeds, which expedite re-vegetation of the cut bank and the slope below the outboard hinge.

***Photo 11.7 - Dispersing Sidecast Soils***

***Photo 11.8 - Finished Trail Tread with an 8% Linear Grade and a 16% Outslope***

## 11.3. Construction in Watercourses

When constructing a trail within the influence of a stream or topographical swale, the soil excavated to create the trail bench must be exported and not sidecast down slope to ensure that the soil will not enter the watershed and have a negative impact on aquatic resources. Either manual or powered wheelbarrows can be used to export the soil to a suitable location. (See Photo 11.9.)

***Photo 11.9 - Exporting Excavated Soil***

Excavated soil can be used as backfill for retaining walls or bridge abutments. If fill material is not required close to the watercourse, it can be sidecast at a location outside the influence of the watercourse. When performing construction that requires exporting excavated soil, the trail crew is reduced in size because more room is needed to load the soil into wheelbarrows as it is excavated out of the hillslope, reducing the amount of working space in the construction line and the number of people able to work efficiently. Excavating and exporting soil and other material are excellent jobs for a mini excavator. This equipment can replace workers excavating and loading the wheelbarrows. Wheelbarrows can also be replaced by more efficient mechanized toters when site conditions allow. Crew workers can be re-assigned to operate wheelbarrows, spread and compact the fill material used in retaining structures, or spread the soil sidecast out of the influence of the watercourse.

### 11.4. Use of Mechanized Equipment

The use of mechanized equipment depends on the policies of the land management agency, the terrain the trail travels through, and the acceptable level of collateral damage associated with the project. Mini excavators and trail dozers are very efficient at moving earth, and can replace the front two-thirds of the hand crew that uses heavy digging tools. The efficiency of using mechanized equipment is amplified as the trail width and percent of hillslope increases. Refer to Figure 11.7 to see how these two factors greatly increase the volume of earth moved when constructing trails. Mechanized equipment does have limitations, however, and should not be viewed as the answer to every trail tread construction need. Heavy equipment is not as effective as hand crews at the final shaping and compaction of the trail tread.

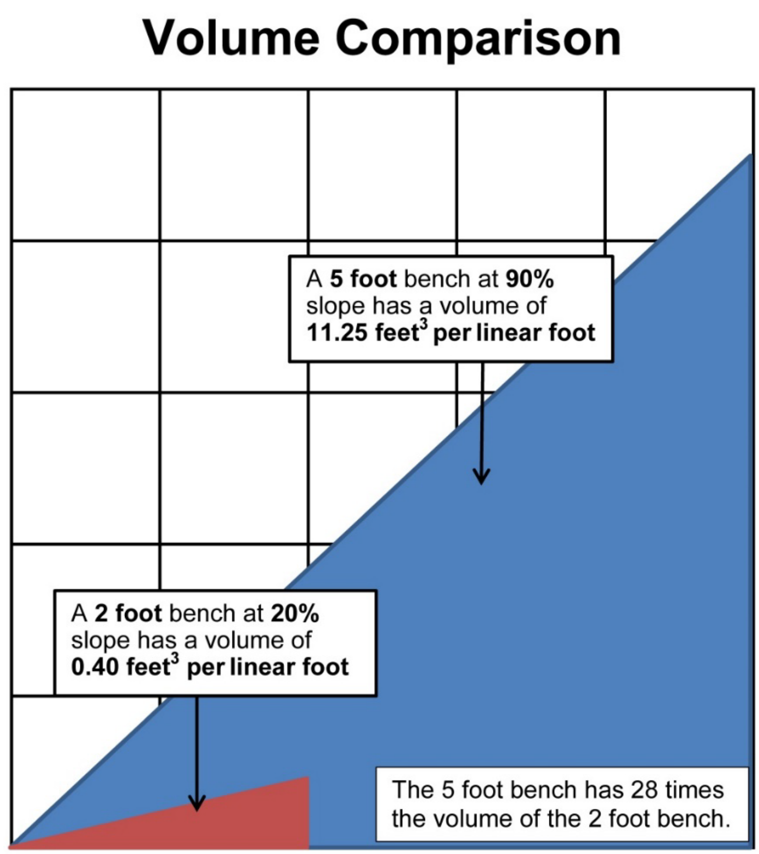


***Figure 11.7 - Volume Comparisons by Trail Width and Percent of Hillslope***

The best combination of mechanized equipment and hand crews is to have the equipment perform rough trail excavations and hand crews brush and clear, construct all trail structures such as retaining walls, and perform the final shaping and compaction of the trail tread. The value of using mechanized equipment to construct trail tread is largely based on the skill level of the operator. Because equipment can move earth so much faster than a hand crew, an unskilled operator can do a substantial amount of damage in a short period of time. Relative to mechanized equipment, a hand crew moves slowly but adjustments or corrections to their work can be made immediately. Trail dozers, on the other hand, can remove hundreds of yards of soil before being stopped to make adjustments and corrections. Another issue related to mechanized equipment is the quality of the finished product they create. Unskilled dozer and excavator operators often will not follow curvilinear alignment when constructing the trail bench. Inexperienced operators may cut across small swales and crenulations, cutting off the high ground and filling in the low ground, leaving a trail that resembles a highway. This construction produces a trail that is hydraulically less functional and aesthetically unpleasing. Inevitably, experienced trail builders are better with trail dozers and excavators than heavy equipment operators, because they understand the nuances of curvilinear construction.

The trail dozer is most effective when used to construct the trail bench, lay back the cut bank, and remove the berm on the outboard hinge. It may also be used to remove tree stumps and reposition downed logs. The best trail dozers have a maximum track width of 48 inches, a six-way blade, good ground clearance, and enough weight and horsepower for the traction required to work on rocky ground and push full blades of dirt. They are also equipped with air and hydraulic pumps to power a variety of tools, slope boards, berm busters, and winches. Unless working in wet, saturated soil, steel tracks are a must as their grousers (metal bars extending beyond the surface of the tracks to provide additional traction) grip rocky soil better and are far more durable than Kevlar or rubberized tracks.

A trail dozer cuts into the hillslope slightly above or near trail grade. On hillslopes less than 30% with a full soil profile, dozers with their blade set at a 45 degree angle can cut straight through and the soil will roll out the end of the blade. On a steeper slope or in rocky soil, earth moving is performed in a sweeping motion, so that the dozer digs into the hillslope with its blade and then pivots toward the outboard edge and pushes a full blade of earth over the slope. This process is repeated until the dozer has carved out a bench at or near trail grade. Cutting trail on a shallow hillslope of less than 20% represents the most difficult challenge for a dozer operator as blade control is critical. Often a trail bench cut on a shallow slope is over-excavated resulting in through-cuts that impede sheet flow across the trail. Experienced and skilled operators are able to prevent over-excavation by controlling the throttle, speed, and blade depth of the dozer. Often “back blading” (driving the dozer in reverse with the blade down) is the most effective technique in these conditions.

The dozer continues down the trail alignment until the operator comes to a feature that it needs to go around, such as a watercourse crossing, or that requires a structure, such as a retaining wall or bridge. A dozer is not appropriate for construction through a watercourse crossing because earth is sidecast as it excavates. The issue of water quality problems associated with discarding excavated soil within a watershed was discussed previously. To avoid watercourse crossings and trail structures the dozer is often driven around them. However, sometimes the terrain is too steep, rocky, or the dozer will create too much collateral damage to the adjacent shrubs, trees, and/or soil to drive around these features. To solve this problem, it is prudent to use a hand crew to construct through locations where sidecast material from a dozer could impact the watercourse. In addition, the hand crew can construct trail watercourse structures prior to the dozer reaching these locations. The dozer can then use the hand crew constructed trail and watercourse structure to access the flagged alignment beyond the watercourse and continue excavating the trail.

A trail crew can move ahead of the dozer to brush and clear the alignment, construct retaining walls and bridges, and excavate through rock outcroppings. Once a hand crew has completed these trail segments, the dozer can use the completed trail to access the flagged alignment and resume excavating the trail. If logistics and site conditions permit, it may also be possible for the dozer to move to the other end to the trail alignment and excavate the trail back toward the problematic feature.

As previously discussed, a mini excavator could be used to construct the trail bench in watercourse crossings or trail segments within the influence of a watercourse. The mini excavator also can effectively be used to construct trail tread. The operator initiates construction at the top of the cut bank in the same fashion as the hand crew, and excavates downward until reaching the desired trail grade. The excavated material is sidecast in the interfluvial areas outside the influence of the watercourse. A skilled operator leaves a fairly smooth trail bench by using the back of the bucket or the small blade attachment to smooth the tread surface. Compaction is often accomplished by rolling over the trail bench with excavator tracks or tamping the trail bench with the back of the bucket. Neither method produces a uniformly smooth and compacted trail bench. Hand crew support is needed for the final shaping and compaction. Mini excavators can also be used to excavate through rock (with hammer attachment), place rock (with thumb attachment), and backfill a retaining wall or bridge abutment. Using a trail dozer and mini excavator with the support of other mechanized equipment, such as a powered wheelbarrow or vibraplate compactor, provides a versatile and efficient approach to trail construction.

Trail dozers should be used to excavate as much of the trail bench as possible. Not only can they be used to make the initial bench cut, but the slope board can be used to lay back the cut bank; the berm buster can be used to cut off the berm on the outboard hinge; and the six-way blade can be used to establish the outslope and clean the trail bench. Dozers are often used to pull a drag, roller, or sheep’s foot over the trail bench. The drag smooths out the trail tread by scraping off loose soil and depositing it in the low areas. This technique looks good initially, but the trail tread will quickly develop depressions that trap water, leading to its deformation and the displacement of soil. Sometimes trail builders rely on the dozer’s tracks to compact the trail bench, but grousers attached to the tracks leave the trail surface broken and with depressions that trap water. They also only cover half the trail bench and leave the center of the trail with no compaction. In addition, to steer equipment with tracks, one track moves forward while the other is stationary or reversed. This action causes the tracks to pivot sideways resulting in the lateral shearing of the trail tread. If the trail tread is wider than 4 feet, pulling a roller or sheep's foot behind the dozer only compacts the center of the trail and leaves the outer portions compacted by the grousers. The sheep's foot also leaves depressions in the trail tread that trap water and result in soil saturation. All these methods result in a poor quality finished product and lead to the deterioration of the trail bench.

### 11.5. Role of the Trail Crew Leader

The trail crew leader's role is to ensure that the trail is being constructed to the appropriate standards and quality. As the trail crew is working in a hook line, the crew leader is ensuring that the crew has the proper spacing and is working safely and efficiently. The crew leader ensures the flag line is being followed, the initial cut bank excavation is at the correct height and location, the proper back slope, trail grade, and outslope are being produced, and the trail bed is being shaped and compacted to standards. The crew leader also monitors the construction line so that the correct excavation and clearing tools are used in the right sequence, and makes adjustments to keep the construction line balanced and moving together. If the front of the line moves faster than the middle or back of the line, the crew leader asks the front of the line to excavate more soil before moving forward, or shifts workers with clearing tools to the center of the line to reduce the number of workers in the front. The construction line is dynamic, requiring constant monitoring and frequent adjustments.

Crew leaders also monitor individual worker production, fatigue, body mechanics, and proper tool usage. They instruct workers on how to use tools in the most effective and efficient manner and routinely move workers to different locations in the construction line to keep them fresh, working different muscle groups, and teach them all the elements of trail construction. To do these tasks effectively, crew leaders constantly move along the construction line. They also motivate the crew by setting attainable goals for each day, week, or the entire project. Constructing trail tread is hard and monotonous work. Establishing daily goals keeps the crew motivated and gives them a sense of accomplishment.

Another important role of the crew leader is to balance the construction work. The crew may brush and clear for several days, and then shift to trail tread construction for several days to give the workers a variety of tasks, reduce fatigue, and improve morale. The crew leader may also mix in a trail structure construction project, such as a retaining wall, prior to encountering an area that requires the export of fill material. Doing so ensures that the soil is moved only once, because the structure requiring the fill is ready to receive it. Crew leaders will also adjust the crew's work to match weather conditions. When the soil conditions are too wet for tread construction, the crew can brush and clear or build structures such as puncheons or bridges. In this case, the crew leader assigns the appropriate number of workers to any given task, ensures that they have the required skill sets or training, and that all materials and tools are staged before the start of the project. To successfully balance and complete a trail construction project, the crew leader has daily, weekly, and monthly plans that are adjusted as project conditions change.

## 11.6. Trail Curing

Once the new trail is completed, it needs time to cure before it is opened for use. Curing is necessary to allow the soil to bond and form a thin crust before subjecting the trail to mechanical wear. If a newly constructed trail is not allowed to cure before being opened to recreational use, the soil will rapidly deform causing it to trap water, become saturated, and lose its structure. If that happens, the trail may never achieve maximum durability, even after the soil is allowed to dry out and the trail is re-shaped and compacted. (See Photo 11.10.) A new trail should be closed for one wet season, but that is not always practical. If the trail is completed during the winter or wet season, it should not be opened but allowed to dry and "firm up." The land manager can keep the trail closed by not constructing the last 150 feet or so of the trail until it is ready to open. If the new trail replaces an existing route, the existing route can be left open for public use until the new route is ready, relieving some of the public pressure for trail access. Once the new route is opened, the old route can be removed and rehabilitated. Proper signage and public outreach efforts, working closely with user groups, and patrolling help with implementing necessary trail closures.

***Photo 11.10 - Insufficient Trail Curing Resulting in Damaged Trail Surface***

## 11.7. Trail Hardening

To construct a sustainable trail, a variety of factors must be considered including the strength and durability of the soil where the trail is being constructed. These factors are likely to vary throughout the alignment of the trail, as the trail passes through different elevations, slope aspects, percent of side slope, etc. In many instances, the strength and durability of the soil can also be altered through the application of tread surfacing materials such as aggregate and stones. The application or installation of trail surface materials is typically referred to as “trail hardening”.

When evaluating the trail for the possibility of hardening the tread, it should be determined if the damage that hardening would attempt to minimize or prevent can be mitigated in another way. For example, if unauthorized users are damaging a tread that would otherwise sustain normal use, then perhaps better communication and education or enforcement can keep users off a trail not designated for their use.

Other factors to be considered when evaluating whether trail hardening is needed and/or appropriate include: proper trail layout and construction, partial or full bench cut; and proper cyclical maintenance. Evidence of rilling or berm formation does not necessarily indicate that the trail must be hardened. If the tread has not been maintained in the past three to five years, it may just be that the trail is due for cyclical “trio maintenance.” (See Chapter 23, *Trail Maintenance Principles*.) Trails built across grassy areas are especially susceptible to berm formation. Grasses encroach on the trail tread and trap the minute quantities of fines (soil and organics) that are easily mobilized by light traffic. In short order, these fines build up in the grasses and create a berm that collects and conveys water down the trail. Problems that result from the trapping and collection of water on the trail are typically due to a combination of layout and maintenance issues that will not be solved by aggregate surfacing.

If the trail performs fine in the dry season, but deforms under heavy use in wet periods, a seasonal closure or restrictions on high-impact user groups might solve the problem. Make sure that the issue is not simply over-use or improper use of a trail during wet weather.

Finally, the trail may simply be too steep, poorly laid out, or improperly constructed so as to not facilitate sheet flow. Hardening a trail with built-in problems will not likely solve the problems. A reroute or reconstruction is a better solution.

### 11.7.1. Aggregate Surfacing

Once these factors have been considered, aggregate surfacing might emerge as the appropriate solution. (See Photo 11.11.) Typical issues addressed by aggregate surfacing include creating a firm and stable surface for accessibility, providing an elevated tread through flat, poorly drained ground that cannot be avoided, or hardening those portions of the trail tread that don't have the strength and durability to sustain the intended use.

***Photo 11.11 - Aggregate Surface***

Before pursuing the aggregate surfacing process, consider some of its common pitfalls. Make certain that the sheet flow of the area is not altered. Elevated trails can serve as a long, narrow dam to sheet flow, if relief is not provided at topographically appropriate locations. Check for subsurface flow or even ephemeral surface flow. A drain lens or armored drain swale might be the better solution. Have a clear understanding of what the trail hardening process entails. Perform the math to calculate the cubic volume of material needed (length of the trail multiplied by the width of the trail multiplied by the depth of the hardening material). Convert this volume to cubic yards by dividing the cubic volume by 27 (the number of cubic feet in a cubic yard). Finally, multiply the total cubic yards by 1.25 to figure the total tons of aggregate needed. Also, consider the logistics of transporting this much material to the project.

Trail hardening can be some of the most challenging work a crew will undertake. Besides the physical challenge of pushing hundreds or thousands of tons of aggregate in wheelbarrows, using toters or dump trailers pulled by ATVs over the same few thousand feet of trail day after day, week after week, tends to become boring and tedious. However, the final finish and shaping of the aggregate must be done properly. This process becomes as much art as science to get the perfect shape, height, and texture to the tread surface.

Finally, consider the other logistics of the project, such as having a location where hardening materials hauled to the project staging area can be dumped. Large trucks must be able to get into the stockpile area and turn around. Few carriers are willing to transport less than a day's work. They may not be willing to transport a single load at a time, which might mean that several hundred cubic yards of aggregate have to be stockpiled at the trailhead. Consider how delivery requirements will affect operations, natural and cultural resources, and visitor use in the area.

### 11.7.2. Aggregate Material

The source of aggregate is another consideration. There are numerous types of aggregates or road bases, none of which are particularly relevant to trail work. If the quality of onsite native material is good, it may be the best choice considering its proximity to the project. A hillside trail that requires full bench construction will frequently provide serviceable material for turnpike construction. (See Chapter 14, *Drainage Structures*.). This material is native, with color and texture that match the environment and will not import non-native seeds.

If native material is not an option or is not appropriate for the project, then select an aggregate source from a commercial vendor. The aggregate should come from a vendor on the list of surface mines approved and licensed by the State of California. Aggregate imported into an otherwise natural setting cannot be assumed to be benign. Imported aggregate must be evaluated for invasive, noxious seeds. A monitoring element should be built into an aggregate surfacing project budget to ensure that any seeds transported into a site will be chemically or mechanically removed. Imported aggregate should also be checked for its serpentine content, which could lead to trail workers and users being exposed to asbestos dust.

The five primary factors to consider in selecting the appropriate aggregate for a trail project are fractured faces, gradation, fine materials (small rock particles and soil), color, and texture. The more jagged and fractured faces in the rock, the more surfaces are available to lock together. Rounded surfaces do not bind together as well as flat surfaces. Therefore, aggregate from an “open” pit, (quarried from a hillside and having no round surfaces) will perform much better than aggregate from a “wet” pit (a river bar source mostly comprised of rounded rock). Specify that the aggregate must be from an open pit when talking to vendors.

Aggregate with good gradation (i.e., varying sizes) will have fewer voids once compacted, producing a more consolidated and stronger tread material. Ideally, the entire matrix of sizes is represented, from large angular faces down to clay sizes. Good trail tread aggregate should have a high percentage of fines, because fines, especially clay, can fill small voids between rocks and serve as a binder for the entire matrix of rocks. Rock dimensions of 3/4 inches minus to 1 1/2 inches minus are sufficient. Dimensions of less than 3/8 inches minus do not have the same strength and durability as larger aggregates. If possible, try to locate aggregate with a similar color and texture to the native soil and rocks at the project site.

When choosing an aggregate source, talk to road maintenance professionals who have experience with different local aggregate sources to find out about the different aggregate pits in the project area. Look at some aggregate surface road projects in the area to see how the different aggregate types are performing. Which ones hold their shape and which ones turn to marbles? The two most common aggregate sizes used in trail hardening are 3/4 inches minus and 1 1/2 inches minus. The 3/4 inches minus is best for accessible trails and the 1 1/2 inches minus is best for pedestrian, mountain bike, and equestrian trails. The 3/4 inches minus grade provides enough durability for lighter mechanical wear and also provides a relatively smooth surface and the coefficient of friction needed for mobility assistive devices. Aggregate in the 1 1/2 inches minus grade is more durable and can withstand greater mechanical wear but may lack a smooth surface.

The aggregate must be 100% crushed and be free of vegetable matter and other deleterious substances. The aggregate should conform to the grading requirements shown in the following table. (See Figure 11.8.)

**1 1/2" Minus Aggregate Grading Requirement Chart**

| Sieve Sizes | Gradation |
|---|---|
| 2" | 100 |
| 1 1/2" | 87-100 |
| 3/4" | 45-90 |
| No. 4 | 20-50 |
| No. 30 | 6-29 |
| No. 200 | 0-12 |

**3/4" Minus Aggregate Grading Requirement Chart**

| Sieve Sizes | "Gradation |
|---|---|
| 1" | 100 |
| 3/4" | 87-100 |
| 1/2" | 70-85 |
| No. 4 | 30-65 |
| No. 30 | 5-35 |
| No. 200 | 0-12 |

***Figure 11.8 - 3/4 in. Minus and 1 1/2 in. Minus Aggregate Grading Specifications***

### 11.7.3. Aggregate Surface Installation

Prior to installing aggregate surfacing material, the trail bed should be shaped to reflect the same linear grade and cross slope as the desired finished surface. Organics on the trail bed are raked to the downhill side of the trail and stored for future use. This material can temporarily serve as an organic waddle to catch soil coming off the trail during construction. If suitable for mixing with the aggregate, mineral soil excavated during re-shaping of the trail tread can be raked to the uphill side of the trail and stored there for future use. The trail bed must be uniformly smooth and lightly compacted. Compaction should consist of one pass over the entire trail bench with a 180 pound vibraplate compactor.

If the aggregate is to be stored at the trailhead or near the project worksite, it must be covered with a tarp during inclement weather to prevent the aggregate from segregating. Segregation occurs when the aggregate is repeatedly exposed to rainfall and small aggregate and fines wash away and migrate to the bottom of the aggregate pile leaving the upper portion of the pile with an insufficient amount of small aggregate and fines. Exposure to high winds may also blow away fines near the surface of the piled aggregate. Aggregate from the upper portion of the pile will not lock together due to its poor matrix. Crews loading the aggregate for transport to the trail must be cautious about taking aggregate from the bottom outside edge of the pile as this aggregate tends to be segregated and lacks the desired matrix. This segregation can occur when a trail worker inserts a shovel into the bottom edge of the aggregate pile. The disturbance to the pile (blunt force and changing the angle of repose) causes the large coarse aggregate to tumble from the flanks of the pile to the bottom outside edge of the pile.

The aggregate is applied to the trail bed to a minimum depth of 6 inches. The application is performed in two separate 3-inch “lifts” (“courses”). The aggregate in each lift is shaped to the proper linear grade and cross slope prior to compaction. One of the best tools to shape the aggregate is an asphalt lute. Be careful to not overwork the aggregate as it will segregate if it is over-raked. The initial lift begins at the point closest to where the aggregate is stored. The second lift begins at the location furthest out the trail and is applied back toward the starting point. With this process, the first aggregate lift is applied, shaped, and compacted. Once complete, the second lift is applied shaped, and compacted back to the beginning of the surfacing application. Following this process reduces disturbance of the finished tread surface. Compaction consist of a minimum of three passes with a 180 pound vibraplate compactor or two passes with a 1,300 pound double drum vibratory roller.

The aggregate should be kept moist to achieve the maximum level of compaction. Performing this work during the rainy season often provides the required moisture, but if climatic conditions do not provide sufficient moisture, water must be imported. Water can be pumped through a 1-inch fire hose or using a trailer-mounted water tank with a spray bar. The native soil stored above the trail tread (if it has sufficient clay to act as a binder) is blended into the top 1 1/2 inches of the last lift of aggregate. If there is insufficient soil stored above the trail tread for this purpose, then it will need to be imported. One inch of soil across the entire tread surface is the normal depth of application but it may vary depending on the clay content of the soil and the water content of the aggregate at the time of application. Mixing native soils into the aggregate accomplishes several objectives: it adds fine textured material to better bind the aggregate and give better water retention properties to the matrix; it changes the color of the aggregate to better match the native material; and it changes the texture of the aggregate so it feels and sounds better underfoot. The finished surface of the trail tread must be uniformly smooth without holes or concave depressions that can trap water. The organic material stored below the trail bed is then scattered over the trail tread to further soften its appearance.

On hillside trails, aggregate is installed evenly across the surface of the tread to the outboard hinge, atop a normally constructed trail tread. The inboard edge of the aggregate must extend all the way to the newly elevated inboard hinge of the trail; be flush against the cut bank; and be evenly outsloped across its entire width. (See Figure 11.9.)

Installing an aggregate surface on flat, poorly drained ground requires a similar process. The biggest difference is to ensure that water is not trapped behind the turnpike structure created from the aggregate installation. (See Chapter 16, *Drainage Structures.*) If working on an existing trail, it is likely already entrenched and carrying water. It can be valuable to visit the project site in advance of a project and during a heavy rainstorm when the ground is saturated to see how water interacts with the trail. Find and mark those locations where water is entering the trail. These locations are where water must be allowed to cross the trail. It might be desirable to construct a puncheon, install a drain lens or culvert, or simply excavate below native grade and fill to native grade with rock (see "Stone Pitching" below), so water can flow uninterrupted but still create a hardened surface on which users can travel. In the event that the location where water is entering can't be identified prior to construction, carefully study the landform for depressions, very slight swales, or other indicators on the trail of where water has been flowing to identify the crossing locations. Be prepared to return to the project site after completion to identify any damming action that may occur and relieve it by installing one of the trail structures described above. On flat ground where sufficient outslope cannot be achieved, the aggregate should be placed and shaped with a crowned surface. In this manner, the center of the trail is higher than the outside edges, which sheets water to the outside edges of the trail. (See Figure 11.9.)

### 11.7.4. Stone Pitching

Conditions where aggregate surfacing will not provide the desired durability and sustainability include weak and unstable soils, steep linear grades, high mechanical wear, or any combination of these three conditions. When the linear grade is low and the soil is weak and unstable, or the user traffic has a high rate of mechanical wear, "stone pitching" is a viable option. Stone pitching is paving the trail tread with large rocks that have a relatively flat surface. (See Photo 11.12.) This trail hardening technique has been used for thousands of years. When installed properly, stone pitching provides a hard, durable tread that is highly resistant to mechanical wear. In the absence of bedrock or a hard native rock surface, stone pitching can provide a tread that is able to withstand the most aggressive and erosive trail uses. Unfortunately, this trail hardening technique is often misused or improperly installed.

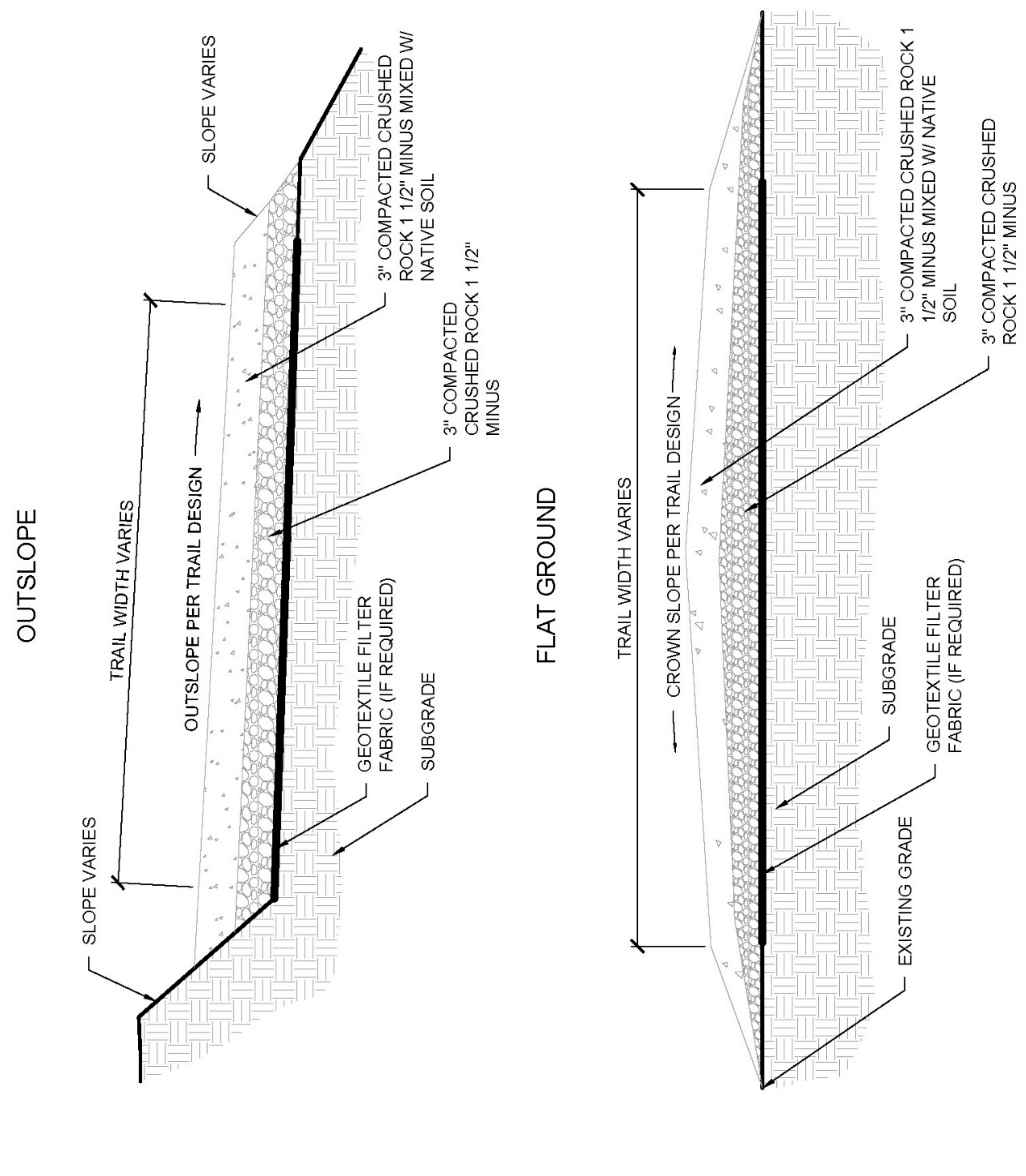


*Figure 11.9 - Aggregate Surfacing Outslope/Flatground*

AGGREGATE SURFACING OUTSLOPE / FLATGROUND

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NOT TO SCALE

***Photo 11.12 - Applications of Stone Pitching***

One of the limiting factors for the use of stone pitching is linear grade. Since the surface of stone pitching is comprised of flat relatively smooth rock, it tends to become slick or slippery when the grade gets steep or wet. Therefore, this technique should be limited to trail segments with low linear grades, especially if the trail is for use by equestrians or people with disabilities. The exception to this rule is downhill mountain bike trails where stone pitching is required to offset high rates of mechanical wear and the users expect a more challenging experience. When used on equestrian trails, the linear grade should be nearly level and stone pitching structures should be relatively short in length.

Rocks used for stone pitching must have sufficient mass to retain their position and support the intended uses. For pedestrian and mountain bike trails, rocks should be a minimum of 300 to 400 pounds. For equestrian trails, they should be a minimum of 400 to 500 pounds.

Like all rock structures, stone pitching requires a good foundation. To install stone pitching, a footing is excavated into the trail bed that is wide enough to produce the desired tread width and long enough to address the condition requiring this structure. The depth of the footing will vary. If the structure is elevated above the surrounding grade, it must be deep enough that a minimum of one-third of the rock's mass is below grade. If the top of the structure is even with the surrounding grade, then the depth is equal to the height of the rock.

If stone pitching is used where the underlying soil is weak and chronically wet, a layer of non- woven geotextile fabric is placed at the bottom of the footing. Once the excavation is completed and the geotextile installed as required, the stones can be placed. The installation process is similar to that described in Chapter 13, *Retaining Structures*. The initial stones are laid at the lowest point of the structure. These key stones should be the largest stones within the structure. If possible, these stones should be locked into existing bedrock to further anchor the structure. The key stones must be well secured because they will serve as a buttress for the rest of the structure. Since the top of the stone will serve as the trail tread, it should be relatively flat and uniform. On mountain bike trails, it may be desirable to leave the surface rough and irregular ("textured") as a means of reducing cyclists' speed. The sides of the stone need to have a shape that makes good contact with the stones placed next to it. The bottom of the stone can have an irregular surface because it will be in the bottom of the footing and the soil can be excavated to match the shape of the stone.

The stones are placed so that the top is at the desired tread elevation. To achieve this elevation, it may be necessary to further excavate into the foundation bed or to place crushed rock underneath the stone to raise it to the desired elevation. (See Figure 11.10.) The next stones are selected and placed to achieve a tight fit against those previously installed. Stone shaping tools, such as hand chisels, hand points, and spalling hammers, may be required to obtain a close fit between the rocks. The gap between these rocks should be a maximum of 1/2 inch. The surfaces of the rocks should match each other and conform to the designed trail grade. (See Figure 11.10.)

Once all the stones are laid in this fashion, it may be necessary to drive in 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 the stone pitching structure is to chink the spaces between the rocks at the surface. Chinking is performed by pounding pieces of crushed rock into the voids between the rocks until the surface of the structure is relatively uniform and smooth.

### 11.7.5. Rip Rap

"Rip rap" is a trail hardening technique that is used primarily on equestrian trails especially those trails receiving heavy use or pack stock traffic. It is also used to harden the trail tread when the parent soil is weak and the linear grade is steep. This technique is not suitable for accessible trails. Its use on mountain bike trails should be limited to technical and downhill trails. It is similar to stone pitching in that the trail tread is comprised of large stones. However, these stones are laid on end rather than flat. They are laid in rows ("courses") that are perpendicular to the direction of the trail. Each course progressively rises above the previous course to match the trail grade. (See Photo 11.13.)

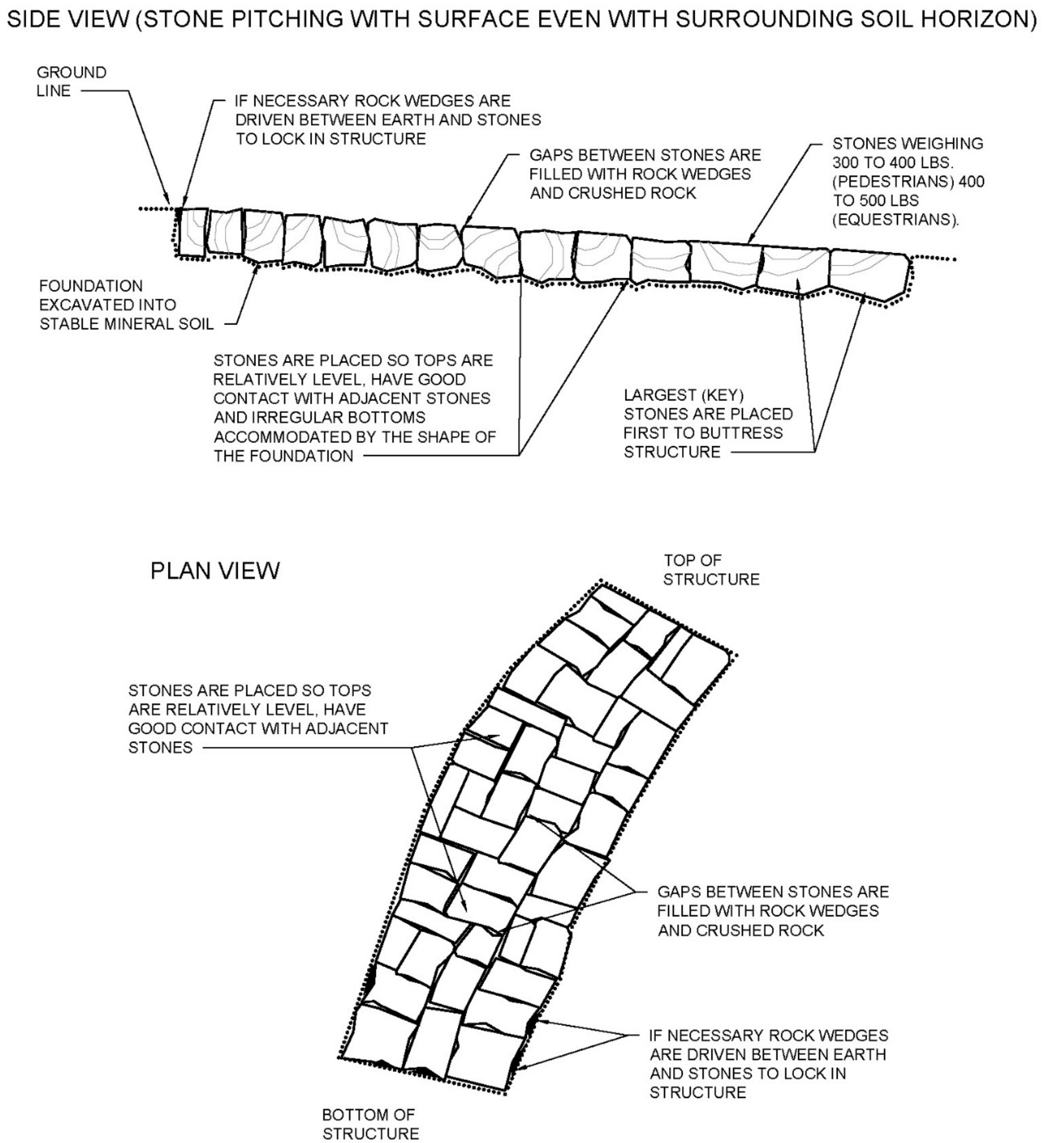


*Figure 11.10 - Stone Pitching*

STONE PITCHING

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NOT TO SCALE

***Photo 11.13 - Rip Rap Armoring***

Rip rap is also used in combination with framed rock steps. The rip rap is laid between each step and hardens the landing. In this application, the steps also serve as headers that buttress the rip rap courses. (See Photo 11.14.)

Placing stones approximately 4 to 8 inches wide on-end provides a durable tread surface with much better traction than flat, smooth stones. Shod horses and mules slip less often with this rough, irregular surface. Hikers also benefit from this rough surface when ice or snow has accumulated on the trail.

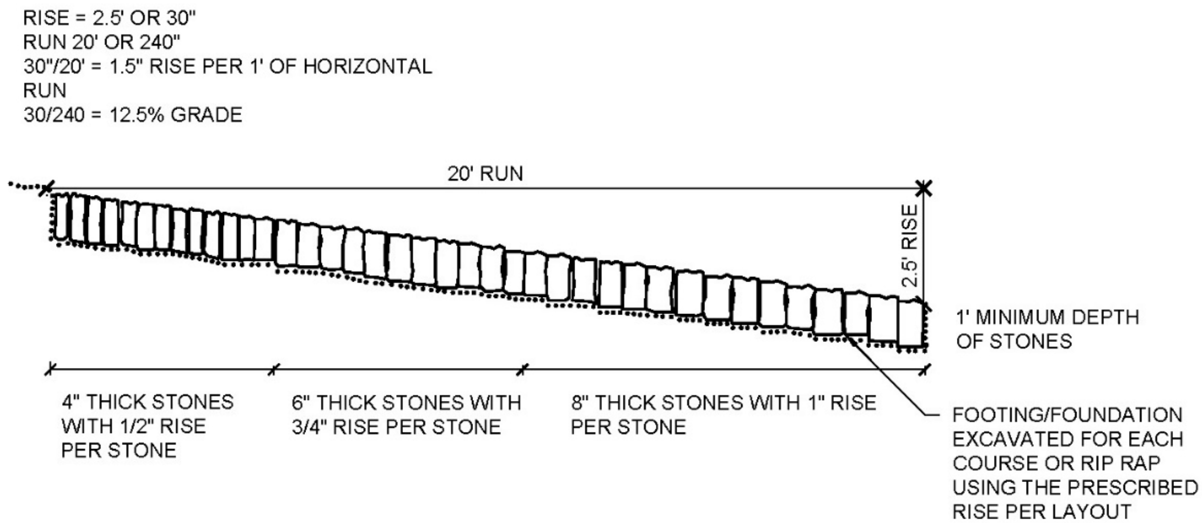
***Photo 11.14 - Rip Rap Used with Rock Framed Steps***

Prior to installing rip rap, an initial layout must be performed using rise and run calculations. To determine the rise and run of a rip rap section, use the same process described for step rise and run calculations in Chapter 17, *Trail Steps*. For the purpose of this discussion, the horizontal run is 20 feet and the rise is 2.5 feet. (See Figure 11.11.) Since it is rare to have enough stones of the same thickness for an entire rip rap structure, it is not practical to calculate the average rise per rip rap course. Therefore, it is necessary to calculate the average rise for every 12 inches of horizontal run by converting the overall rise of 2.5 feet into inches (2.5 ft. x 12 in. = 30 in.). Then divide the overall rise by the 20-foot run to determine the average rise per 12 inches (30 in. ÷ 20 ft. = 1.5 in./ft.). Based on these layout calculations, each foot of run will need to rise 1 1/2 inches. Using this calculation as a guide provides more flexibility in laying the rip rap courses.

When using stones of different thicknesses in a rip rap structure, sort the available stones by thickness to determine the number of courses that can be installed. Identify that there are enough 8-inch thick stones for 15 courses of rip rap. Based on the dimensions in Figure 11.11, each course will rise 1 inch (with a required 1 1/2 inch rise per foot of run, an 8 inch run would need to rise 1 inch: 8 in. ÷ 12 in. = 0.66, 0.66 x 1.5 in. = 1 in.) above the next for a total of 15 inches or 1 1/4 feet of rise. (See Figure 11.11) If there are enough 6-inch thick stones for 12 courses of rip rap, each course would rise 3/4 inch above the next for a total of 9 inches or 3/4 foot of rise. If there are enough 4-inch thick stones for 12 courses of rip rap, each course would rise 1/2 inch above the next for a total of 6 inches or 1/2 foot of rise. (See Figure 11.11)

Using this layout, the rip rap structure would rise 30 inches and have a total of 39 courses. It is important to maintain as uniform a rise as possible throughout the rip rap run. Although the average rise is 1 1/2 inches for every 12 inches of linear run, the rise between the rip rap courses varies depending on the thickness of the stones. To minimize any irregularity, all the 8-inch thick courses with a 1-inch rise should run together, followed by the 6-inch thick courses with a 3/4-inch rise, and then the 4-inch thick course with a 1/2-inch rise. (See Figure 11.11.) Avoid installing rip rap courses of varying thickness together or in alternating patterns as an uneven rise can create a potential tripping hazard and make it more difficult for trail users to traverse the structure. Also avoid having a vertical rise greater than 1 inch between courses, as higher rises increase tripping hazards, reduce traction for shod animals, and decrease user comfort.

## SIDE VIEW




## PLAN VIEW

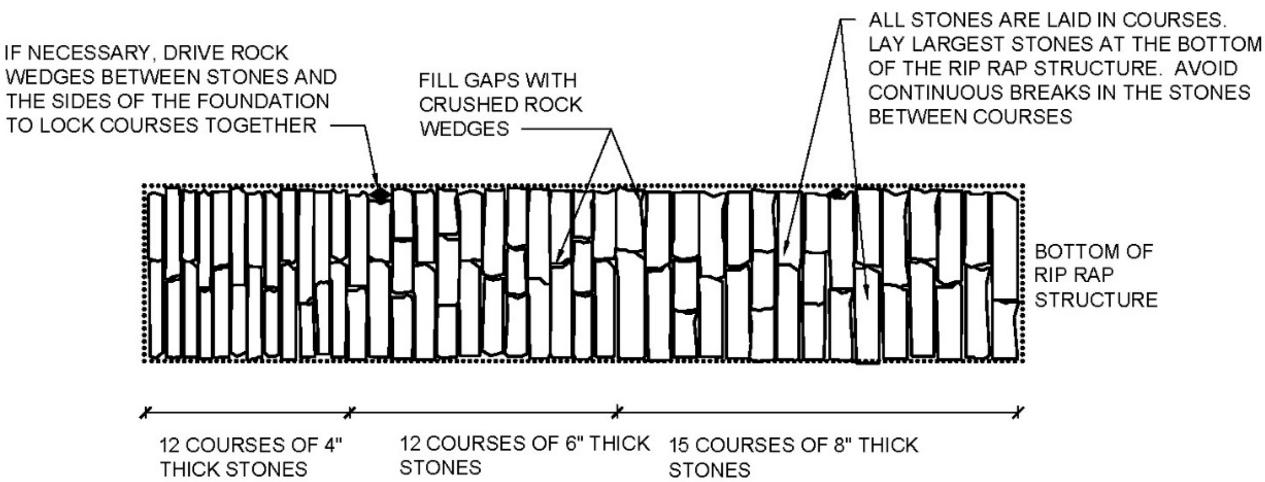



*Figure 11.11 - Rip Rap*

RIP RAP

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To install a rip rap structure, excavate a foundation the length and width of the first rip rap course. The depth of foundation should be sufficiently deep so that the top of the rip rap stones are at trail grade. The depth of the excavation will vary to accommodate the height of the stones. (See Figure 11.11.) Again, since the bottom of the foundation can be excavated to conform to the shape of the stones, the most irregular side of the stone is placed down against the soil. Rip rap stones should weigh a minimum of 150 pounds each and have a minimum height of 1 foot. The initial stones are laid at the lowest point of the structure. These key stones should be the largest stones within the structure. Generally the thickest stone courses start at the bottom of the structure. If possible, these stones should be anchored or locked into existing bedrock that further lock in the structure. The key stones must be well secured as they will serve as the buttress for the rest of the structure. Since the top of the stone will serve as the trail tread, it should be relatively flat and have a rough texture to provide good traction. The sides of the stone need to have a shape that makes good contact with the stones placed next to it.

Once the first course is laid, the foundation for the second course is excavated. The depth of this excavation must accommodate the height of the stones so that they project above the first course to the designed rise. (See Figure 11.11.) These stones should have a similar thickness to the first course and be placed so good contact is made with the first course of stones. Again, the top of the stones should be relatively flat and have a rough texture to provide good traction. This process is repeated until all the stones of similar thickness are used. When stones with less thickness are used, the designed rise will change as per the layout previously discussed. Adjust the foundation excavation accordingly and place the stones as previously described. (See Figure 11.11.)

This process is followed until the rip rap structure is finished. Excavation of the last course of stones should be narrow enough that the stones are jammed tightly against the soil at the top of the excavation. If necessary, drive stone wedges between the last stone and the sides of the excavation to lock the stone in place. Once all the stones are laid, fill all gaps between stones with small rock wedges, being careful not to wedge them apart. If necessary drive wedges along the outside of the courses to ensure they are tightly locked into place. (See Figure 11.11.)

## 11.8. Road-To-Trail Conversion

Road-to-trail conversion is a technique used for transforming an existing road into a recreational trail. Road-to-trail conversion is largely a heavy equipment project but the best results occur when trail crews perform the trail finishing and trail structure construction work. Similar to road removal, road-to-trail conversion involves excavating road fill from the embankment and placing it against the cut bank to match the slope above. However, the trail conversion requires leaving a 4- to 5-foot-wide portion of the original road bench to serve as the new trail tread.

A common mistake in road-to-trail conversion is building a new trail bed on recently re-contoured fill. Using that technique, the road is fully re-contoured and then the excavator re-excavates or tamps in a new trail tread. Reconstructing a trail in loose fill can result in severe settling problems on the trail tread and over-steepens the cut bank, resulting in long term failures that require regular maintenance. Instead, a portion of the original roadbed with a solid, well-graded surface that can withstand recreational traffic should be maintained to serve as the trail tread.

Another common mistake is to convert a poorly designed road into a poorly designed trail. Road-to-trail conversion should only be performed where proper trail design criteria can be met. A successful conversion requires that the road be located on stable ground and have a gentle curvilinear alignment consistent with proper trail layout. Roads that are excessively steep, located on ridge tops or flats, or cut into unstable terrain are all poor candidates for conversion. In these situations, it is best to remove the road and route the trail on a more suitable alignment.

Unlike backcountry road removal projects, road-to-trail conversions are highly visible to the public. The visual impact of a recently completed conversion can be softened by spreading large woody debris and native mulch associated with project implementation over the completed project worksite. Plantings of native vegetation can also speed recovery of the site following conversion.

### 11.8.1. The Conversion Process

Proper trail layout requires training and experience in trail design, construction techniques, and watershed processes. Include road and trail removal experts on the planning team for road-to-trail conversions to ensure a well-built, sustainable trail.

Depending on the surrounding terrain and the original construction of the road, the trail alignment may meander across the road's surface. Where swales intersect the road, the cut bank usually disappears, so the trail tread should meander all the way to the inboard hinge of the road. Likewise, where springs exist, the trail should meander to the inboard hinge. Where small ridges are encountered, the trail meanders to the outside hinge of the road. Where large trees are growing through the embankment fill, the trail can meander to the outboard hinge of the road. By laying out the trail in this manner, a visually stark, straight road can be converted into a pleasing pathway through the forest. A meandering layout can also help reduce steep grades along the alignment by increasing the running length of the trail. (See Figure 11.12.)

When identifying the trail alignment, it is important that the outer edge of the trail be located on native ground (the portion of the road bench cut into native ground). If the trail bench is located on portions of the road bed that are comprised of compacted fill, it may be prone to settling or slumping. Fill is not as durable as native material and will not withstand the mechanical wear of the user groups. The edge of the native road bench must be located prior to marking the outer edge of the trail. (See Figure 11.13 and Photo 11.15.)

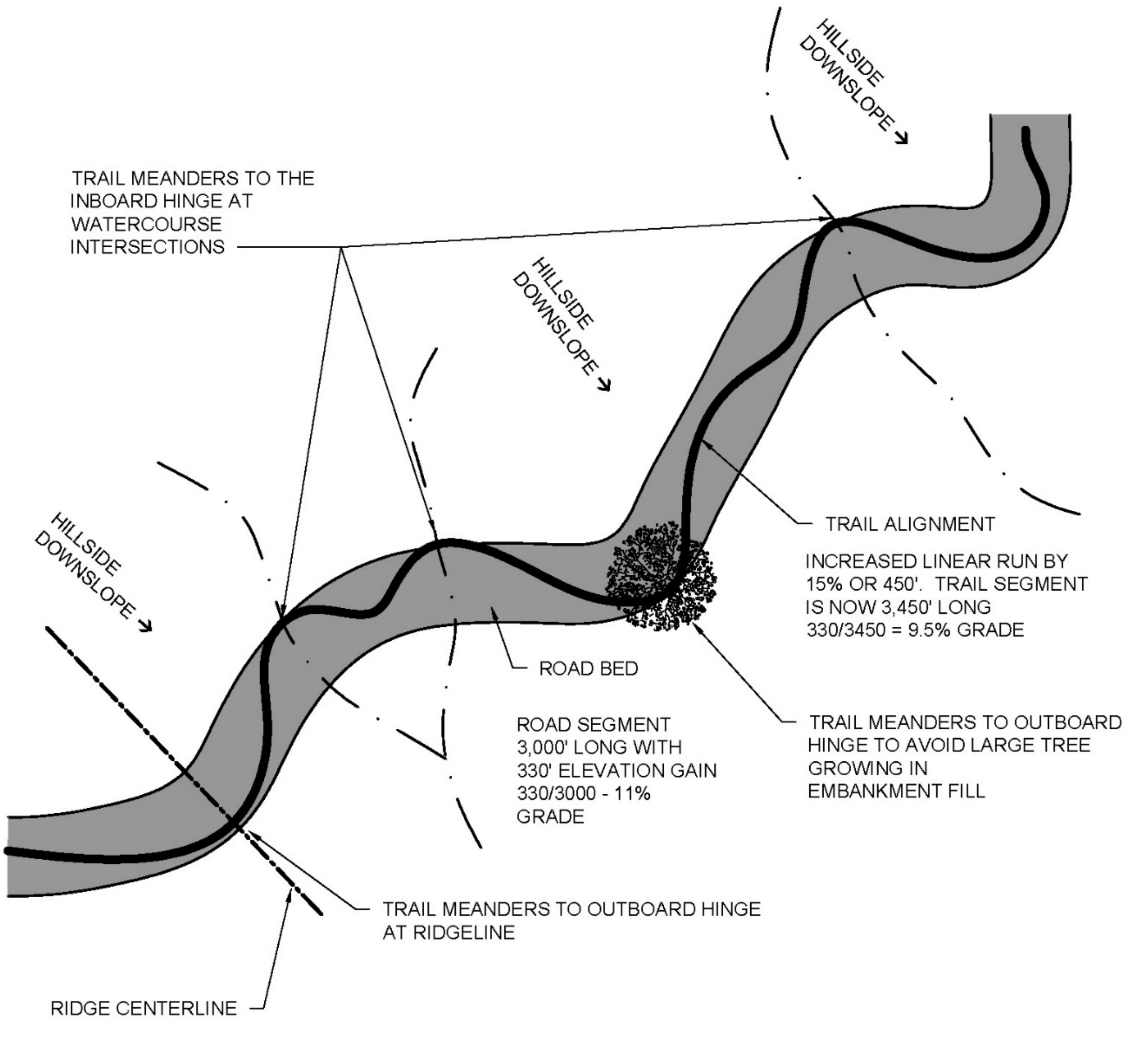


*Figure 11.12 - Road to Trail Conversion Layout*

ROAD TO TRAIL CONVERSION LAYOUT

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***Photo 11.15 - Blue Line is Original Road Profile; Yellow Line is Native Bench***

Before the trail alignment is marked or flagged, an equipment team, usually consisting of an excavator and a dozer, will be driven to the far end of the road where the excavation work will begin. While driving the equipment out to the end of the road removal segment, the excavator is used to brush the alignment, removing all the vegetation from the cut bank and fill slope. This vegetation is stashed above the cut bank where it can be reached later by the excavator and spread across the disturbed soil. The excavator also scarifies the cut bank so the soil placed against it later will bond with the cut bank soil.

After brushing and prior to excavating, identify the location of the trail tread on the road surface with marking paint or pin flags. The markings should consist of two lines - one indicating the inboard hinge of the trail and one indicating the outboard hinge. (See Photo 11.16.)

***Photo 11.16 - Inspector Marking the Trail Bench***

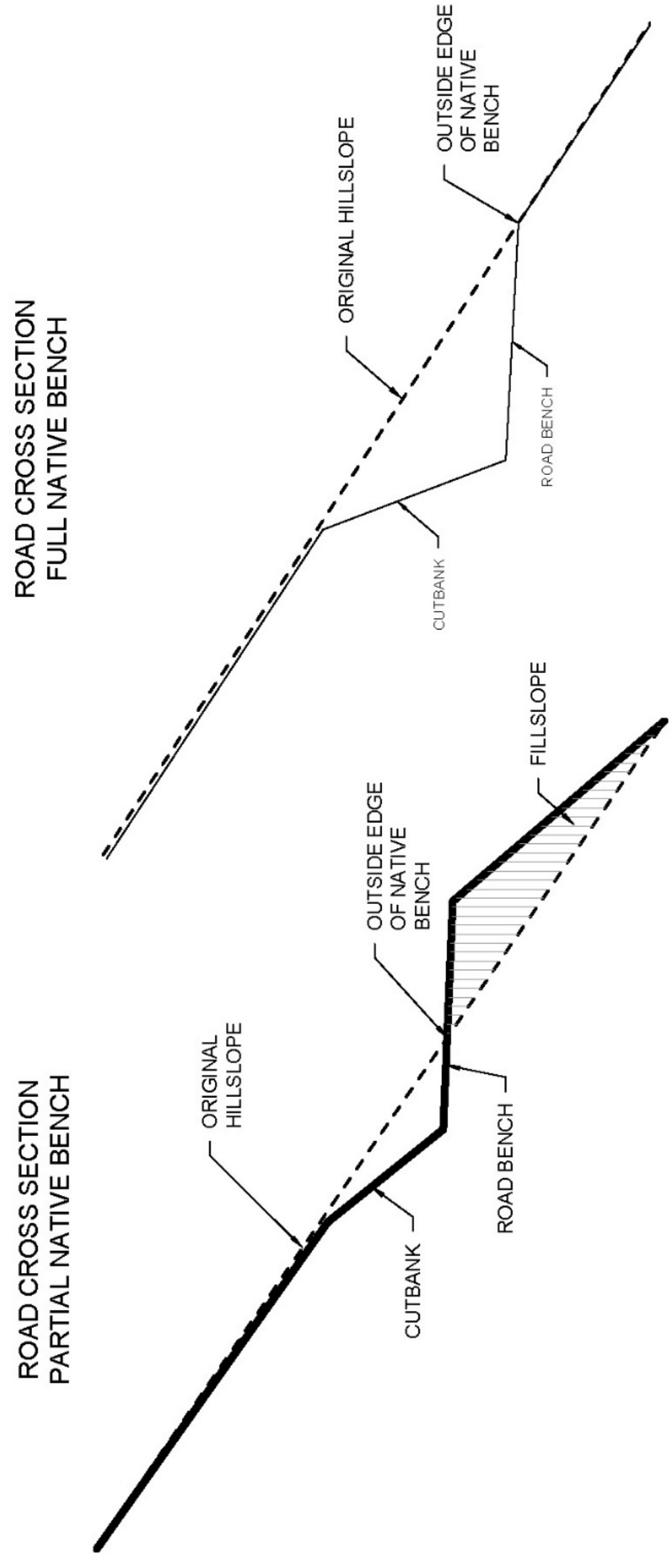


***Figure 11.13 - Edge of Native Road Bench***

EDGE OF NATIVE ROAD BENCH

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NOT TO SCALE

Once the trail is flagged, the dozer begins by “ripping” the sections of the road that are not marked as trail to de-compact the soil and facilitate bonding the new soil to the base soil. (See Photo 11.17.) When the ripping is done, the dozer begins cutting down the outboard road edge in much the same way as for re-contouring. However, the outboard hinge of the trail marks the limit of the excavation. No material should be excavated inboard of the outboard trail hinge. The first few pushes from the dozer are used to cover the trail tread in 6 to 8 inches of soil to protect the surface from damage by the grousers. Once the trail bed is covered, the dozer can continue to push material across the trail and into the cut bank, as far as the inboard hinge of the trail. When the dozer has pushed all it can, the excavator comes in and moves the remaining embankment, placing the fill along the inboard side of the trail. (See Photos 11.18.)


***Photo 11.17 - Dozer Ripping Road Bed***

Wherever possible the dozer should compact and shape the inboard fill. If a small trail dozer is used to perform the initial shaping of the trail tread, the excavator can excavate a small notch below the outboard hinge of the trail to catch loose soil covering the trail bench. (See Figure 11.14.) This step eliminates the build-up of a berm on the outboard hinge of the trail when the embankment is not steep enough for the soil removed by the dozer to fall down the embankment. (See Photo 11.19.) The last step is for the excavator to spread brush and mulch on the finished surface off both sides of the trail. When the excavation is finished, the trail remains buried under the soil originally spread by the dozer. This material will be removed during the final shaping by the trail dozer or hand crew.

***Photo 11.18 - Sequence of Heavy Equipment Trail Construction***

### 11.8.1. Shaping and Mulching the Trail

Shaping the trail surface includes removing the protective soil spread on by the dozer during the excavation, and outsloping the trail tread to provide sheet drainage. A small trail dozer is commonly used to clear and rough out the shape of the trail. If a dozer is not available, hand crews can usually remove the loose soil easily. The final shaping and compaction of the trail tread is performed by a hand crew, which creates a smooth and uniform full trail bench that is properly outsloped. (See Photos 11.20.)

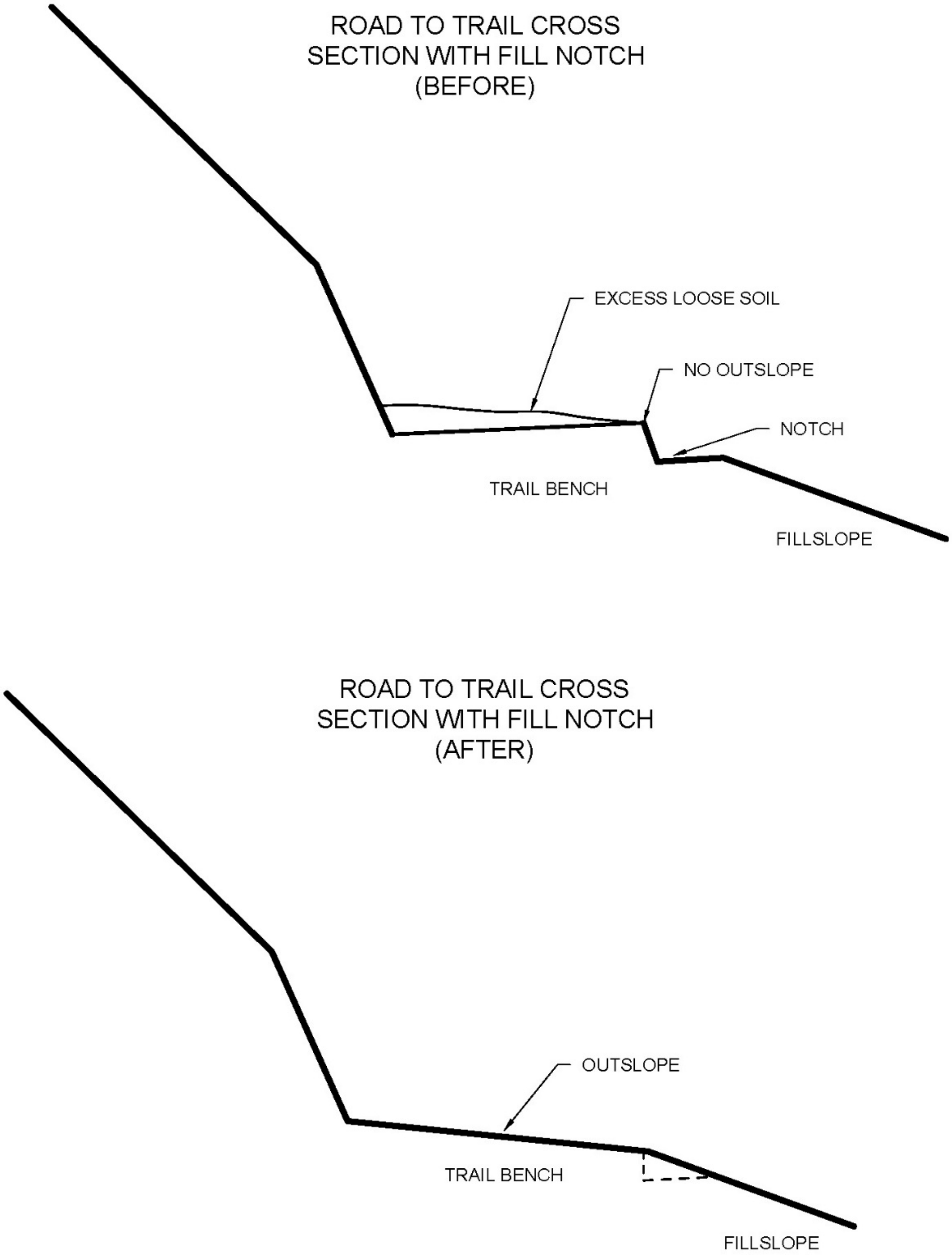


*Figure 11.14 - Fill Notch*

FILL NOTCH

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***Photo 11.19 - Small Dozer Trail Construction***

***Photo 11.20 - Hand Crews Performing Final Trail Construction***

"Mulching" is the practice of cutting and spreading brush and mulch left by the excavator along both sides of the trail. Because an excavator is not efficient at sorting and spreading mulch and small brush to cover exposed soil, hand crews are used to perform this task. After the excavator spreads large brush and limbs on the exposed soil, hand crews cut the material into small pieces, and then spread it evenly on the exposed surface. "Mulching" also includes spreading leaves, needles, and other organics over the trail bed. In especially sensitive areas, crews can be used to transplant native plants into the re-contoured fill to soften the appearance and speed re-vegetation. (See Photo 11.21.)

***Photo 11.21 - Completed Road to Trail Conversions***

11.8.2. Watercourse Crossings

When converting a road-to-trail, watercourse crossings are completely removed and replaced with a watercourse crossing structure appropriate for trails. Watercourse crossings are designed to provide safe passage for users while improving water quality and protecting the riparian and aquatic habitats along the watercourse. Because trails follow a curvilinear alignment, filled or culvert crossings are not required, and, in most cases, can be replaced by a simple low-water crossing structure that conforms to the stream channel profile.

Constructing a trail through a watercourse crossing is similar to the treatment at swales. On the approach to the crossing, the trail should meander to the inboard edge of the road and descend toward the stream. This layout will maintain a curvilinear alignment through the crossing and eliminate the potential for diversion of water along the trail. In most cases, heavy equipment can complete the trail approach as part of the crossing excavation, but cannot be used where the trail intersects the stream. Once the heavy equipment is safely away from the crossing, a suitable trail structure, such as a bridge or a rock armored low-water crossing, is constructed by hand using trail crews. (See Photo 11.22.)

Although they can be found anywhere on the landscape, watercourse crossings are often concentrated along the lower and middle segments of a hillslope where watercourses are more numerous. Removal of a watercourse crossing requires excavating the crossing fill, culverts, logs, and other debris from the channel. The excavated soil is moved away from the crossing, so that it cannot clog the crossing in the future, and it is deposited in a stable location to prevent delivery of soil directly into the stream. Removing the crossing fill restores the watercourse to its original course and grade and disconnects the trail hydrologically from the watercourse, preventing diversion of the watercourse flow down the trail.

***Photo 11.22 - Drainage Crossing Structures***

Removal of a watercourse crossing includes the removal of “Humboldt crossings.” Built by placing logs into the watercourse channel and then pushing fill over them with a dozer, “Humboldt crossings” pose the gravest threat to aquatic and riparian habitats. These crossings can plug easily during high flows and catastrophically fail or divert runoff onto an adjacent trail. Excavation of a watercourse crossing includes removing culverts, pipe arches, or log bridges that will eventually fail if not maintained. In some cases, a trail is constructed across a watercourse without any drainage structure, leaving the flow to cross directly over the trail.

The best time to remove a crossing is during late summer when the watercourse is low or dry. If the watercourse is flowing, it can be temporarily diverted around the site using a small cofferdam and flexible pipe. A temporary diversion will help keep the work area dry and prevent sediment from moving downstream during construction. It also helps protect fish and other aquatic species. To prevent pooling and catastrophic failure, removal of wet crossings must begin at the downstream end of the crossing. For a dry crossing, the excavation can start at either end. However, unexpected rainfall and runoff before the crossing excavation is complete can lead to disaster.

As with other re-contouring efforts, the first task is to remove the trees and brush from the fill material. Because thorough mulching is necessary on all watercourse crossings, removed vegetation should be stockpiled nearby for later use as mulch. Once the brushing is finished, the dozer digs out as much fill material as possible from the crossing. The dozer pushes soil in both directions away from the center of the crossing and places it on the adjacent road surfaces that will be converted to a trail. The soil is compacted in 6-inch horizontal lifts against the cut bank. Avoid placing fill against the cut bank immediately adjacent to the crossing. Instead, push it as far away from the crossing as possible. As the dozer digs down into the crossing, the banks become steeper. When the hole becomes too steep and the dozer can no longer push out of the crossing, the excavator moves in to finish the job. The excavator can reach deep into the crossing and place soil up slope where the dozer can continue to push it away.

In some cases where a stable location does not exist adjacent to the crossing, the fill from the crossing is hauled away from the watercourse to locations where there is insufficient soil to complete the road to trail conversion (i.e., reconstruct the cutbank above the trail). In those cases, an additional excavator or wheeled loader can load a dump truck from a pile pushed up from the crossing by the dozer. When planning an excavation that requires export of removed material, it is important to leave a serviceable road into the site for the trucks to use until the last of the fill is excavated. If access to the site is cut off too soon, the excavator may have to move the same soil several times to get it all the way out of the watercourse.

During removal of a watercourse crossing, all fill located in the crossing is removed to reveal the natural watercourse bed and banks. Natural features, such as large woody debris, rounded gravel, cobble, boulders, dark organic soil, and bedrock, are usually reliable indicators of the original watercourse bed and banks. When excavating a watercourse crossing, look for buried stumps that indicate the natural slope adjacent to the watercourse, and adjust excavations accordingly. It is also useful to examine the banks up- and downstream to get a feel for the natural shape of the watercourse. If a natural streambank is difficult to locate, lay the bank back as much as possible to create a gentle slope adjacent to the watercourse.

The watercourse gradient through an excavated crossing is typically a constant slope from the upper to lower control points. On a high-gradient watercourse, the channel should follow its original course through the excavation and not have any sharp bends. The watercourse should follow the fall line and run directly down the slope. On a low-gradient, meandering stream, try to locate and match the bends and turns of the natural channel. Preserve natural nick-points in the streambed, such as bedrock or large stumps still rooted to the ground, to help protect against gully formation.

Large rocks and woody debris resting on the bed of the channel should be removed. These obstructions may deflect water flow into the soft banks of the crossing, leading to slope failure and delivery of sediment directly into the watercourse. (See Photo 11.23.) Natural recruitment of large rocks and woody debris will occur over time, giving the bank a chance to harden and re-vegetate. When available, brow logs can be placed so they span across the stream channel above future high water flows. The center of these logs is then partially sawn through with a power pole saw. The weakened log will fail within a couple of years and drop into the channel, adding woody debris to the stream channel after it has made its post-excavation adjustments and without causing undo lateral channel scour.

***Photo 11.23 - Watercourse Crossing Removal During and After***