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Appendix C. California State Parks' Best Practices

The term "best practices" as used in this handbook is defined as the processes, methods, and techniques that result in the most effective and efficient trail management. Best practices produce trails that have minimal impacts on park resources, have the longest duration with the least maintenance requirements, and meet the needs of the trail users. Best practices should evolve through adaptive management.

The following best practices were extrapolated from the 27 chapters of this handbook. They have been summarized by chapter for use in planning, environmental review, permitting, and contracting documents.

Section 1. Planning and Administration

Chapter 1. Introduction

Management Philosophy
To accomplish the mission of providing high quality recreation while protecting park resources, a trail must be routed, designed, constructed, and maintained to the highest standards, which requires understanding the landform associated with the trail. It also requires knowledge of the user groups the trail is intended to serve, and the needs and design standards specific to each user group. In addition, the highest quality construction standards are applied to the building and maintenance of trails. Only by combining all of this information can sustainability for each trail be achieved.

A sustainable trail is a trail that has been designed and constructed to a standard that does not have an adverse impact on natural and cultural resources, can withstand the impacts of the intended users and the natural elements while receiving only routine cyclic maintenance, and meets the needs of the users so they do not deviate from the established alignment.

Trails provide a vital connection to a park's natural and cultural resources and should never significantly compromise or detract from them.

Aesthetic considerations in trail design, construction and maintenance should always be a primary concern. The trail itself or any of its components should not overpower or distract from the natural or cultural setting, but should be seamless with the natural environment and provide the visitor with the illusion that they are traversing the land without being separated from it. The senses of a trail user should be focused on the surrounding environment rather than the trail itself. A well designed, constructed and maintained trail will provide the visitor with a pleasant and memorable park experience.

Trails are developed for the use and enjoyment of the visitor. The visitor's experience on the trail is one of the primary considerations of trail management. Trails need to meet the recreational trail needs of the public in a manner that is safe, sustainable, and enjoyable for current and future generations.

Not all trails can be fully accessible, but all trails should be built as obstruction free as possible considering the site constraints including sensitivity of cultural and natural resources, landform limitations, trail use designations, and local construction practices and regulations.

Consider access to the entire trail and related facilities, not just individual elements. Support facilities, such as trailhead parking, restrooms, signage, and picnic areas, should not present barriers to the accessible components of a trail. When a trail structure is replaced, even on a section of trail that is not considered accessible, the new structure should be made as accessible as possible so that access is incrementally improved on a system-wide basis.

Chapter 2. Trail System Development and Management

Trail Systems

Typically, a park has more than one trail and more than one type of trail use (hiking, biking, equestrian, etc.). To meet the long-term recreational needs of the public and to effectively budget and allocate resources, trail program managers should plan and manage for the entire system of trails in a given park unit. A system may consist of trails for hiking, biking, equestrian, interpretive, administrative, or a combination thereof. To the extent possible, public land managers should strive to achieve trails that are accessible and sustainable.

A trail system also includes trail amenities such as signs (informative, interpretive, and regulatory), parking, benches, picnic tables, viewing platforms, and backcountry camps. These amenities are necessary to provide a safe and comfortable recreational experience for trail users and to reduce impacts to natural and cultural resources. These facilities must be developed and managed as part of the trail system and should be included in any trail management plans and actions.

Base Map Development

The first step in trail management is to define the quantity and location of all trails in the system. This process begins with the development of a base map that identifies all the trails in the trail system. Base maps are typically developed by walking the trails with a Global Positioning System (GPS) to collect electronic line and point data, which are then incorporated into a Geographic Information System (GIS) for graphic display. Trail brochures and maps, aerial photography, USGS maps, and local knowledge also can be used to develop a base map.

Segmentation

Prior to assigning trail attributes, trails on the base map are divided into segments based on trailheads, intersections, and trail ends. Segmenting the trail enables trail program managers to break the trail into manageable pieces and efficiently identify the unique characteristics of that portion of trail. Segments are identified and stored in GIS, which allows for easy identification of specific locations along the trail.

Assigning Trail Attributes
The term “attribute” refers to the general characteristics of a route, such as designated uses, road or trail, and classification, as well as specific characteristics such as types of trail structures, landscape features, and design features. The assignment of attributes to a route allows trail program managers to differentiate or group trails and trail features based on these characteristics.

<u>Trail Classification</u>
A hierarchy for trail management must be established. Not all trails have the same value as a recreational asset. To establish such a hierarchy, each trail is placed into a class using specific criteria with predetermined values.

Classifying a trail system requires input from staff that are knowledgeable about the facilities, transportation routes, circulation patterns, and trail usage. Classification should be performed at least once every five years. Facilities, sensitive resources, and visitor use patterns are subject to change, and a trail’s point value may rise or fall accordingly. Periodic re-evaluation of a trail ensures that assigned standards and work priorities reflect the current system’s needs.

<u>Trail Use Type</u>
Trails are also categorized by the type of use allowed. In addition to “accessible” or “non-accessible”, trails are assigned a use designation from one of the following categories:

- Pedestrian
- Equestrian
- Bicycle
- Multi-Use

Trail Standards
Each trail class must be assigned minimum standards for construction and maintenance. Additional standards are identified for each trail use type and structure.

Developing Trail Facility Numbers
After the trails are grouped by classification, facility numbers must be assigned. Trails and trail segments are not assigned unique facility numbers but are grouped together based on trail classification, designated use type, and accessibility. Trail program managers can then use these groupings to develop an appropriate maintenance budget.

Trail Inventory and Assessment (Zero Basing the Trail System)
Once the trails are attributed and the facility numbers are established, each trail segment is thoroughly inventoried and inspected. In trails, “zero base budgeting” is the process of inventorying and identifying all features and structures within a trail system, identifying their size, quantifying their total number, identifying the frequency for maintenance or replacement, identifying the tasks and corresponding person hours for performing this work, and identifying the cost of materials, tools, and equipment

associated with these tasks. Through this process the cost for maintaining a trail system can be accurately and fairly identified and traced back to its original trail inventories.

Trails are inspected to determine their deviation from design standards, structural integrity, and general condition. Deficiencies are noted and those structures that require repairs, upgrading, or replacement are entered into a Trail Log. Through this process, a complete inventory of trail features and structures is recorded and every deficiency is identified and quantified.

Trained personnel are essential for an accurate representation of the facility, and those assigned to complete the inventory must understand trail construction and structures.

Information entered into the Trail Log should be consistent. If an action is recommended, the prescribed treatment should be the same as for similar trail features. Variation between similar features can be noted in the comments section of the Trail Log. To help standardize data entry, a standard list of trail features in the Trail Feature Attribute Sheet is attached to the Trail Log.

Sustainability and Maintainability
After each trail has been inventoried and evaluated it is categorized into sustainable, maintainable/unsustainable, or unmaintainable/unsustainable.

Sustainable trails are:
1. Designed and constructed so they do not adversely affect natural and cultural resources (i.e., “take”). Any impact considered “take” is avoided, and in areas considered “sensitive,” impacts are mitigated through planning and environmental review.
2. Designed and constructed to not disrupt or alter the natural hydraulic flow patterns of the landform. Sheet flow runoff is not diverted or accumulated, and runoff is allowed to continue on its normal flow path. Watercourses, including micro-watercourses, are not captured, diverted, or coupled with other watercourses by the trail. Water does not accumulate on the trail and does not drain onto the landform where natural watercourses do not exist.
3. Designed and constructed to withstand the impacts of the intended user and the natural elements while receiving only routine cyclical maintenance.
4. Designed and constructed to withstand the impact of 25- to 100-year storm events. These events minimally affect the trail tread and structures, including above and below the trail alignment. Impacts are anticipated and avoided through good planning and design.
5. Designed to meet the needs of the intended user group or groups. A high level of satisfaction results in users staying on the designated trail alignment and not creating unauthorized or volunteer trails. User satisfaction also results in the continued use of the trail.

Unsustainable but maintainable trails are trails that do not meet the sustainable trail definition but are considered integral to park operations; allocating maintenance or reconstruction funds and resources can reduce impacts related to natural and cultural resources, visitor safety, and/or access.

Unmaintainable/unsustainable trails are trails that are not properly designed and constructed. The cost for maintenance and rehabilitation of these trails exceeds their value to park operations. This group of trails represents a liability to park resources and operations and cost more to maintain than they are worth to park operations. These trails should be removed and rehabilitated, or removed, rehabilitated, and replaced with a sustainable trail alignment. Until the land management agency has the resources to remove these trails, they receive the maintenance necessary to minimize their impact on park resources and provide safe use.

Trail Project Development

A rehabilitation program may be necessary when a trail system's maintenance needs exceed the trail program's maintenance capabilities, which usually occurs due to poor initial trail design and layout, inadequate funding, poor management, lack of assigned staff, or natural disasters such as floods, storms, and earthquakes.

The process of identifying and quantifying the work in a rehabilitation program or project consists of listing, quantifying, and recording those items that require repairs.

To quantify trail rehabilitation cost, Trail Log totals are sorted and entered into trail cost estimating worksheets. The worksheets identify the costs for labor, materials, tools, equipment, and contracts required to perform the trail construction project. They also identify project planning, management, and permitting, as well as natural and cultural resource surveys.

<u>Project Prioritization</u>

To provide an objective and impartial selection process, trail maintenance and rehabilitation projects are selected using the trail project selection matrix. Criteria such as visitor safety, resource protection, preservation of investment, visitor convenience, and new trail construction are used to assign point values to each proposed trail project.

Which trails are selected for maintenance and rehabilitation is also influenced by their classification. Assuming visitor safety, resource protection, and trail investment concerns are equal, trails with the highest classification and point total receive the highest priority.

<u>Scheduling Trail Projects</u>

Scheduling is performed a minimum of one to three years in advance to ensure that there is adequate lead-time to complete the necessary environmental documents (e.g., CEQA), cultural documents (e.g., 5024), surveys, and consultations, as well as obtain all required permits.

Staff from each park program must have the opportunity to identify and submit trail projects for the prioritization, selection, and scheduling.

Trail project schedules are developed for work crews, supervision, and specialized equipment and tools.

All trail projects must have a qualified lead person to organize and direct daily activities, maintain quality control, and ensure that the required tools, equipment, and materials are available when needed.

When developing project schedules, the following variables need to be considered: visitor use patterns, weather, rare and endangered species restrictions, project logistics and access, soil moisture conditions, labor source availability and appropriateness, and crew development and training needs.

Prior to finalizing project schedules, drafts are sent out for review and comment to staff from other park programs to ensure that there are no conflicts or operational problems with the schedules.

Contracting
Trail construction contracts should be clear, concise, equitable, enforceable, and performance-based.

Project Implementation
Before starting any trail project, all environmental and cultural approvals, surveys, permits, and consultations must be completed. The content and conditions of these documents should be reviewed with the project leader and crew, and copies of the documents kept at the project site while the work is being performed.

The necessary materials, tools, and equipment must be secured prior to the start of a project. Not having these items available at the beginning of a project results in poor morale and the loss of crew production.

Production Rates/Daily Work Records
Daily work production records must be maintained to monitor the progress of the work crew, quantify the units of work completed for contract payment, and refine trail production work rates.

Project Communication and Evaluation
Frequent communications must be maintained between the project leader and the program supervisor to keep the supervisor abreast of the projects progress and alert them to any issues that may affect the project.

Trail program supervisors must perform regular inspections of ongoing trail projects. These inspections are required to ensure that the project leader is achieving the desired outcomes for the project and that the work being produced is meeting the program's standards.

Once the project is completed, the trail is re-inventoried to update the Trail Log associated with that trail. The data from the new Work Log is sorted and entered into the facility maintenance budget.

Post project evaluations are conducted to identify both the positive and negative attributes of the project. Positive attributes are evaluated for further improvements and future replication, and negative attributes are evaluated and corrected to eliminate future problems (i.e., adaptive management and best practices).

Monitoring and Adaptive Management

Completed trail projects should be monitored and evaluated over a long period of time to determine the effectiveness of the project design and construction and adjust future design and construction methods accordingly (i.e., adaptive management and best practices).

Chapter 3. Planning and Environmental Compliance

Proper trail planning ensures that recreational trail opportunities are available at their fullest potential, while providing adequate and often enhanced protection for cultural and natural resources. Park-wide or regional trail planning is the preferred and most effective avenue for establishing trailheads, recreational trail corridors, and trail linkages.

Departmental Trail Policy

Through a public planning process, the Department will strive to meet the recreational, educational, and interpretive needs of its diverse trail users by developing trails within state parks consistent with park unit classification, general plan directives, cultural and natural resource protection, public safety, accessibility, user compatibility, and other legal and policy mandates. Multi-use trails and trail connectivity with adjacent pubic trail systems will be considered in development of trail plans or individual trails.

The Planning Process

The purpose of a trail, the user groups it will serve, its length, and other features and amenities are determined through the planning process. A plan can encompass a large geographic area, such as a state, region, or park unit, or be specific to individual trails.

A detailed project description should be developed based on the geographical scope of the plan, including the specific trail or system of trails. For large, complex plans, seek the input of other agencies, stakeholders, and the public to assist with scope development. Data from surveys, interviews, and workshops should be combined with staff recommendations and used to identify a preliminary plan including proposed change-in-use designations. Adjustments to the scope should be based on input from the public, stakeholders, and specialists.

When developing a trail plan, clear goals and objectives must be identified. The goals of a trail plan describe the desired end result. Objectives describe how to achieve the goals.

Trail planning requires an extensive literature search on the geographic area that the trail or trail system will be constructed. Collect all relevant planning and policy documents that have been prepared for the geographic area, including those prepared by other agencies or quasi-public organizations. Other types of planning documents with relevant information may include transportation corridor plans and general land use plans. Additionally, a number of regulatory agencies may have policies governing land use in the area.

Data is essential to inform decision making. It should be objective information about the physical site or project area, as well as subjective information regarding public interests and regional issues. Data should be consolidated and organized for efficient use during the planning process.

The types of information useful to trail projects include:

- Unit classification policies and use restrictions;
- Maps of land ownership, easements, and right-of-ways;
- Restrictions imposed by deeds and covenants;
- Control agency regulations and concerns;
- Landscape and/or topographic limitations;
- Sensitive natural and/or cultural resources;
- Water quality issues; and
- Potential user types and associated mechanical wear.

Site inventories and assessments are used to determine the types and conditions of existing features and to guide decisions about trail alignment. The scope of the plan determines the extent of the assessment. For regional plans, GIS can be used to assemble large amounts of information over large areas. However, GIS can have low accuracy when relating the information to specific ground points. Without GIS and/or other accurate spatial data, information must be gathered from the field. Even with GIS and other spatial data, information should always be gathered from the field.

Some of the common information critical to trail inventory and assessment include:

- Natural and cultural resources;
- Location of sensitive and/or critical habitats such as wetlands and riverine systems;
- Topographic conditions and limitations;
- Soils; and Aesthetics and visitor experiences, such as vistas and points of interest.

Identify and involve pertinent agency stakeholders with regional jurisdiction and/or abutting ownership. Since trails are transportation systems, they often connect various jurisdictions. Additionally, control agencies frequently have permit authority within project jurisdictions. Asking for agency participation can help identify critical issues early in the process.

Public input is critical to identifying trail system needs and issues and for review of proposals and alternatives. It can produce valuable feedback and provide an opportunity to work out issues that may interfere with the environmental review or permitting process later.

Written or oral visitor surveys conducted over time can be used to identify the needs and issues of trail users. Be sure to survey users during various seasons and periods of use.

Public and stakeholder meetings are another means to obtain focused input. Meetings of this nature can also be used to formulate the scope and goals for large, more comprehensive plans.

In complex trail planning projects, a series of alternatives should be developed. Often public interest or the environmental review process requires that alternatives be considered. For simple plans, less emphasis is put on developing alternatives.

Road and Trail Management Plans
A formal road and trail management plan (RTMP) should be completed prior to making significant changes to existing trail usage, design, or alignment, constructing new trails, or eliminating existing trails. Increases in use, changes in user types, significant park acquisitions, damage from natural disasters such as wildfire, and the need to restrict use for public safety or to prevent significant resource damage may trigger the need for an RTMP.

If an RTMP is developed in the absence of an approved general plan, it should not conflict with any future general plan and may require a higher level of environmental documentation than those in a park with a general plan that has already been through environmental review.

Once approved, this document serves as an umbrella environmental document for all projects in the plan. When the park is prepared to construct a new trail or change an existing trail as described in the RTMP, the initial environmental review will already have been completed. Required project surveys and permits still have to be obtained but documents necessary for approval may be reduced.

Change-In-Use Process
The Department has developed a process to facilitate and make consistent the review of change-in-use proposals that would add or remove uses from existing recreational roads and trails in the state park system. This process is intended to identify those changes that best accommodate accessibility and recreational activities appropriate for each road or trail. Specifically, the process is intended to achieve the following objectives:

- Implement the Department's Trail Policy, including consideration of multi-use trails and trail connectivity;

- Ensure that projects can be implemented in a manner that avoids or mitigates significant impacts to the environment;
- Inform decision-making to include the diversity of resources and users at each park unit;
- Ensure that changes are considered in a transparent process; and
- Establish a process for decision making with objective criteria for evaluating proposed changes to trails.

When a change-in-use is conditionally approved, all required conditions need to be implemented, project specific environmental compliance completed, and funding secured prior to the change taking affect.

Environmental Review - CEQA and NEPA
For the purposes of environmental compliance, a "project" refers to a proposed activity, such as trail construction, that has the potential to impact the environment. A project may be either a physical change to a trail or a change-of-use. All trail projects in California require compliance with the California Environmental Quality Act (CEQA) or the National Environmental Policy Act (NEPA). CEQA applies to all projects undertaken by or requiring approval from state and/or local government agencies in California. NEPA is the federal equivalent to California's CEQA and applies to all projects undertaken on federal land or any project with a federal nexus such as federal funding. Some projects require both types of analysis.

Preparation of an environmental document requires a thorough understanding of the physical environment of the plan or project area. If little is known about the environment, data must be gathered and inventories conducted before potential effects can be assessed.

The documentation required to comply with CEQA depends on the scope of the project and environmental factors in the project area. The Project Evaluation Form is the environmental checklist used by the Department to initiate the environmental review process and identify the documents required for compliance. It is initiated after the project has been scoped, and a project description and preliminary design developed. This form is required of every proposed project in the California state park system.

Public Resources Code Section 5024.5, a subsection of CEQA, requires protection of cultural resources on lands owned or leased by the Department ("5024 review"). This review is common to all departmental projects and is part of the Department's project review and compliance procedures.

The California Public Resources Code also requires that "[a] project with an effect that may cause a substantial adverse change in the significance of a tribal cultural resource is a project that may have a significant effect on the environment." To help determine whether a project may have such an effect, the Public Resources Code requires a lead agency to consult with any California Native American tribe that requests consultation and is traditionally and culturally affiliated with the geographic area of a proposed project.

Regulatory Permits
Requirements for regulatory permits vary depending on the project's jurisdictional boundaries. An expert should be consulted to determine the required permits for a particular project and assist in their development.

Chapter 4. Visitor Trail Facilities and Amenities

General Principles and Guidelines
The installation of support facilities should be done with an eye toward maintaining the harmony of the environment while providing the necessary services and visitor convenience intended by the amenity. Environmental constraints are important elements that ultimately influence the location and size of a facility. Consultation with professionals and specialists when planning and designing these facilities is highly recommended.

Facilities must be functional and accessible, without requiring extensive maintenance. The location and materials selected for a facility should be unobtrusive and fit into the environment to the extent possible. Facilities should not alter natural drainage patterns and ground disturbance should be minimized to reduce the potential for erosion.

All facilities must be accessible to the extent possible. Even if the trail is not accessible, the concept of universal access (i.e., designing for all visitors) should be applied to visitor facilities.

Trailheads
A functional trailhead must have enough space to accommodate vehicle parking and other visitor services for the amount of use anticipated. For existing trailheads, user counts are gathered to determine parking demand. If visitor use levels are unknown, it is always better to plan for more usage than less.

Overlooks
Improvements to overlooks on a trail should be in keeping with the natural environment and kept to a minimum, to support use and not interfere with the user experience. The size of an overlook is dictated by the level of anticipated use by visitors and the physical and resource limitations of the site. Popular trails with highly regarded overlooks need substantial space and may require substantial infrastructure development. Avoid locations that cannot accommodate the level of anticipated use.

Overlooks surrounded by vegetation may require regular maintenance to protect the view shed. Vegetation can also be used to help frame the view, screen other development, or to establish a barrier that can prevent user encroachment outside of the overlook. Native species should be used to complement the surrounding environment.

Visitor Information and Signage
The primary location for disseminating public information about a park or trail is at the trailhead. Relevant information is provided through brochures and signage. Information along the trail itself is mostly interpretive and regulatory.

Displays at a trailhead should include as much information as possible including the location of the trail and trailhead relative to the trail system, trail length and difficulty, connector roads and trails, overlooks and unique features, and visitor amenities, such as restrooms and visitor centers. Additional information regarding up-to-date trail conditions, special rules or regulations, and emergency contacts should also be provided.

Most trail users look at a display for quick information and are not interested in spending long periods of time reading text. Large, complex displays are appropriate at trailhead locations, whereas succinct interpretive information should be available along the trail.

Signage on the trail should be discreet so as to not distract from the trail experience. In open settings, displays are kept low to prevent disruption of the view. In heavily vegetated areas, taller displays may be acceptable.

Trail signage identifying the trail name and distance are placed at the beginning or end of a trail and trail intersections. Directional signage or a route marker should be used when the trail corridor is not obvious or may be confused with other trails and should be placed where all users can see it, either on approach from the parking area or at the beginning of the trail where all users pass. Interpretive signage may be installed to identify special features but should not detract from the trail experience.

Regulatory or warning signs are only used as needed to ensure the safety of the trail user. A few signs properly worded and strategically placed serve trail users better and maintain a quality experience.

Barriers
Barrier wall should be no higher than 42 inches or meet accessibility guidelines as required. Low walls (17 to 18 inches) are also effective barriers and can be sat upon. At trailheads, a single boulder of 36 inches or more can bar vehicles without barring trail use. A single rock barrier should be set in the ground to a depth approximately one-third of its diameter so that it appears permanent.

Fencing on equestrian trails or in equestrian staging areas should extend high enough to avoid creating a trip hazard to the horse. The finished height is adequate to eliminate the reasonable possibility of a horse jumping over the fence. Fencing for equestrian applications should be wood, composite, concrete, plastic, or metal pipe and never barbed wire, which can result in injury to the animal.

Stiles
Stiles are used to allow specific user groups to access a trail while prohibiting other non-designated trail users or livestock from accessing the trail. For pedestrian trails, stiles should be designed to be accessible to the extent possible.

A gate is another alternative for allowing trail users and livestock to pass through a fence while limiting motor vehicle access. A self-closing stock gate with a lever latch mechanism can ensure that no gate is left open.

Benches
Where possible, benches should comply with accessibility standards. Benches constructed using these standards are comfortable and usable by all. The final product should be of sound quality and free from splinters or rough edges. In the trail setting, natural finishes are preferred. Benches should be oriented such that the experience of the setting is maximized, while providing protection from prevailing wind or sun in hot climates. Benches and tables should be placed on level ground and not interfere with the flow of trail traffic. They may need to be anchored to prevent people from moving them, but anchoring methods should be inconspicuous so as not to be a distraction.

Section 2. Trail Layout and Design

Chapter 5. Principles of Trail Layout and Design

Trail layout and design are the processes of applying modern trail design concepts to a systematic approach of laying out trails. They are used to determine the location and construction standards for a trail and are the most important elements of a trail system because if they are not performed correctly the trail will not be sustainable and will always be a liability. Trail layout and design are as much art as they are science, and a well-designed trail has both form and function.

Life of a Trail
All trails have an impact on the land where they are constructed. This impact can be minor or severe, depending on how well the trail is designed and constructed. In addition, all trails require maintenance. Even the best-designed and constructed trails require cyclical maintenance to perform properly.

Trails can last for hundreds of years. With such a lifespan, trails that are not properly designed, constructed, and maintained can have long lasting adverse impacts on natural and cultural resources, and can be a liability to the land management agency’s funding and staffing resources.

The ideal trail is integrated with the outdoor environment or setting, provides access to unique and aesthetically pleasing features, provides the user with a sense of discovery, and does not distract from the users’ experience. Such a trail is designed for long-term sustainability and resource protection. A well designed trail results in cost savings over the long-term because storm-related failures are avoided or greatly reduced and annual maintenance is minimized.

Elements of a Good Trail
A well-designed trail has the following characteristics:
- Avoids sensitive natural and cultural resources;
- Avoids problematic geomorphic features;
- Follows curvilinear alignment;
- Does not disrupt or alter the hydrology of the landform;
- The linear grades do not exceed the maximum sustainable grade;
- Has full bench construction with adequate outslope;
- Has stable and well vegetated fillslopes and cut banks;
- Has crossings sized for the maximum foreseeable flood event and are passable to aquatic species, bed load, and debris;
- Requires minimal routine and cyclic maintenance; and
- Meets the needs of the intended user groups.

A trail is more than a route to a desired destination; it is an experience. The designer integrates points of interest and aesthetic experiences with a technically sound alignment. A well-designed trail seamlessly traverses the natural setting. The focus of the user is on the environment they are passing through and not on the trail.

Identification of Trail Use Types, Classifications, and Design Standards
In designing, laying out, and constructing a trail, each trail classification has minimum design and construction standards that must be considered along with specific standards for each user groups and trail structures and features.

Mechanical Wear
The potential rate of mechanical wear associated with the designated user types and anticipated amount of trail use must be identified when designing and laying out a trail. Mechanical wear is defined as the erosion of material from a surface by the action of another surface. As it relates to trails, mechanical wear is caused by the interaction between the trail tread and the mode of locomotion used by the trail user. The most common interaction of trial users with trail tread occurs through pedestrian footwear, tires, or horse hooves.

<u>Identification of Mechanical Wear</u>
All trail uses cause mechanical wear to the trail tread. However, the rate of wear will vary by the type of user and how aggressive their interaction (use) is with the trail tread.

Factors influencing the rate of mechanical wear include:
- Hardness and shape of user surface;
- User weight and surface contact area;
- Velocity, angle of impingement, and coefficient of kinetic friction; and
- Acceleration, braking, and turning/curving.

<u>Linear Mechanical Wear and Vertical Point Depression Features</u>
When identifying the potential for mechanical wear, linear depressions and vertical point depressions must be considered significant factors. Linear depressions can capture,

channel, and divert water down the trail. Vertical point depressions can disrupt sheet flow across the trail and break up soil structure. Both can quickly erode the trail tread and affect the trail's ability to sheet overland water flow.

Sudden Grade Changes
Because of the increased mechanical wear, a sudden grade increase should be avoided. If a drainage structure such as a grade reversal is used, the grades going into and out of the structure should be gradual and never exceed the maximum sustainable linear grade.

Parent Soil Strength and Durability
The composition of the soil comprising the trail tread affects the rate of mechanical wear. The harder and more consolidated the tread surface, the more resistant it is to mechanical wear. For this reason, the more the rate of mechanical wear increases, the more important it is to locate the trail on the most stable and durable soil.

Natural Erosion
The potential for natural erosion must be identified and included in the design and layout of a trail. Natural erosion is caused by the impact of solid or liquid particles against the surface of an object that gradually removes material from the surface.

Mechanical Wear and Natural Erosion
When mechanical wear deforms the trail tread, the trail loses its structure and is more susceptible to natural erosion. Divots, vertical depressions, linear depressions, gouges, scrapes, and scuff marks can trap and concentrate water or divert it down the trail leading to soil saturation, displacement, and mobilization. Loose, unconsolidated soil is subject to wind erosion during dry periods and mobilization during wet periods. Once the tread becomes deformed by these natural processes, it is even more vulnerable to mechanical wear. In a deformed state, the trail tread will rapidly deteriorate as mechanical wear and natural erosion work together.

Categories of Mechanical Wear

Low Mechanical Wear

Some trail users are seeking a more passive trail encounter where the user experience is on the "setting" rather than the mode of travel. The user's interaction with the trail tread is non-aggressive, which minimizes mechanical wear.

Trail design, construction, and management techniques for low mechanical wear include:
1. Perform thorough background research to increase your knowledge of the landform.
2. Avoid significant impacts to sensitive natural and cultural resources
3. Mitigate potential impacts to natural and cultural resources and avoid problematic landform controls.
4. Layout trails following curvilinear alignment.

5. Separate trails from all watercourse features including micro-watercourses (dip in and pull out).
6. Stay within the maximum sustainable grade of the landform.
7. Avoid sudden grade changes.
8. Locate trail alignments on hillsides whenever possible.
9. Construct trails with a full bench whenever possible.
10. Outslope the trail tread sufficiently to maintain natural sheet flow across the trail.
11. Perform trail construction to the highest standards.
12. Allow the trail tread to cure before use.
13. Perform the proper selection, placement, and construction of all trail structures.
14. Design and construct trails that meet the needs of the intended user group(s).
15. Employ seasonal trail closures when tread soils are weak and unconsolidated.
16. Inspect trails annually for maintenance and repair needs.
17. Perform the required routine and cyclical trail maintenance.
18. Monitor trails and apply adaptive management concepts to constantly improve design, layout, construction, and management practices.
19. Establish, post, and enforce speed limits.

Moderate Mechanical Wear

With uses that cause moderate mechanical wear, the user is focused on both the setting and mode of travel. The mode of travel is as important as being in the natural environment. The user’s interaction with trail tread is more aggressive, which increases mechanical wear.

Trail design, construction and management techniques for moderate mechanical wear include:
1. All of the techniques listed above for low mechanical wear.
2. Increase trail sinuosity to reduce the speed of users.
3. Trail sinuosity should be horizontal on the landform and not vertical.
4. Trail design utilizes natural features to create a slalom type experience going around features such as trees and rocks.
5. In the absence of natural features, install pinch points to slow trail users.
6. Reduce tread width and sight distance to slow trail users.
7. Install trail texturing to slow trail users.
8. When outsloping is insufficient to effectively maintain sheet flow across the trail, install grade reversals with moderate grade approaches to facilitate drainage across the trail.
9. Employ the use of “run outs” at the bottom of downhill trail segments.
10. Use tread armoring techniques such as turnpikes, causeways, rip rap, stone pitching, aggregate surfacing, chemical hardeners, running planks, boardwalks, corduroy, concrete pavers, geo blocks, or grass pavers, etc. to reduce mechanical wear and improve tread life.
11. Expand the use of seasonal and temporary trail closures.
12. Limit amount of use to reduce user impacts.

13. Inspect trails biannually for maintenance and repair needs.
14. Increase routine and cyclical trail maintenance to compensate for increased mechanical wear.

<u>Heavy Mechanical Wear</u>

With uses that cause heavy mechanical wear, the user is primarily focused on the mode of travel. The user's interaction with the trail tread is very aggressive, which substantially increases mechanical wear.

Trail design, construction and management techniques for heavy mechanical wear include:

1. All of the techniques listed above for low and medium mechanical wear. Note that the use of curvilinear alignment, staying within the maximum sustainable linear grade, and using the standard switchback and climbing turn designs may not be applicable to some trail uses in this category as these concepts conflict with the trail experience some users are seeking.
2. Locate trail alignments on bedrock or rocky terrain whenever possible to reduce mechanical wear.
3. When outsloping and grade reversals are insufficient to effectively maintain sheet flow across the trail, install rolling grade dips to facilitate drainage across the trail.
4. Increase the use of water management control structures to keep water from accumulating on the trail.
5. When installing climbing turns and switchbacks, design the turns to be banked and incorporate rolling dips.
6. Increase tread armoring where required and appropriate.
7. Develop a sediment budget to monitor and manage soil erosion.
8. Install erosion control measures.
9. Install sediment collection basins below the trail alignment to reduce the volume of sediment entering the watershed.
10. Monitor the performance of soil erosion control techniques including water sampling for turbidity levels.
11. Employ one-way traffic to increase safety.
12. Close, rehabilitate, and rotate trail alignments once they become degraded.
13. Increase management patrols to ensure user compliance, improve safety, and respond to emergencies.
14. Inspect trails quarterly for increase routine and cyclical trail maintenance to compensate for increased mechanical wear.
    Substantially increase routine and cyclical trail maintenance to compensate for increased mechanical wear.

Maintaining Natural Watercourses

Water is the most influential factor in designing and laying out trails. Overland runoff must be allowed to travel its natural path. Water in a watercourse, even an ephemeral swale, needs to stay in the watercourse and not be captured by the trail surface.

Natural flow is maintained by laying out trails on the contour of the land, which helps facilitate natural sheet drainage. This type of trail layout is called curvilinear alignment (crossing contour lines at nearly flat or oblique angles). Curvilinear layout keeps the trail alignment nearly perpendicular to natural sheet runoff, and requires following the landform, pulling in and out of swales and crenulations.

Curvilinear alignment combined with sustainable linear grades, hillside construction, full bench construction, and outsloping prevents water diversions and accumulation. Retaining the landform's natural drainage patterns is the key to sustainable trails.

Trail Layout

<u>Review of Existing Information</u>

Before a trail designer begins field work they must have a thorough understanding of the landform the trail will be traversing. A review of all applicable literature, including geology, hydrology, soils, topography, and cultural and natural resources, is required. Extra attention needs to be given to reports on sensitive cultural, plant, and animal resources that could be impacted by the proposed trail. Other important background information includes property boundaries, easements, rights-of-way, and other transportation routes.

Historic photographs, topographic maps, and aerial photographs aid better understanding of the landform. If available, LIDAR imaging and SHALSTAB digital mapping programs provide even greater detail and geomorphic information on the landform. In addition, CEQA documents and biological assessments developed for projects in the vicinity can contain information valuable to trail planning and construction.

<u>Major Control Points and Average Linear Grades</u>

Once the existing information is reviewed and assimilated, the major control points between the starting and ending of the trail are identified. Generally, these points are where the new trail alignment must pass through or avoid. After these points are confirmed and established, the broad trail corridor is narrowed and adjusted to accommodate these locations.

The average linear grade between control points is calculated by dividing the elevation difference between two control points by the linear distance between the points.

<u>Maximum Sustainable Linear Grades</u>

Maximum sustainable linear grade is the linear grade of a trail that, when combined with proper layout and construction, will result in a trail bed that requires only routine maintenance and will not threaten resources, even when subjected to severe weather conditions or heavy use.

The maximum sustainable grade is determined by evaluating information obtained during the literature research, design standards, and field reconnaissance. The following variables are evaluated in order to establish the maximum sustainable trail grade:

- Specific trail design standards
- User group, user interaction with the trail, and amount of use
- Soil strength and durability
- Annual rainfall
- Rainfall intensity
- Canopy cover
- Percent of hillslope
- Location on the hillslope
- Season of use
- Evaluation of existing trails

Once the maximum linear grades have been identified between the major control points, they can be compared to the average linear grade between the major control points determined by the rise over run calculations. If the average grade is steeper than the maximum sustainable grade, the trail alignment needs to be adjusted (lengthened) to conform to the grade limit.

If land base, resource, aesthetic, or construction feasibility issues prohibit lengthening the trail in a curvilinear fashion, then trail features and structures such as topographic turns, climbing turns, and switchbacks need to be considered to lengthen the trail. These trail features and structures must be placed at appropriate locations and themselves become minor control points.

Designed Linear Grades

Sometimes a maximum sustainable grade may exceed the user‘s comfort level or needs. In that case, the linear grade should be adjusted (lowered) to meet the need of the user group.

Field Reconnaissance

Once a proposed trail corridor that incorporates the major control points and average linear grade between the points is identified on a map, field reconnaissance is performed along the route to investigate the landform. It is a good idea to involve resource specialists, including engineering geologist, hydrologist, botanist, resource ecologist, wildlife biologist, archeologist, and historians. Getting their involvement early in the design and layout process improves the evaluation of the landform, enhances the synergy that occurs between disciplines, and reduces any conflict that may occur before the environmental review.

Prior to setting foot on the landform, it may be desirable to use a helicopter or fixed wing aircraft to fly above the proposed alignment to give the designer a “bird’s eye” view of the landform. An overhead view provides an image of the land and helps locate potential problems, such as landslides, unstable inner gorges, cliffs, and steep slopes. It also provides the designer with a view of the vegetation types growing within the trail corridor. Vegetation is often a good indicator of soil type. Some plants prefer saturated soils while others prefer rocky well drained soils. Identifying vegetation and the soil types they prefer gives the designer a good indication of the soil types they will encounter once they perform on the ground reconnaissance.

This “big picture view” also helps to understand the spatial relationships of topographic features, such as ridges, watercourses, hilltops, rock outcrops, and flat benches of land. If an overhead flight is not possible, viewing the area from a prominent elevation such as a mountain top or ridge is the next best option. Earth observation software such as aerial photographs and Google Earth can also provide the designer with a three dimensional view of the landform. These programs provide a virtual flight over the landform with a variety of views. The quality of the view depends on the aerial photographic coverage and how recently the photographs were taken. On the ground, this kind of overview is more difficult and time-consuming to obtain.

On-the-ground reconnaissance involves walking the trail corridor several times to become familiar with the landscape. The reconnaissance is necessary to:
- Ground truth earlier planning and mapping efforts;
- Identify additional control points along the proposed trail corridor and the average grade between control points, which are then worked into the adjusted trail alignment;
- Provides an opportunity to inspect the landform to assist in determining the maximum sustainable linear trail grades. These grades are compared to the average linear grades between the control points. The alignment is adjusted as needed to stay within the maximum linear grades.

Minor Control Point Identification
Minor control points are locations that the trail should go to or avoid. They differ from major control points in that issues they present may be resolved through engineering or construction techniques. Identification and mapping of minor control points further narrows the trail corridor and breaks it up into smaller segments. Segmenting the trail corridor in this way simplifies the layout process and provides the designer with information necessary to more easily flag the trail route.

Designed Control Points
Designed control points are locations on the landform that call for a trail structure. Incorporating certain characteristics of the landform is essential to the successful performance of some trail structures, such as watercourse crossings and turns.

Wet Watercourse Crossings
Some wet trail crossings in low volume watercourses can be crossed even during peak flows. These streams are usually ephemeral. Appropriate crossing locations have a mild stream gradient that is controlled by a feature such as bedrock, boulders, or large trees, often referred to as “nick points”, in or near the channel. These features stabilize the channel gradient and make it easier to construct and maintain the crossing. The channel must be straight and not subject to lateral scour, undercutting, or deposition.

Streambanks must be stable with moderate slopes for successful construction of the trail in and out of the channel.

Fords are primarily intended for use by horses. They are located in streams that have low to moderate flows, or are closed to use when higher flows occur, usually in winter and early spring. Good ford locations exist where the stream gradient levels off after a steep run and the channel is comparatively wide. This leveling off causes small rocks and coarse aggregate to drop out of suspension and deposit in the streambed creating a streambed that is easy for horses to cross without slipping on large, smooth, slick rocks.

Dry Watercourse Crossings

Dry crossing sites are usually located on large and deep bodies of water or on Class I trails, where user expectations do not include getting wet. These sites have bridges with their own design requirements. A bridge site is located where the stream channel narrows and the banks are high above the stream. A narrow channel limits the length and size of the bridge, and the high banks keep the bridge above future flood events. Careful investigation of the stream channel is required to ensure that the bridge is above future flood events (100-year flood event minimum).

The channel should be inspected up and downstream of the crossing site to find indications of past flood events such as scour marks on streambank walls, vegetation loss or changes, 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. To determine the high water mark, design for the largest woody debris that might be carried downstream in a flood event. Floating logs and trees can project several feet above the high water mark, so additional freeboard is required for these objects to pass under a bridge.

The general condition of the stream channel must also be evaluated. Banks need to be stable and, if possible, composed of scour-resistant material such as bedrock. In the absence of bedrock, the bank material should not be subject to sloughing or crumbling. The banks adjacent to the bridge abutments must not be subject to erosion and undercutting from lateral scour. Any bridge site should be located away from the outside bend of a channel where banks will be eroded by the current.

The general health of the watershed should also be evaluated. Channels lacking exposed bedrock, boulders, or large woody debris may be in a “depositional” mode. This condition is exemplified by small aggregate and silt deposited in terraces adjacent to the channel and reflects an unstable watershed. The true scour line, “thalweg”, of the channel may be substantially lower than what is observed in the field. Knowing the true thalweg is critical in determining the depth of the bridge abutments that are to be constructed adjacent to the channel. In addition, a stream channel filled with aggregate may cause lateral bank scour that could undermine abutments adjacent to the channel.

Prior to the final selection of a bridge-crossing site, a hydrologist or a qualified engineer should be consulted to evaluate the crossing site and calculate the water discharge levels during a 100 year flood event.

When designing a watercourse crossing, it is important to make certain that the downhill leg of the trail coming out of the crossing is fully separated from the inner gorge before beginning the descent. If the downhill descent occurs within the watercourse's inner gorge, the trail will likely traverse through wet and unstable ground.

Turns

Turns are trail features or structures used to gain additional linear run to reduce linear grades. If landbase, resource, aesthetic, or construction feasibility prohibits lengthening the trail in a curvilinear fashion, then trail features such as topographic turns, climbing turns, and switchbacks are used to overcome elevation gains between control points. If a turn is required, the designer must find the appropriate location for it. The appropriate location for a turn will depend on a number of criteria related to the design, function, and sustainable performance of the feature.

The first option is a topographical turn, facilitated by a small hill or knoll, which allows the trail to contour around a small hill while maintaining an outsloped trail bench. This feature facilitates a change in direction without the additional construction and drainage design associated with climbing turns and switchbacks.

A climbing turn or a switchback is the next option for a turn. Generally, a climbing turn is preferable to a switchback because it requires less excavation and retaining wall construction. Typically, a climbing turn is located on a hillslope of 30% or less, and a switchback is located on a hillslope steeper than 30%. Switchbacks located on steep slopes require more excavation into the hillside to construct the upper leg and the inside (upper) corner of the turn. The lower portion of the switchback usually requires a retaining structure to support the fill material used to build the lower or downhill portion of the turn. Located on steep hillslopes, the change of direction associated with the upper and lower leg of a switchback is more acute than those of a climbing turn.

The design and location of climbing turns and switchbacks are very similar. Both are built into the hillslope and located on the landform where they can be properly drained. Since the upper legs of the climbing turn and switchback need to be insloped to prevent water from draining onto the lower leg, they must be placed where the upper leg can drain freely off the corner of the turn. The best place for these turns is on the nose of a ridge or near the upper flanks of a watercourse. Both locations allow the water collected on the upper leg to drain freely off of the corner of the turn.

Another important location criterion for climbing turns and switchbacks is a break in slope. By locating the corner of the turn where there is a distinct change or break in the slope of the hillside, one leg can be located above the break and one leg can be located below the break. This break in slope can effectively be used to obscure the lower leg from the field of vision of a trail user coming down the upper leg. This break in slope can be further enhanced by taking advantage of natural barriers such as trees, large rocks, or dense brush. The turn is placed where these barriers are located between the two legs.

Topographic Control Points
Sometimes there are topographic features on the landform that can serve as control points. The most common of these features is a low point or saddle on an extended ridge. These locations control the elevation of a potential trail alignment simply by being the lowest point of land that a trail can pass through. Recognizing these control points early in the layout and reconnaissance process can expedite the determination of the trail corridor, the location of control points, and the grades between those control points.

Problematic Topography
Certain locations on the landform should be avoided by trail designers whenever possible. One of these locations is a ridge top. Trail designers often locate trails along the tops of ridges for the view and to minimize the amount of required brushing, clearing, and trail construction. If the ridge is comprised of very durable bedrock, this layout practice is acceptable. However, if the ridge top is comprised of soil the construction of the trail tread (even light brushing and clearing) will result in the trail bed being lower than the surrounding soil horizon. With the trail bed lower than the terrain adjacent to it, surface runoff cannot flow off the trail, and it will begin to flow down the trail. The trail effectively becomes a ditch and the combination of water erosion and mechanical wear quickly incises the trail bed.

A similar problem occurs when trail designers layout trail on flat ground. As soon as the trail is constructed, the trail bed is lower than the surrounding soil horizon. Even if the sod is not removed, the initial user traffic will compact the soil in the trail bed below the adjacent terrain. Sheet flow accumulates in trail bed and ponds in or flows down the trail. Again, the combination of soil saturation, mechanical wear, and water erosion creates an entrenched trail that cannot be corrected with water bars or grades reversals. If flat, poorly drained areas cannot be avoided then the trail must be hardened or elevated using construction techniques or structures such as aggregate surfacing, turnpikes and causeways, stone pitching, timber planking, puncheons, or boardwalks, etc.

Orientation/Aspect
An important factor to consider when designing and laying out a trail is its orientation to the sun (“aspect”). A southern aspect will often provide more direct exposure to sunlight while a northern aspect will provide less. The trail’s aspect can influence snow melt, vegetation composition and density, and ambient temperatures.

Final Grade Reconciliation
Once all major and minor control points are located within the trail corridor, the average and maximum sustainable linear grades between control points are identified. The maximum sustainable grade and average linear grade can then be compared to the

designed trail grade. The final linear grade between each control point must be equal to or less than the maximum sustainable linear grade limit and the designed grade.

By the end of the field reconnaissance, the designer has explored every possible routing and selected one that represents the best possible alignment.

At this point in the design and layout process, the trail designer determines if the proposed trail alignment is sustainable or not. If it is sustainable, move forward with flagging the trail alignment. If it is not sustainable, the findings should be documented and the proposed trail should not be pursued. However, in some cases, the proposed trail is required due to critical operational needs or public demand. In those cases, the designer should identify the deficiencies in the proposed trail and quantify the additional costs required to construct and maintain the trail.

Flagging the Trail Alignment

Reconnaissance determines the average linear grade for the entire trail route and the average grade between major and minor control points. This process produces an alignment that is consistent with the design standards and provides the trail designer with known linear grades between control points prior to the flagging process. These linear grades are then used in establishing the flag line for the proposed trail.

Initial Flagging Process

Using the known linear grades, two individuals using clinometers or Abney hand levels perform the flagging of the trail route. The trail is flagged between the established control points, rather than from the starting point to the ending point in a linear fashion. Flagging between control points is sometimes performed by flagging from both control points toward the center. At the location where the two flag lines meet, the flag line is adjusted or mended to provide a well-graded joining of the two lines. This process breaks down the job of flagging a new trail alignment into manageable segments; helps keep the flag line within the desired linear grade; ensures that all control points are accounted for; and eliminates abrupt grade changes.

Curvilinear alignment should be carefully followed during flagging. Linear grade shots should be taken between all topographic breaks in the landform including subtle breaks so that the trail is kept nearly perpendicular to overland sheet flow. To ensure the trail will not accumulate or divert water, natural drainage patterns should be maintained, including dipping the trail in and out of topographic watercourse features, such as small swales and undulations. Additionally, linear grades should be adjusted relative to changes in the percent of hillslope to prevent the trail from becoming fall line and able to capture and convey the hillside sheet flow. A properly laid out trail will be nearly hydrologically invisible on the landform and will prevent water from entering and running down the trail.

The location of a trail alignment flag represents the approximate finished grade of the trail bed, not the centerline of the trail bed. With full bench construction the flag represents the outside edge of the trail. To achieve full bench construction (regardless of the percentage of the hill slope), the trail bench is simply constructed further into the hillside.

Upon completion of the initial flag line, the flagging team re-traces the alignment and evaluates the route. It is good practice to re-evaluate the flag line and make adjustments that improve the alignment. Once re-evaluation has been completed, the route is "tight flagged" by spacing the flags 20 to 30 feet apart.

If the project supervisor, equipment operators, and hand crews are skilled enough to adjust the clearing limits of the trail prism to the steepness of the hillslope, this flag line is sufficient to initiate the clearing and brushing of the trail. If not, additional flag lines representing the clearing limits are installed. These outer flag lines are established by using a combination of trail construction standards, percent of hillslope, and construction methods to be used for the project.

Developing Work Logs and Cost Estimates
After completion of the initial flag line, a Trail Log is developed for construction. The Trail Log identifies the trail construction activities and structures required for the project. Usually the designer and crew supervisor hike the alignment and use a Rolatape or GPS to establish a location or station and linear trail distance for each construction activity. When a structure location is encountered, the designer identifies the location, type of structure or work activity, size or quantity of the structure or work activity, and materials to be used. For local native materials, the source is also identified. This information is entered into a Trail Log using pre-determined work category descriptions and units of measurements so the data can be sorted later. After the Trail Log is complete, the data is sorted by work category and work volume. This information is put into electronic worksheets that calculate labor, materials, equipment, and time required to construct the trail. These calculations are critical for planning and budgeting trail construction.

Second Flagging of the Alignment
Once the trail prism has been brushed and cleared, the original flag line is obliterated. Before construction can begin, the alignment needs to be re-flagged. Re-flagging is performed in the same fashion as the first flagging effort, with the exception that the ground is now bare and can be seen in greater detail. In addition to the trail grade flag line, additional flags may also be placed to identify the top of the cutbank, and the inboard and outboard hinges of the trail bed. The location of the top of the cut bank varies, depending on the percent of the hillslope. If the goal is to achieve a full trail bench, the cut bench will be high. The need for additional flagging depends upon the experience of the trail supervisor and the work crew. Along with second flagging process, additional pin flags are placed where trail structures are to be constructed. These flags are marked with a permanent pen to identify the location (footage or station) and the specific work prescription at that station. These flags, along with the Trail Log, will later serve as a detailed guide for the trail supervisor.

Chapter 6. Mountain Bike Trail Design

Mountain bike trails are designated for non-motorized bicycles equipped for off-road use. Hikers may also use these trails, but they are not the intended primary user group for whom the trail is designed to accommodate. These trails are designed to meet the requirements of mountain bikes and their riders, protect resources, and achieve a durable and maintainable trail. They are not equestrian, multi-use, or accessible trails.

Mountain Bike Uses, Resource Protection, and Sustainability Goals
There are several types of mountain bike users. When designing trails, it is important to match the use with the park unit classification, resource protection policies and trail sustainability goals for the land management agency. Mountain bike users can be separated into four basic groups:

- Beginning or casual cyclists
- Intermediate cyclists
- Advanced technical cyclists
- Advanced downhill cyclists

Cyclists may participate in more than one of these riding activities. Together, these categories demonstrate the range of mountain bike riding activities that trail program managers may accommodate.

Design Requirements

Trail Length and Circulation
To accommodate mountain bikers in frontcountry settings, strive to provide trails of varying lengths. Trails of 3 to 10 miles provide the distance desired by most cyclists for afternoon or evening rides. Longer trail opportunities are provided for cyclists that have more time and for weekend activities (if the landbase is large enough). Backcountry trails receive the most use on weekends, when cyclists have time to ride longer distances. Interconnected loops provide route options to cyclists. A good way to accommodate all trail users when there is competition for trails is to establish multi-use trails as the main arteries of the system, and have specific designated use trails branch off the main arteries. These trails can connect to other similarly designated loops or loop back to the multi-use artery.

Tread Width
Class 1 trails have a minimum tread width of 36 inches. Although the primary user is the mountain biker, hikers are frequently encountered. In locations where the hillslope is steep and hikers have difficulty stepping off the trail, passing space should be provided. Passing space should be a minimum of 60 inches wide and 60 inches long. Class 2 trails have a minimum tread width of 24 inches, and passing areas are a minimum of 48 inches wide and 60 inches long. Class 3 trails have a minimum tread width of 18 inches, and passing areas are a minimum of 36 inches wide and 60 inches long.

Trail Layout and Tread Construction

An important element in mountain bike trail design is reducing biker speed. High rates of speed can lead to increased user conflicts (even with other cyclists), safety issues, resource degradation, and trail sustainability issues. There are several design techniques that can be used to help reduce bike speed, including:

- Increasing trail sinuosity;
- Reducing long sight lines;
- Staying within the maximum sustainable grade;
- Reducing tread width;
- Use "run outs" at the bottom of downhill trail segments;
- Using natural or artificial features to create pinch points; and
- Texturing the trail tread.

Using these design techniques collectively rather than simply relying on a single technique will result in greater speed reduction, and user safety and satisfaction.

Avoiding Flat Ground

Mountain bike trail layout should avoid low gradient hillslopes (less than 20%) and flat ground. If flat ground cannot be avoided, elevate the trail tread by constructing a turnpike or causeway. On hillslopes, mountain bike trails should always have a full bench for more durability and sustainability.

Texturing and Hardening the Trail Tread

The trail tread must be uniformly firm and smooth to allow overland sheet flow. However, on mountain bike trails where native rock is encountered during construction, a portion of that rock can be retained within the tread if it does not impede overland sheet flow or present a significant tripping hazard. Leaving rocks that project into the trail tread (sometimes referred to as tread texturing) further reduces the speed of cyclists and provides a more challenging ride. If the parent or native soil is not suitable for long term sustainability, trail tread can be strengthened by adding crushed rock aggregate. In addition, the application of stone pitching and rip rap will mitigate even the heaviest rates of mechanical wear. These techniques could also be considered "texturing" because the rough, irregular surface help slow cyclists.

Low Trail Structures

Low trail structures, such as steps and water bars, should be avoided on mountain bike trails. Cyclists have a difficult time negotiating these structures, especially when riding uphill, and often will ride around them, which can cause resource damage.

Trail Drainage

If additional drainage is required, drain dips also known as grade reversals are an option. Since these structures collect and divert surface runoff from the trail where natural watercourses do not exist, they are not considered a sustainable design. Use of these structures should be judiciously applied and not arbitrarily installed based on a formula that does not take into account the specific site conditions of the trail. To reduce the hydrological impacts of these structures, they must be located where the landform can best withstand the concentrated surface runoff. Furthermore, these drainage structures must be designed and constructed to avoid abrupt grade changes that can lead to increased mechanical wear, tread degredation, and soil erosion.

<u>Switchbacks and Climbing Turns</u>
For bikes, a minimum turning radius of 8 feet is required for switchbacks and 6 feet for climbing turns. At the turn, the grade of the upper and lower legs should be the same. Abrupt grade changes at this location should be avoided as they will increase mechanical wear. The grade of the upper and lower legs of the turn should not exceed 12%, unless the material is durable enough to support a steeper grade. If site conditions allow, low linear grades are desirable to reduce strain on the rider and decrease mechanical wear. Even when the trail tread is extremely durable, linear grades should not exceed 14% due to the difficulty of climbing such a steep turn on a bike.

Watercourse Crossings
Wet crossings should not be considered for mountain bike trails unless flows are shallow and have low velocities. All wet crossings, even those across swales, should be armored to protect soil and stream gravel, reduce erosion and sediment delivery, and be sustainable.

Dry crossing designs are preferable for mountain bike trails. Culverts, puncheons, and bridges on mountain bike trails should be designed to pedestrian trail standards. All approaches to watercourse crossings should be constructed at trail grade.

Chapter 7. Equestrian Trail Design

Equestrian trails are primarily designated for use by equestrians (horseback riders). They are designed to meet the requirements of horses and their riders, protect resources, and achieve sustainability. They are not multi-use or accessible trails, but pedestrians may also use them even though they are not the primary user for whom the trail is designed to accommodate.

Horse Behavior

The trail designer needs a basic understanding of horse behavior. Design that incorporates and accommodates the needs of horses will result in trails that have less impact on resources, provide a safe and enjoyable experience for the horse and rider, and are more sustainable.

Design Requirements

<u>Trail Length and Circulation</u>
The majority of equestrians in the United States live in urban areas. Horses are stabled or pastured near the owner’s home for riding on weekends. To accommodate these equestrian users, Class I trail designs should provide trails of varying lengths.

Generally, 3 to 8 miles provide the distance desired by most equestrians. Longer trail riding opportunities are provided only if the landbase is large enough to support them. Interconnected loop trails provide equestrians a variety of route options to meet their needs.

Loop trails are preferable for all user groups. Retracing a path is not as stimulating as traversing over new ground. With equestrians, loop trails are important because a horse can become “barn sour” when retracing a path. When a horse knows it is heading back to camp or a trailhead, it sometimes get anxious. Knowing that food, water, the company of other horses, and the relief of not carrying their rider is close at hand can cause a horse to pick up its pace and become difficult to handle. This behavior is reduced when riding a loop trail.

A good way to accommodate all users when there is competition for trails is to establish multi-use trails as the main arteries of the system and have designated use trails branching off the main arteries. These trails can connect to other similarly designated loops or loop back to the multi-use artery.

Water

Horses require between 12 and 20 gallons of water per day, depending on the weather, amount of exercise, physical size, and the amount of food consumed. Class I equestrian trails longer than 7 miles require watering stations. Water troughs should be properly located and of appropriate design. Horses should not be allowed to drink from streams, ponds, or springs due to the impact associated with their ingress and egress, or from urinating and defecating in sensitive areas. Some of the important criteria for horse trough location and design are:

- They should be spaced approximately 5 to 7 miles apart.
- They should be located near a year-round fresh water source.
- They must be located on durable and stable ground outside the influence of a water course and adjacent to the trail.
- The trough should be installed on a rock dry stone tray and the approach area hardened with aggregate/soil mix.
- The trough is designed with an inlet for fresh water and an overflow outlet to maintain a constant supply of fresh water in the trough.
- The outlet water is piped back to the watercourse.
- An escape screen is installed in the trough to allow rodents to climb out of the trough if they fall into the water.

Tread Width

Class I and 2 equestrian trails should have a minimum tread width of 36 and 24 inches, respectively. Although the trail is designed primarily for equestrians, pedestrians will be encountered frequently on these trails. In locations where the hillslopes are steep and hikers have difficulty stepping off the trail, passing spaces should be provided. Passing areas should be a minimum of 60 inches wide and 60 inches long.

Trail Layout and Tread Construction
Equestrian trail layout should avoid low gradient hillslopes (less than 20%). When flat ground cannot be avoided, elevate the trail tread by constructing a turnpike or causeway. On hillslopes, equestrian trails always have a full bench for greater durability and sustainability.

If native soil is not suitable for long-term sustainability, the trail tread can be strengthened by adding crushed rock aggregate. Apply crushed rock to the trail bed by mixing native soils into the top layer of aggregate to help bind the aggregate together, soften its appearance, and reduce the impact to the underside of the horse's hooves (frog). Hardened and smooth trail surfaces, such concrete, soil cement, asphalt, and non-permeable soil stabilizers, should not be applied to equestrian trails. These surfaces are slippery and cause horses to lose their traction and fall. They also can injure the bottom of the hoof.

Grade Uniformity
A sudden increase in linear grade is to be avoided when laying out and constructing equestrian trails. When a grade suddenly increases, such as going from a 5% to 10% grade in 10 linear feet, horses will adjust their stride to compensate and substantially increase mechanical wear to the trail tread.

Trail Structures
Due to the blind spot directly in front of the horse's feet, low trail structures such as steps and waterbars should be avoided on equestrian trails. Horses have a difficult time recognizing these structures and will trip over them or walk around them. Steps on a horse trail are also problematic. When designing and laying out a new equestrian trail, steps should be avoided. If an existing trail has steps, the trail should be rerouted to eliminate the steps, if possible. If a reroute is not possible, the steps should be constructed per the equestrian step design.

Switchbacks and Climbing Turns
When designing switchbacks and climbing turns for horses, a minimum turning radius of 10 feet is required. If the trail is used by pack stock, the radius should increase to 15 feet. The grade of the upper and lower legs of the turn should not exceed 14%, unless the parent material is durable enough to support a steeper grade.

Watercourse Crossings
For equestrian trails, wet crossings ("fords") are preferred over bridges. All wet crossings, even those across swales, need to be armored to protect soil and stream gravel, reduce erosion and sediment delivery, and provide a sustainable crossing.

When approaching a drain swale and armored stream crossing, horses have a tendency to walk below the developed crossing site. This behavior results in user created trails developing below the intended crossing site. To correct this problem, the ground below the approach to the crossing needs to be blocked by installing rock or log barriers perpendicular to the watercourse and above the high water elevation. Given a horse's aversion to low lying structures, these barriers will force the horse to use the intended crossings.

Bridges on equestrian trails should be designed to accommodate the size, weight, and traction needs of horses. The bridge should be wide enough and the railings high enough that the horse and equestrian feel unconfined and protected from the edge of the bridge.

To reduce the chance that a horse slips on the running boards of a bridge, install boards (thick enough to provide a reasonable life expectancy) perpendicular to the direction of travel. The approaches to all watercourse crossing structures should be constructed at trail grade.

Chapter 8. Accessible Trail Design

The U.S. Access Board under the Architectural Barriers Act has established accessibility standards for outdoor developed areas on federal lands. These standards provide detailed specifications for accessible trails and apply to facilities that are built, altered, or leased with federal funds. These federal standards are also the basis for the "California State Parks Accessibility Guidelines" that should be followed for all state park projects, programs, and activities.

As defined for the purposes of applying accessibility guidelines, a trail is a pedestrian route developed primarily for outdoor recreational purposes. A pedestrian route developed primarily to connect elements, spaces, or facilities within a site is not a trail.

Applicable Trails
Accessibility standards only apply to trails designated for pedestrian use. Trails designated for bikes, equestrians, ATVs, off highway vehicles, or a combination thereof are exempt from these standards.

Accessibility standards only apply to pedestrian trails directly connected to a trailhead or trail that substantially meets the technical requirements for an accessible trail. New or existing pedestrian trails not connected to a trailhead or accessible trail are exempt for these standards.

Accessibility standards only apply to existing trails where the original design, function, or purpose of the trail is altered. Trails that receive routine or cyclical maintenance that does not change the original design, function, or purpose of the trail are exempt from these standards.

Additional Trail Design Considerations
Understanding the needs and limitations of the intended trail user is critical in designing trails. Users with disabilities have a broad range of independent mobility problems that can range from severe ambulatory restrictions that require specialized breath-activated powered wheelchairs, to less severe impairments that make it difficult to walk up or

down steps, steep grades, or rough, irregular ground. Users with visual impairments and no ambulatory restrictions may have difficulty negotiating trails with protruding objects and irregular tread or other barriers to mobility. Accessible trail design provides a reasonable level of independent access for trail users with a variety of disabilities.

Users with disabilities want the same outdoor experience as other trail users. Highly developed asphalt or concrete trails located on flat ground behind the visitor center or in the campground may be desirable for some users with a disability, however, these types of accessible trails are designed and constructed using traditional methods of the “built environment”. They often do not provide access to the primary resources that visitors are seeking. The building materials, colors, textures, and defined edges of these paths contrast with the surrounding environment and perceptually separate the user from that environment. The challenge for the designer is to develop an accessible trail that provides intimate access to high quality resources in a fashion that is seamless with the environment.

Standard, hospital-style wheelchairs have narrow, smooth tires that limit their flotation and traction on soft, smooth, or slick surfaces. The chair’s suspension consists of a single axle for the rear wheels and small castors in front. This suspension design causes the chair to pull toward the downhill side of the trail, and the user must correct this pull by turning the chair toward the upper side of the trail. Once it reaches the upper side, the chair straightens until it is gradually pulled to the downhill side of the trail and the process begins again. This zigzag motion requires more trail width and more effort from the user. The braking system on hospital wheelchairs consists of the user grabbing the rim of the rear wheels and applying pressure with their hands. This system is a poor braking method on steep grades.

Coefficient of friction is the ratio of frictional force between two surfaces in contact with each other. On accessible trails, a high coefficient of friction creates better traction between the wheels of the mobility assistive device and the trail tread. The tread surface needs to be firm and stable and have a rough texture to provide this level of traction, especially when the trail surface is wet or covered with leaf litter.

When redesigning existing trails or designing new trails to meet accessibility requirements, the designer should follow this process below.

1. Thoroughly research and evaluate the landform for potential trail routes, resource concerns, boundary issues, land use capabilities, and political constraints.
2. Evaluate existing trails to determine if the initial layout and construction was fundamentally sound. Trail conditions with resource damage and sustainability problems reflect poor trail design and construction. These problems are due to an incomplete understanding of the landbase, its capabilities and limitations. Neglecting to layout a trail that accommodates major and minor control points (locations the trail has to connect to or avoid), ignoring curvilinear alignment principles, and constructing trails that disrupt the surface and shallow groundwater flows will lead to future maintenance problems. These deficiencies need to be corrected as a standard practice in trail design and reconstruction. Designing to

incorporate and anticipate resource protection and sustainability issues significantly enhances a trail's potential for accessibility.

3. Once major and minor control points are established, the linear grade between those control points is identified and compared with maximum sustainable grade for the landform, and the linear grade required by accessibility standards.
4. If no conditions for exception are present and if linear grades between the control points are within accessibility standards and the maximum sustainable grade, the trail can be realigned between the control points. New trail alignments and reroutes will incorporate curvilinear layout and maximize hillside construction. All abandoned trail segments are fully rehabilitated by re-contouring the trail bench and re-vegetating the former tread and excavated area with plants salvaged from the new alignment.
5. If the linear grade between control points is in excess of accessibility standards, evaluate minor control points to determine if they can be modified to reduce the linear grade. Examples include: (1) constructing a retaining wall under a large tree (minor control) to allow the trail to pass under and reduce the linear grade; (2) lengthening a bridge at a stream crossing (minor control) to elevate the approaching trail grade and reduce the linear grade; or (3) excavating the trail bench through a rock outcrop to keep the linear grade within compliance. If minor controls cannot be modified without encountering one of the conditions for exception, evaluate the landbase to determine if additional linear grade can be achieved through the use of properly placed topographic turns, climbing turns, or switchbacks.
6. If minor control point modifications or turns cannot be achieved to reduce the linear grade, the segments of trail that do not comply with the accessibility standards will meet the "not feasible due to terrain" condition for exception. However, every effort should be made to achieve the lowest linear grades possible for these segments and they still should be constructed or reconstructed to comply with the standards that can be met (e.g., tread width, cross slope, tread firmness and stability, and overhead clearance).
7. Trail redesigns and reconstruction efforts should focus on the simplest solution and graduate to the more complex, as needed.

<u>Tread Width and Surface</u>

Trail segments with minor bench and surface deficiencies are reconstructed to obtain a uniform linear grade and outslope. Locations where the tread surface fails to meet firmness and stability requirements are augmented with trail hardening techniques that produce a firm and stable trail surface that closely matches the color and texture of the native soils. The material should also provide a good coefficient of friction during wet conditions, as well as when the trail is littered with organic material. It should allow water to percolate through and evaporate off to minimize seasonal resource impacts. The material should be simple to install, long lasting, sustainable, and easy to maintain.

<u>Obstacles in the Tread Surface</u>

Remove rocks and small roots from the tread surface to provide a uniform and smooth trail tread. Large roots are covered or capped with crushed rock and native soil to bridge over the obstacles ("turnpiked").

Vertical Clearance in the Trail Corridor

Protruding limbs or trees spanning the trail corridor are removed if they do not comply with accessibility guidelines and their removal does not adversely impact the resource or the user experience. Slight trail realignments can be made instead if adjusting the trail route a few feet provides the proper clearance. Raised edges are installed or vegetation is used along the side of the trail to guide users with visual impairments to the clear opening. When possible, edges are elevated to allow sheet drainage to flow underneath the edging. The trail should be rerouted when a significant number of downed trees are encountered, if a route can be identified that still provides the user with an up-close, tactile experience wherever possible.

Combinations of Linear Grade and Cross Slope

Where the linear grade is steep (8% to 10%) and the cross slope is 5%, consider widening the trail between 48 and 60 inches where possible, and hardening the trail surface to increase the coefficient of friction.

Combination of Linear Grade, Cross Slope, and Change of Direction

Consider widening the trail tread to between 48 and 60 inches where possible; improving the tread surface by using a hardening technique to increase the coefficient of friction; and installing edge protection along the radius of the turn if site conditions dictate.

Edge protection

Edge protection consists of an elevated barrier to prevent users from going over the edge of the trail. Consider edge protection at locations where there is (1) a steep hazardous drop-off along the outer edge of the trail; (2) a steep linear grade, cross slope, or a precipitous drop-off; or (3) a combination of steep linear grade, cross slope, and change of direction. Site specific evaluations will determine potential safety risks and recommend proper design solutions. Consistent treatment of safety issues should occur along the trail. Edge protection may consist of native vegetation (if strong enough to restrain the user); logs or large tree limbs securely fastened to the ground; large rocks firmly attached to the ground or incorporated into a multitier retaining wall; or a combination of hand rails, diagonal rails, and bull rails on bridges and puncheons/boardwalks. All edge protection is installed to allow for overland sheet flow and to blend in with the natural surroundings. Edge protection is only installed where it is needed and its application is uniform and consistent across the trail system.

Watercourse Crossings

Small watercourses can be traversed by installing armored crossings (cobblestones), drainage lenses, or culverts. Low volume perennial watercourses are crossed using puncheons or boardwalks. Bridges are constructed to cross large perennial streams. These structures must be designed to have a final elevation at trail grade and meet linear grade, cross slope, tread obstacle, and opening requirements. Puncheons and bridges should have edge protection. When the trail grade approaching a watercourse crossing is too steep to comply with accessibility standards, puncheons, boardwalks, and bridges can be elevated and lengthened to reduce the approaching trail grade and bring it into compliance.

<u>Aesthetics</u>
During construction, every attempt is made to match the building materials to the natural environment and local architecture. Native materials such as rocks, logs, and soil are used to the extent practical. If synthetic materials are used (cellular confinement and geotextile fabric), they are covered by native soil and vegetation. Applying the principles of curvilinear alignment, the trail should have an element of sinuosity, and its edges should be irregular and non-linear. Every attempt is made to create a finished trail that is seamless with the natural environment, providing a quality outdoor experience

Firmness and Stability
An important requirement for accessible trails is that the tread surface be firm and stable. This requirement is essential because trail surfaces that are soft and easily displaced require more effort to traverse, are more difficult to maintain to standard, and have a higher safety risk. Users with disabilities expend substantially more energy traversing loose and unconsolidated soil than firm and stable soil. A loose and unconsolidated surface, when combined with a moderate linear grade and cross slope, is also slippery and difficult to negotiate. These conditions can cause one to fall or lose control of a mobility assistive device. The U.S. Access Board defines a firm and stable trail as follows.

> *A firm trail surface resists deformation by indentations. A stable trail surface is not permanently affected by expected weather conditions and can sustain normal wear and tear from the expected uses between planned maintenance.*

During construction it can be difficult to determine whether you have achieved these definitions. A more precise method for determining the firmness and stability of the trail tread is to test it with a rotational penetrometer.

“Firmness” refers to the penetration of the surface when a foot or mobility assistive device applies downward force on the trail tread. “Stability” refers to the displacement of the surface when a foot or mobility assistive device rotates on the surface. Measurements conducted with a penetrometer must be performed during different seasons to ensure that tread conditions do not change as a result of soil moisture variations. The recommended penetration depths for firmness and stability are 0.3 inch or less maximum penetration for firmness and 0.5 inch or less maximum penetration for stability.

<u>**Chapter 9. Multi-Use Trails**</u>

Multi-Use Trail Limitations
Multi-use trails accommodate three different use types: pedestrians, cyclists, and equestrians. Each has its own design needs and user expectations. When all of these

groups share the same trail, some of the design needs and expectations cannot be met. Multi-use trail design and construction represent a compromise between the different groups. This compromise can often result in less user satisfaction and greater difficulty in the design and construction of a sustainable trail.

Multi-use trails are appropriate when the land base is insufficient to support a trail system that can accommodate trails specifically designated for hiking, equestrian or mountain bike use, or when they are used as the main arteries of a larger trail system that connects to designated use trails branching off of these arteries.

The most significant safety concerns are between cyclist and equestrians. These safety concerns center on the reaction of horses to the movement of cyclists. The physical and behavioral characteristics of horses make them susceptible to flight when cyclists approach unexpectedly. The size, shape, sound, and speed of the bike and rider can startle a horse, which can lead to the horse rearing up, kicking, or bolting. Safety concerns can be partially mitigated by posting speed limits and designing trails that slow the cyclist, giving the horse more time to recognize the rider and react appropriately.

Another design technique is to make the multi-use trail wider and straighter, with longer sight distances and broader turning radii than are typically employed. These characteristics allow users to see and hear each other sooner, giving them more time to stop and get off the trail and providing more passing room. Unfortunately, these characteristics also conflict with the design needs and expectations of users. The resulting trails have more structures, less sinuosity, and less intimacy with the surrounding environment. In addition, making trails wider and straighter with greater sight distances and broader turning radii can encourage cyclists to ride faster, which diminishes the effectiveness of design elements intended to slow users.

Many trail systems use backcountry roads as adjunct trails to connect trails and expand user circulation. Properly designed and constructed backcountry roads with increased width, sight distance, and turning radii can be very effective multi-use routes.

When planning a multi-use trail or improvements to an existing network, it is essential to involve the potential user groups. Their input and problem resolution strategies can ease future complaints and trail user issues. Some approaches to problem resolution include “trail etiquette” signage, park-sponsored multiple user trail rides, user group self-enforcement, and trail problem resolution workshops.

User Protocols

When different user groups share the same trail, cyclists and hikers on a multi-use trail must yield the right of way to equestrians and bikers yield to pedestrians.

Design Requirements

Design for multi-use trails is based on the highest standard for the intended user groups. Equestrian trails have the highest design and construction standards, so those are the minimum standards for any multi-use trail.

Trail Length and Circulation
Since multi-use trails accommodate horses and mountain bikes, appropriate trail lengths, connecting loops, and circulation patterns should be applied whether the entire trail system is designed as a multi-use trail or as a connecting artery.

Tread Width
Multi-use trails have a minimum tread width that is consistent with the Class 1 equestrian standard of 36 inches. In locations where the hillslopes are steep and hikers and cyclists may have difficulty stepping off the trail, passing areas a minimum of 60 inches wide and 60 inches long should be provided. The frequency of passing areas along the trail is determined by site conditions, including sight distance, percent of hillslope, stability of the parent soil, and characteristics of the terrain.

Trail Layout and Tread Construction
Multi-use trails should avoid low gradient hillslopes (less than 20%) and flat ground. If flat ground cannot be avoided, elevate the trail tread by constructing a turnpike or causeway. On hillslopes, multi-use trails should have a full bench for greater durability and sustainability. Since horses and mountain bikes have a tendency to use the outside portion of the tread, full bench construction is a must.

Grade Uniformity
When laying out and constructing multi-use trails, it is important to avoid sudden changes in linear grade to avoid the additional mechanical wear caused by trail users when they encounter a sudden grade pitch.

Sinuosity
Unless a multi-use route is placed on a well designed and constructed backcountry road, the trail alignment will need sufficient sinuosity to slow down mountain bikers. Alignment techniques include curving the trail around native trees, brush, and rocks, or installing pinch points.

Low Trail Structures
Low trail structures, such as steps and water bars, cause problems for horses and cyclists, and should not be used in multi-use trails. Elimination of these structures will reduce the barriers to users with mobility challenges.

Switchbacks and Climbing Turns
When designing switchbacks and climbing turns, the design and construction standards should be for equestrian trails, which are the highest standards of the three user groups.

Watercourse Crossings
For the layout and design of multi-use trails, dry crossings are preferable to wet crossings. Culverts, puncheon, and bridges on multi-use trails should be designed to equestrian trail standards. All approaches to watercourse crossing structures are constructed at trail grade.

All wet crossings, even those across ephemeral swales, need to be armored to protect soils and stream gravels, reduce erosion and sediment delivery, and provide a sustainable crossing.

Chapter 10. Non-Motorized Snow Trails

Non-motorized snow trails can be single use or shared routes used for cross country skiing, skate skiing, snowshoeing, fat tire bikes or other types of over-the-snow devices.

Monitoring over-the-snow trails is important to prevent damage to vegetation and soils from usage when the snow pack is insufficient to cover and protect these resources.

Specific design criteria, such as tread width, grade, and clearing and brushing guidelines, are dependent on the corridor, the type of over-the-snow use, and the grooming to be performed. Over-the-snow trails can be an important part of a trail system and must be included in the trail planning process.

User Packed Trail Design
The depth of the snow pack must be factored into the clearing and brushing maintenance. In locations with shallow snow pack, clearing and brushing can usually be accomplished during the summer months. In locations where the snow pack is deep, clearing and brushing is accomplished during the winter months when fallen trees and vegetation can be reached. Removal of trees and brush during the winter has to be followed-up in the summer months, so the cut trees and brush can be removed and stashed from view of the trail. Brushing the trail keeps the backcountry snow traveler on the trail and helps to protect vegetation from breakage.

Streams crossed with snow bridges that could melt or wash out during a warm winter storm or spring melt are bridged to protect riparian habitat. These crossings are most vulnerable during the spring melt, when the snow trail is still in use.

Snow routes should be marked when the snow is deepest. Trail markers need to be at a location and height where they can be easily observed by trail users. In more dynamic snow conditions, it is important to monitor winter trails and adjust route markings to the changing snow depth.

Snowmobile Packed Trail Design
Trails packed by snowmobiles must be wide enough to accommodate both traditional cross-country skiing and snowshoeing. The minimum recommended trail width for these trails is 4 feet. If there are not two paths of travel, there is the potential for user conflict, with tracked ski trails being destroyed by the snowshoe user. When providing two paths of travel side by side, the width and turning radius of the snow mobile must be factored into the width of the trail. If a narrow opening between trees or large rock outcrops is encountered, it may be necessary to narrow the tread width to avoid the removal of these features.

Bridges must be engineered for the live load requirements of a snowmobile, plus the dead load weight of the anticipated snow pack.

Snow Cat Packed Trail Design
Routes packed by snow cats with trail groomers primarily use roadbeds or over the snow routes that are open only during the winter. Maintenance and design requirements are the same as for roads, but the design requirements for these trails are quite different from those of user and snow mobile packed trails. To accommodate the large equipment necessary, a wider and higher corridor must be established for the trail route.

Stream Crossings
Small stream crossings need to be protected prior to the onset of winter conditions by installing appropriately sized plastic culverts at these crossings. Often plastic culverts cut in half and placed open-side down are sufficient for this purpose. Without these temporary structures, trail users can break through the snow covering these watercourses and trample and damage the channel and banks. These culverts must be removed prior to the onset of the spring snowmelt. Culverts should never be left in place during spring runoff because they are not designed to withstand the high flows of snowmelt and could become channel-blocking devices that will adversely affect the stream channel.

Design Considerations
To protect natural and cultural resources, over the snow routes that occupy corridors only used in the winter must be closed earlier in the season than roads and trails that occupy year-round routes. Year-round roads and trails are designed for use when there is no snow present, whereas over the snow routes are not.

With routes that occupy corridors only used in the winter, large vegetation, such as trees and tall brush, should be removed to create a corridor appropriate to the height of the snowpack. Low growing brush and vegetation should be left to discourage use in summer. Prior to opening for use, adequate snow pack depth is required to protect the vegetation from compaction and trampling. These routes should be brushed in winter, and seasonal route signage is required. Additionally, these routes should be plotted using a GPS to ensure that the winter route of travel is not migrating into new areas.

Section 3: Trail Construction

Chapter 11. Principles of Trail Construction

Trail Construction
Trail construction begins once the initial flagging of the trail alignment has been completed and the required environmental compliance and permitting are approved.

Clearing and Brushing

Clearing and brushing the alignment, including removing all trees, downed logs, and brush within the trailway (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 multiuse trails and 8 feet for pedestrian and mountain bike trails. The clearing limits vary depending on the size of the trail bench and the intended user group. The clearing limits 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.

It is important not to clear and brush too little or too much area. Not clearing and brushing enough means additional clearing and brushing 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.

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 trailway should be identified as construction material, then cut in workable lengths and staged for later use.

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 unnecessary to stash cut brush until after the trees are removed and logs repositioned. Stash cut brush and tree limbs above the trail and out of sight using a "human chain" to minimize worker movements, reduce resource impacts, and improve efficiency.

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.

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.

Reflagging the Alignment

Once the trail alignment has been cleared and brushed, the flag line is re-established. The trail crew or equipment operator must have the trail alignment clearly identified prior to excavating the trail bench, 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.

Tread Construction

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. In most situations the trail tread will be outsloped to facilitate sheet flow across the trail bench. However, some trail structures, such as climbing turns and switchbacks, require the upper legs to be insloped to direct sheet flow to the corner of the turn and prevent it from draining onto the lower leg. In addition, when the trail alignment is on flat ground, the trail bed is crowned to provide an elevated trail tread, prevent water from accumulating on the tread, and provide a stable and dry surface.

The percent of outslope, inslope, or crown grade varies according to the designated use, linear grade, soil conditions, weather conditions, canopy conditions, percent of hillslope, and location of trail on the hillslope.

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 it shall be mineral soil, free of organics, uniformly smooth, compacted and without holes, rock/root protrusions, and concave depressions that can trap water. 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. The cross slope on trails with native tread is a minimum 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).

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 root represents a hazard or obstruction to the trail user and either leaves the root in place or bridges over it with compacted aggregate or mineral soil.

Once trail bench is excavated and properly shaped it can be compacted using a vibraplate compactor. If regulations prohibit the use of a vibraplate compactor, hand tampers can be used to achieve a moderate level of compaction, but they are 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.

The soil side cast 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.

Once proper compaction is achieved, duff is scattered over the trail cut bank, bed, and slope below the trail. 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 slope below the trail.

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.

Use of Mechanized Equipment

The use of mechanized equipment depends on the policies of the land management agency, 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. 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.

The best combination of mechanized equipment and hand crews is to have the 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 mechanized equipment is used to perform the trail tread excavation and roughly shape the trail tread.

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. A new trail should be closed for one wet season to allow for curing. If the trail is completed during the winter or wet season, it should not be opened but allowed to dry and "firm up."

Trail Hardening
Before prescribing aggregate surfacing, make certain it will not alter the sheet flow of the area. Elevated trails can serve as a long, narrow dam to sheet flow, if relief is not provided at topographically appropriate locations.

<u>Aggregate Material</u>
If the native soil and aggregate produced from trail bench construction has the proper mixture of fractured rock and soil, it may be appropriate for trail hardening. The material would have the same color and texture as the surrounding environment and would not introduce non-native seeds. The use of native soil must be identified and approved in the project's environmental documents.

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 larger 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.

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.

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. Mineral soil (if suitable for mixing with the aggregate) excavated during re-shaping of the trail tread is 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. The aggregate should be kept moist to achieve the maximum level of compaction. 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. Compaction consist of a minimum of three passes over the entire trail bench with a 180 pound vibraplate compactor or two passes with a 1,300 pound double drum vibratory roller. 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.

Stone Pitching

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. When installed properly, stone pitching provides a hard, durable tread that is highly resistant to mechanical wear.

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 horse 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.

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.

When installing stone pitching, 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 anchored or locked into existing bedrock to further anchor the structure. The key stones must be well secured as 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 as it will be in the bottom of the footing and the soil can be excavated to adjust to the shape of the stone.

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 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 trail uses.

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.

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. 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.

Road-To-Trail Conversion
Road-to-trail conversion is a technique used for transforming an existing road into a recreational trail. Road-to-trail conversions are 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.

Road-to-trail conversion should only be applied 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, and roads cut into unstable terrain are all poor candidates for conversion.

A common mistake in road-to-trail conversion is building a new trail bed on recently re-contoured fill. 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 should be maintained to serve as the trail tread by ensuring that the trail bed is located on a solid, well-graded surface that can withstand recreational traffic.

The Conversion Process

Depending on the surrounding terrain and the original construction of the road, the trail alignment may meander across the road surface. Where swales intersect the road, the cut bank usually disappears, so the trail tread should meander all the way to the inboard edge of the road. Likewise, where springs exist, the trail should meander to the inboard. Where small ridges are encountered, the trail meanders to the outside edge of the road. Where large trees are growing through the embankment fill, the trail can meander to the outboard edge 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.

When identifying the trail alignment on a road to trail conversion, 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 were 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 marking the outer edge of the trail.

Before the trail 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, the excavator is used to remove 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 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 edge of the trail and one indicating the outboard edge.

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 to facilitate bonding the new soil to the base soil. When the ripping is done, the dozer begins cutting down the outboard edge in much the same way as for re-contouring. However, the outboard edge of the trail marks the limit of the excavation. No material should be excavated inboard of the outboard edge. 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 edge 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.

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. 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. 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.

Shaping and Mulching the Trail

Shaping the trail surface includes removing the protective soil spread on by the dozer during the excavation work 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.

"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 fine mulch and 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.

Stream Crossings

When converting a road-to-trail, stream crossings are completely removed and replaced with a stream crossing structure appropriate for trails. Trail crossings are designed to provide safe passage for users while improving water quality and protecting the riparian and aquatic habitats along the stream. 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.

Removal of a stream crossing includes the removal of crossing fill, culverts, logs, and other debris from the stream channel. The material is moved away from the crossing, so that it cannot clog the crossing in the future, and deposited in a stable location to prevent delivery of soil directly into the stream. Crossing removal restores the stream to its original course and grade and disconnects the road hydrologically from the watercourse, preventing diversion of the stream flow down the trail.

The best time to remove crossings is during late summer months when the stream is low or dry. If the stream is flowing, it can be temporarily diverted around the site using a small coffer dam 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 always begin at the downstream end of the site.

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

On a high-gradient stream, the channel should follow its original course through the excavation and not have sharp bends. The stream channel 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.

The finished stream channel should be free of large rock and woody debris. Although natural, these obstructions may deflect water flow into the soft banks of the crossing, leading to slope failure and delivery of sediment directly into the stream. 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.

Chapter 12. Topographical Turns, Switchbacks, and Climbing Turns

Topographic, switchback, and climbing turns are trail features used to gain additional linear run to reduce linear grades. If landbase, resources, aesthetics, or construction feasibility prohibits lengthening the trail in a curvilinear fashion, then trail features such as topographic turns, climbing turns, and switchbacks are used to overcome elevation gains between control points.

Construction

Topographic Turns

Topographic turns require the least amount of construction effort. A topographical turn allows the trail to contour around a small hill or knoll while maintaining an outsloped trail bench. The hill conceals one leg of the trail from the other, so cutting across the turn by users is minimized. The only place where an outsloped trail bench cannot be accommodated is where the trail crosses over the saddle during circumnavigation of the hill. The short section of trail that crosses the saddle will usually be turnpiked to provide drainage and greater tread sustainability.

Switchbacks

The construction of a switchback begins with proper layout on the landform. The layout must allow for drainage from the corner of the landing, a natural barrier between the upper and lower legs, a break in slope between the two legs, and perhaps a vista off the corner of the turn. At a minimum, a switchback must be located where the water from the upper leg can drain freely off the corner of the landing. The other criteria are important and the trail designer should incorporate as many of them as possible.

During layout and flagging of the switchback, the corner is marked with two flags. These flags must not be disturbed during clearing and brushing. Vegetation, downed trees, and rocks needed for barriers or screening between the two legs must also be undisturbed. The double flags indicate the center of the outside edge of the turn and the finished grade of the center of the outside edge of the landing.

Since a switchback is located on side slopes greater than 30%, constructing the switchback landing can require a retaining wall to support the lower corner of the landing. If the entire landing can be constructed into the hillslope on native ground, a retaining wall is not required. The switchback landing should have no fill material unless it is contained by a retaining structure. Given that the hillslope is often steeper than 30%, the necessary ingredients for this type of construction are site specific and often not available. If a retaining wall is required, the location, size, design, finished elevation, and building materials must be identified. Usually the retaining wall is constructed first, since fill material for the wall is generated from excavation of the landing, especially the upper half of the landing, which is built into the hillslope.

If there is sufficient fill material from excavation of the landing, construction of the trail legs on either side of the switchback starts before the retaining wall is built. If not, construction of the legs must be coordinated with construction of the retaining wall. The upper leg of the switchback and climbing turn starts where the trail drainage changes from outslope to inslope (“transition”). The exact location of this transition depends on how far back from the landing the upper leg can drain to the downhill side of the trail without impact on the lower trail leg. The amount of sheet runoff received, the distance (the amount of ground) between the two legs, and the amount of vegetation and organic material between the two legs are critical factors in deciding the exact location of the transition. If possible, the transition is located where a tree or rock outcropping adjacent to the trail can facilitate the transition. The transition from outslope to inslope is created by constructing a low berm at an approximately angle of 45 degrees to the trail. The berm should be a subtle feature and the trail graded from both directions to provide a nearly seamless transition.

Once the transition is completed, the trail bench is constructed with an inslope toward the center of the landing. If the soil is durable and the switchback properly located, the drainage for this insloped section of trail will not require a ditch. Water should flow along the inboard hinge of the trail and exit at the corner of the landing. If not, a ditch must be constructed with the trail bench wide enough to accommodate both the ditch and the designed tread width.

If a retaining wall is necessary to support the landing, most of the excavation occurs into the hillslope above the center of the turn. Excavation often results in a high cut bank due to the steepness of the hillslope and the need to lay back the cut bank 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 revegetation. The area below the center of the turn will receive fill material, which is compacted into maximum 3-inch lifts. The size of the landing depends on the trail’s classification and user type. For pedestrian trails, the radius of the landing is twice the width of the approaching trail bench or a minimum of 6 feet. For mountain bike trails, the landing radius is two and a half times the width of the approaching trail bench or a minimum of 8 feet. For equestrian trails, the landing radius is three times the width of the approaching trail bench or a minimum of 10 feet. Trails that allow pack stock have a minimum landing radius of twelve feet.

The shape of a switchback landing is designed to facilitate the transfer of the trail drainage from an inslope to an outslope. The upper portion of the landing is insloped into the hillside and the lower portion is outsloped to the downhill side. From the drainage point, the slope of the landing transitions to an outslope as it follows the curve of the landing. Given the mechanical wear associated with turning maneuvers on a switchback, the cross-slope is constructed at a minimum of 1.5 times the outslope of the approaching legs. This cross-slope is applied uniformly through the landing.

Because the upper leg of the switchback is insloped, water drains along the inboard hinge or into a drainage ditch that leads to the upper corner of the landing. For water draining off the landing, a drain ditch outlet is constructed. The gradient of the inboard hinge or the drainage ditch is consistent from the upper leg of the turn to its exit off the landing. When this grade is reduced, water will lose its velocity and sediment will accumulate in the drainage ditch or at the outlet. The drainage ditch and outlet must be sufficiently armored to withstand erosion caused by concentrated flow and to prevent erosion of the landing. In some situations installing an energy dissipater at the drain outlet is required to prevent erosion of the hillslope below the landing.

The lower leg of the switchback may require a retaining wall to support the outside of the trail where it intersects the landing. This structure is incorporated into the retaining wall supporting the landing. The lower leg of the switchback is constructed in a similar fashion to the rest of the trail.

When there are insufficient trees, brush, or rocks to serve as a physical or visual barrier between the two legs of the trail, or there is no break in slope to obscure the lower leg, additional trail structures are needed. Nearby logs or rocks can be placed between the two legs to serve as a visual and physical barrier. These barriers are installed similarly to log and rock crib walls along the outside edge of the upper leg. Large rocks can also be used alone or in combination with logs. If suitable native material is not available, a railing can be installed to discourage trail users from cutting between the legs.

<u>Climbing Turn</u>
A climbing turn is a variation of a switchback. The location, drainage, barriers, and separation of the legs of the structure are the same. A climbing turn requires less excavation because it is built on less cross-slope. Typically, where the cross-slope is less than 30%, a climbing turn is used. In a climbing turn, the legs approach the turn from a wider angle. The lower corner of the landing does not require a retaining wall, though it may require a small crib wall to support the outside edge of the landing. The landing transitions from an inslope to an outslope gradually. The approach to

constructing this structure is the same as a switchback, except that less material is excavated, and the amount of retaining wall is reduced significantly, which reduces the cost.

Accessibility
For climbing turns and switchbacks on accessible trails, the linear grade of the approaching legs is limited to 12% for a maximum run of 10 feet, 10% for 30 feet, 8% for 200 feet, and 5% for any distance. The cross-slope is also limited to a maximum of 5%. Given the need for separation between the two legs, the 5% grade is too shallow and the 12% grade is too short to accommodate these structures. The only practical linear grades for use in these structures are 8% and 10%. With its longer length and more user-friendly angle, the 8% grade is preferable. However, both grades can be used if there is a landing between the two. At the end of an 8% or 10% linear run, a minimum 5-foot long landing with a maximum 5% linear grade and cross-slope is required.

Most accessible climbing turns and switchbacks will have approaching legs with an 8% or 10% linear grade and a 5% cross-slope, and a landing with a 5% linear grade and cross-slope. In addition, the center of the outside edge of the turn should not have a berm for the transition from inslope to outslope. Traversing a berm in a mobility assistive device can be difficult due to the compound angles associated with the linear grade and cross-slope of the berm.

Because of the cross-slope limitations in accessible trail standards, providing adequate drainage on a switchback or climbing turn can be difficult. Using a lower linear grade helps to offset some drainage issues, but in most cases, the trail tread will need hardening to make it less susceptible to erosion. In addition, the low linear grade of the approaching legs makes it more difficult to separate the two legs. To compensate, barrier structures may need to be installed between the legs.

Trail Intersections
Where two hillside trails meet, the intersection is constructed as a modified climbing turn or switchback, depending on the percent of hillslope. These intersections present a number of challenges. Ideally, the two trails should be going in opposite directions, with one trail descending while the other trail ascends. Trying to join two trails that are both ascending or descending will result in trails paralleling each other for a long distance before they come together, which will encourage users to cut the turn. The location of the intersection needs to meet the same physical and visual separation criteria as switchbacks and climbing turns. The intersection should be located at a point that will facilitate drainage from the upper trail because it will have an inslope.

Depending on the steepness of the hillslope, the location of trees and rocks, and the strength and durability of the parent soil, retaining walls may be required to support the bottom of the upper or lower trails or the intersection itself. In addition, an armored drainage dip should be installed to facilitate the flow of water from the upper trail inboard hinge across the lower trail. Use the standard turn location criteria (e.g., ridge nose or drainage) to identify a location that will allow for this type of drainage.

When two intersecting trails go in the same direction and the upper trail is going downhill steeper than the lower trail, it may be necessary to construct additional turns to provide adequate separation between the upper and lower trail.

Chapter 13. Retaining Structures

Retaining structures are used to support and stabilize the trail bed, cut bank, or fillslope, or to elevate other trail structures. They may be used upslope, within, or downslope of the trail bed, or as part of another structure, such as a bridge abutment, ramp, or cribbed steps.

Applications

The determination of when a retaining structure is needed and the type of structure that should be constructed requires a careful examination of the existing conditions and the problem to be solved. The following problematic situations can be improved with the use of some type of retaining structure.

- Stabilize cutbanks
- Stabilize fillslopes
- Repair steam bank erosion
- Maintaining linear grade through minor control points
- Minimizing trail bench excavation and back slope height
- Foundations for trail structures

Criteria for Selecting a Retaining Structure

Logistics

When determining the type of retaining structure, project logistics are a key issue. The availability of native materials that can easily be gathered and transported to the construction site, the distance of the construction site to the nearest trailhead for transportation of non-native materials, and the difficulty of the terrain over which materials will be transported will have an effect on the other criteria and the project's success.

Aesthetics

Construction in the natural environment should always be hidden to the greatest extent possible. Trails are meant to facilitate intimate contact with the environment, and the eyes of the user should be on the natural setting and not on the trail or its structural components. A good trail structure complements the natural setting rather than distracts from it. Using native stone, wood, soil, and vegetation in the design and concealing of retaining structures will enhance the aesthetic qualities of the trail and therefore the experience of the user. If non-native materials, such as synthetic cellular confinement systems, are the best design solution, cover them with soil and native vegetation so the structure will blend in with the natural environment.

Architectural Integration
Observe the existing historic built elements in or near the project site. Some trails and trail systems within a land management agency have a distinct architectural flavor that is linked to a historic era or overriding design that is prevalent throughout the geographic area. Note, the materials used in structures and the construction techniques that define the carpentry or masonry styles. Duplicating a rock wall or unique details in a historic structure's carpentry ensures that the retaining structure will blend in with the existing natural and cultural setting.

Cost
There are many costs to consider when planning a retaining structure. Even when local, native construction materials are selected, the cost of gathering and transporting the materials to the worksite must be calculated. For non-native materials, the cost of purchasing and transporting the material to the trailhead and then to the actual worksite must be considered. In most cases, the labor to build the retaining structure will be the largest expense. Some retaining structure designs are easy to construct, but the materials are expensive. Other designs are difficult and time consuming to construct, but the materials are relatively inexpensive. There are also different life spans associated with each retaining structure design. Maintenance and replacement costs must also be considered.

Labor Source
The skill required to build a retaining structure must match the available labor source. A low skilled volunteer labor force should not be used to construct a highly technical structure. If low skilled labor is all that is available and extensive training is not affordable, the type of structure selected should match the skills of the crew.

Design Effectiveness
The best design solution can be difficult to determine. Different types of structures can effectively retain material, and all have both strengths and weaknesses. A retaining structure may be simple to build, relatively cheap to construct, and blend in with the environment and architecture, but not be an effective solution to the problem. If it doesn't work, don't use it.

General Retaining Structure Design

Foundation
The foundation for any retaining structure must be excavated out of solid, stable, native material. The required depth and size of the foundation depends on the height and weight of the structure and the amount, weight, and slope of the material to be retained. The foundation should account for the weight of the material and the moisture in it from rain and snowmelt.

Any foundation constructed near a stream must be a minimum of 18 inches below the true scour line of the stream to prevent undermining by the stream flow. Check the actual scour depth of the stream channel. It may be below the observable depth if the section of stream being evaluated is unstable and in a depositional mode. Large, dynamic streams may require a foundation that is much deeper than 18 inches below the scour line.

A retaining structure constructed within an active flood channel can also affect the stream's hydrology and morphology by changing flow dynamics. A qualified hydrologist or engineering geologist should be consulted when constructing a retaining structure within an active flood channel or stream that is unstable or has dynamic flows.

The foundation (excavation) for most multi-tier retaining structures should be level from side to side and uniformly smooth. If the structure is tilted to one side, the weight of the wall and backfill material will be distributed unevenly across the wall, which can lead to stress, shearing, and failures.

The bottom of the foundation must also be tilted to the rear or back of the wall by a minimum of 5% to 10%. This "tilt back" helps transfer the weight of the retaining structure and its fill material into the hill slope. Without this subtle tilt, the weight of the structure and fill material is applied straight down and toward the front of the structure. The gravitational force of the weight can lead to premature failure of the retaining structure.

Wall Batter

As the height of the structure increases, a batter should be installed to move the face of the retaining structure back. The amount of batter varies according to the type and height of the structure being constructed. Multi-tiered walls over 3 feet in height require a minimum batter of 2 x 12 inches, (i.e., for every 12 inches of vertical rise, the face of the retaining structure steps back 2 inches) to reduce the pressure that the backfill material exerts on the front (or face) of the structure. When prescribing a pre-manufactured multi-tier retaining structure, especially a structural wall or load-bearing wall, it is essential to consult with the manufacturer or a qualified licensed engineer.

Wall Anchoring Systems

Most retaining structure designs include some type of anchoring system to pull the front (face) or wings (sides) toward the back of the structure. With a log, split wood, or milled wood multi-tier structure, posts can be used to anchor the wall. These posts are installed so that the portion of the post that projects into the back of the structure is at a downward angle of 10%. The weight of the backfill once it is installed on top of the post forces the post down and toward the rear of the wall. In doing so, the post applies a force to the front and sides of the structure, pulling the front and sides of the structure toward the back. This force offsets any pressure being applied outward by the weight of the backfill. The same principle can be used with other types of retaining structures with anchoring systems.

Drainage Systems

A retaining structure must have openings or weep holes designed into the front and sides to allow water to drain from behind the structure. Fill material placed behind a retaining structure should be porous and well-draining to allow water to flow to these openings.

Drainage is necessary to prevent the buildup of pore pressure behind the structure that will exert excessive outward (active) pressure against the back of the structure's walls.

In addition to these features, a curtain drain or a drain lens can be used with retaining structures built into a hill slope to intercept water flowing from the hillside. Instead of weep holes, these structures can use a perforated pipe inside the drain lens to collect water that reaches the back of the structure and convey it to a suitable drainage discharge location. When using these types of drainage designs, a qualified engineer should be consulted.

Non-Structural Rock Retaining Walls
A non-structural rock retaining wall, sometimes referred to as "junk wall", is a simple retaining structure used to buttress the outboard hinge, fillslope, or cutbank of a trail. It is also used to frame in a drain lens, face a synthetic retaining wall, or provide rock slope protection along a streambank. Being non-structural, it is not intended to support or retain fill material used to bear trail traffic or structures such as bridge abutments.

The size of the rocks used to build a non-structural rock retaining wall is dependent on the wall's application. When used to frame in a drain lens, the rocks can range from 100 to 180 pounds. When used as rock slope protection on a streambank, the rocks can range between 200 pounds and 2,000 pounds, depending on the velocity, volume, and geomorphology of the stream.

The construction of a non-structural rock retaining wall begins with the excavation of a footing. The bottom of the footing should be level side to side and the bottom should have a 5% tilt back. The largest rocks used in the structure are placed in the bottom tier to support the rocks above. The footing is shaped to accommodate the profile of the bottom of the rocks used in the first tier. There should be good contact between the sides of the rocks in the first tier. The second and succeeding tiers are placed further back into the hillslope so the face of the wall has a maximum of a one to one slope or 45 degrees. Each rock placed shall have a minimum of three points of contact with the rocks around it.

Single Tier Log and Rock Structures

<u>Construction of a Single Tier Log Wall</u>
Constructing a single tier log wall begins with the excavation of a foundation or footing. The location of the footing should be such that when the structure is completed, the distance from the inboard hinge of the trail to the outside edge of the structure provides the designed trail width. The elevation of the bottom of the footing should be set so that the top of the wall is lower than the outboard hinge of the trail. This elevation difference ensures that proper outslope is obtained and the wall does not impede the flow of water across the trail.

The footing should be large enough to support and secure the logs being placed into it. The depth of the footing should be a minimum of one-third of the height of the log. The bottom of the footing is shaped to accommodate the irregular shape of the logs. These materials must rest flush on the bottom of the trench to be fully supported, maintain their position, and contain the weight of the backfill.

After placing the logs in the footing, secure them by pinning them with rebar. The diameter of the hole is usually 1/16-inch less than the 5/8-inch rebar so that the rebar fits tightly into the log. The rebar should penetrate a minimum of 2 feet into the ground beyond the bottom of the log and is driven through the log with a double jack (sledge hammer). Once this task is completed, the footing is backfilled with crushed rock and soil and the material is compacted in maximum 3-inch lifts.

<u>Construction of a Single Tier Rock Wall</u>

If it is not possible to excavate a level footing, begin construction by placing rocks at the lowest point of the footing. Install the largest rocks first to serve as the keystone that buttresses the rest of the rocks. All the rocks should be placed so that their mass is on the inboard side of the footing (into the hill slope). This orientation, along with the 5% tilt back in the bottom of the footing, transfers their weight into the hill slope and prevents the rocks from rolling forward. Prior to placing rocks in the footing, the bottom of the footing can be further excavated and shaped so the finished elevation of the rock is even with the rock next to it. The bottom of the rocks does not need to be flat, since the footing will be shaped to accommodate it, but the top needs to be reasonably flat as this face serves as part of the trail bed.

The sides of the rocks must be shaped so that they make good contact with the rock next to it. Full contact along both sides of adjoining rocks is preferable, but if only limited contact can be accomplished, it must be toward the top of the two rocks as this high contact (friction) will lock the two rocks together and prevent them from rolling forward.

Once the rocks are in the footing, any gaps remaining between the rocks are filled by inserting small wedge-shaped rocks into the gaps (“chinking”). This process provides additional friction between the rocks and further locks them together. The addition of small rocks should be done carefully. Inserting too large of a rock into a gap can wedge the rocks apart. Chink the back of the wall first and then the front. Once this task is completed, the footing is backfilled with crushed rock and soil and the material is compacted in maximum 3-inch lifts.

Multi-Tier Interlocking Retaining Structures

A multi-tier interlocking retaining structure can be used effectively to retain fillslopes, stabilize back slopes, retain fill used to bridge over tree roots and rocks, or serve as abutments, mid-span supports, and ramps for bridges. They are commonly built in tiers comprised of facers, wings, and anchor posts. All components are interlocked through notching.

The logs or lumber for these structures should be rot-resistant. Redwood and cedar provide the best combination of longevity and structural quality. If logs are used for building materials, it is important that they be all-heart wood, de-barked, and trimmed of all sapwood prior to use because bark and sapwood are more subject to insect infestation and rot. Split products should also be free of sapwood. Non-native materials are also used, such as milled lumber, wood/plastic composites, or structural grade recycled plastic lumber.

Construction

When constructing interlocking multitier retaining walls, the foundation must be laid out so that the wall that begins below the trail will start far enough out from the outboard hinge. When it is finished, the top of the wall must terminate at or just below the outboard hinge of the trail. This layout must account for the overall height of the wall and the batter (if used). The elevation of the bottom of the foundation must also be on stable ground, so the combined height of the tiers (including the gaps between the facers) will equal the finished height of the outboard hinge of the trail.

Each tier of a multi-tier retaining wall may consist of facers, wings, and anchor posts. On any tier, the anchor posts should not be spaced more than 8 feet apart horizontally. Anchor posts need to maintain the one-inch gap between the facers and wings for drainage and are installed at a minimum downward ten percent angle toward the rear of the retaining wall. The length of the anchor posts should be a minimum of 48 inches and installed by digging a trench behind the wall to the necessary depth and length or burrowing the posts into the hill slope. Where the length of the facer or wing wall is such that two or more facers or wings are spliced together, use a lap joint splice instead of a butt joint splice. Splices in the facers and wings in the next tier of the wall are staggered so that the joints are not consecutive. Place anchor posts on each side of the splice to provide additional support. The anchor post should not be more than 2 feet from the splice. Anchor posts should also be staggered and not placed directly above the preceding tier. Both ends of the retaining wall are keyed into native soil to prevent backfill from migrating around the outer edge of the wall.

Notching Dimensioned Lumber

All retaining wall members are joined together by notching. The depth of the notches should provide a 1-inch gap between retaining wall members. This gap is required to allow water drainage between each wall tier. The notches should be laid out and executed so the adjoining notched faces of the retaining wall members fit tightly together and have no gaps.

Notching Logs and Split Products

Due to the non-uniform shape of logs and split products, layout and notching requires a custom fit for each structural member. The layout for split products is similar to that used with milled lumber, except that the depth of each notch varies as the height and width of the log or split product changes. The layout for logs is similar to the method used in building log cabins, as the material is round and has tapered dimensions. To minimize these variables, select logs or split products that have similar dimensions and lay them on the ground so that they can be compared. Place those closest to the same dimensions adjacent to each other. This simple process also determines the approximate height of the retaining structure once it is assembled. Individual logs or split products can be changed until the desired height is achieved. Alternate logs with distinct tapers, so that the succeeding tier can compensate for the taper and the corresponding height differential.

When joining the facer and wing walls, the ends of the facer and wing wall members should extend beyond the notch a minimum of 6 inches to help lock the two members together. Anchor post ends also extend a minimum of 6 inches beyond the notch.

After completing each tier, the area behind the wall is backfilled. Backfill material should be of sufficient size so it will not sift out between the gaps in the wall, and should consist of permeable aggregate, soil, or drain rocks to promote drainage and reduce pore pressure. Rocks larger than 4 inches should not be used as backfill material, as they may leave empty spaces that compromise the backfill.

Wooden Cribbed Bridge Abutment
The elevation layout, foundation excavation, and notching are the same as for interlocking wood retaining walls. However, rather than being constructed into a hill slope, these structures are free standing, built in tiers, and filled with a porous aggregate as each tier is completed.

When constructing wood cribbed abutments within a stream channel (mid-span) or adjacent to a stream channel (abutment), the face wall of the abutment is laid parallel to the stream to minimize deflection of the current toward the opposite bank. The upstream wing wall (shear leg) is laid at an angle of not more than 45 degrees from the line of the stream current, to keep the flow from being directed into the bank. The downstream wing wall (heel leg) is laid at an angle of not more than 60 degrees from the line of the stream flow to reduce possibility of a back eddy that might erode the bank. Wing walls are excavated not less than 48 inches into the stream bank to prevent washing action around the wall end.

Wooden Cribbed Approach Ramp
A wooden cribbed approach ramp to the end of a bridge is made of wood or plastic wood with a minimum diameter or height of 8 inches. This type of ramp has the same standards as wooden cribbed abutments and is at least as wide as the bridge deck. The fill grade approaching the bridge should meet or exceed the standards for accessible grades whenever possible. The height of the cribbed is sufficient to ensure the fill material reaches the level of the bridge deck.

Multi-Tier Rock Wall Retaining Structures
When constructing a multi-tiered rock wall, quarrying, gathering, transporting, and placing rock must be approached in the most efficient manner possible. Prior to quarrying or gathering rock, the volume of rock needed for the structure must be determined. This volume must include both wall rock and crushed fill. The desired size

and shape of the rock must also be identified. The rock source is often limited, but when options are available, only the preferred rock should be gathered or generated. Rocks for the retaining wall must be solid. Those selected for crushed fill can be less competent or more fractured since they will be broken into small sizes and fractured rock is easier to crush. The size and weight of the rock may also be limited by the method of transportation, distance to the worksite, and ability of the trail crew to place the rock efficiently and safely when building the wall. A trail supervisor or someone with advanced rock wall construction skills should identify suitable rock by chalk marking selected rocks with an “X” and segregating them by size (or thickness). This method should prevent unsuitable rock from being transported to the site, often at considerable time and cost. Segregating the rock by shape and thickness also allows trail workers to efficiently access the necessary rocks during construction.

Place the rock at the worksite (segregated by thickness) above the intended wall and out of the construction area to allow trail workers to move the rocks downhill when they need them. Also, the wall rocks should be spread on the ground where they can be easily viewed, rather than stacked in a pile to eliminate having to rummage through a pile every time a rock is needed. Rock for crushed material can be piled above the worksite, as this rock will be broken into smaller pieces and placed behind the wall rock. If the project is large and many rocks are needed, the work area may become too congested and unsafe. Gather only the number of rocks the stockpile area will comfortably hold, yet still provide an adequate selection.

Imported rock usually comes from a commercial quarry. When purchasing rock from a quarry, specify that the rock will be hand-selected by the trail crew. The crew will require access to the quarry to choose the rocks that best meet the project requirements and produce the most competent and efficient wall. Selected rocks are marked with chalk (by the trail supervisor) and placed in a pile where they can be loaded by the quarry operator and trucked to the trailhead. If pre-selection is not performed, then you will most likely receive rocks of unsuitable sizes and shapes that will be difficult or impossible for use in construction. The trail crew may be required to complete a quarry safety training course prior to being allowed to enter the quarry. However, this small investment in training will pay off in project efficiency when only suitable rocks are purchased, transported to the project site, and used to construct the retaining wall. If a quarry will not allow a crew to enter, the trail supervisor can sometimes arrange to work with one of the quarry’s heavy equipment operators to help select the desired rocks. The trail supervisor selects and marks the rocks and the operator uses an excavator with a thumb to pull out the desired rocks. They are then loaded and trucked to the trailhead. If the rock cannot be pre-selected at the quarry, then have the rock delivered to a corporation yard where the trail crew can select the desired rocks for transport to the trailhead. In this case, purchase more rock than needed so there is sufficient material to select from. The amount of extra rock that should be purchased will depend on the quality of the rock in general. The remaining rocks can be used where good rock shapes are not required, such as non-structural (“junk”) walls, slope protection, energy dissipation, or road backfill projects.

Dry Stone Multi-Tier Rock Retaining Walls

Layout and Foundation

Planning a multi-tier rock retaining wall requires taking into account the natural features of the site. Well-anchored rocks and bedrock already in place can be used as anchors and keystones, which improve the wall's structural stability. The location of the foundation is laid out so that the wall begins below the trail and far enough away from the outboard hinge of the trail so that when the wall is finished the top of the wall is lower than the outboard hinge of the trail. The layout should account for the overall height of the wall and the batter being applied. The elevation of the bottom of the foundation must also be determined, so it is located on stable ground, and the combined height of the tiers in the wall is slightly below the finished height of the outboard hinge of the trail.

When natural features such as large rocks and bedrock are incorporated into the foundation, or when the native ground has varying elevations, it is often necessary to construct multiple foundations. These foundations can be located at opposite sides of bedrock that protrudes into the wall location, or at different elevations to compensate for differences in ground height along the length of the wall. Starting foundations at different elevations is necessary to keep each wall course level. Rock walls constructed within these foundations will join together by lapping the higher wall over the lower wall. The builder must account for differences in elevation by adjusting the depth of the foundations, the height or thickness of the rock selected, and the number of tiers constructed. By planning for varying elevations in advance of construction, the trail crew can select rocks that facilitate the leveling and joining of two wall sections. When two walls come together from perpendicular or nearly perpendicular angles, they are joined with overlapping joints. These joints are alternated so there is not one, continuous seam.

Construction

The foundation is excavated so that it is level. However, protruding bedrock or large boulders can cause the foundation to slant to one side. In this case, start the wall at the lowest end of the footing. The bottom of the foundation must also be tilted to the rear or back of the wall by a minimum of 5%. The first rock laid should be a substantial size, as it will become the keystone that buttresses the rest of the wall. Typically, this rock is the largest in the retaining wall. Because the top of the wall is slanted, it is often necessary to pin the bottom (first) rock onto the second and seceding tiers to keep the rocks anchored to the rock beneath them and prevent them from sliding downhill.

The first tier of rock needs three good surfaces for making contact: the ends for contact with the rocks next to it, and the top for contact with the next tier. The bottom of the rocks can be of irregular shape, as they are buried at the bottom of the footing. The footing can be dug out to conform to the shape of the rock. Adjusting the bottom of the footing to conform to the bottom of the rock allows the builder to use rocks of different thickness or with uneven surfaces on the bottom tier. Save the rocks with a flat top and bottom for the next tiers. It is also important to use large rocks in the bottom to give the wall greater stability by keeping its overall mass low in the structure. This placement also allows the rock to be laid with the bulk of its weight set back into the wall. Foundation rocks are laid so that they do not overhang or protrude beyond the front of the footing. Set foundation rocks so they are firm and stable and have good contact with the wall rock next to them. Full contact along the face of adjoining rocks is preferable. If full contact is not possible, there should at least be solid contact between the upper portions (high contacts) of the two rocks.

The top of the foundation tier must be flat to provide good contact and a solid base for the next tier of rock.

When selecting rocks for a retaining wall it is advisable to use a tape measure to identify the size, shape, and thickness of the rock you need. Then go to the pre-sorted rocks stored above the worksite and find those rocks that meet the necessary dimensions. It is also advisable to select several rocks at a time that have approximately the same size and appear to fit together. Sometimes these rocks can be quickly fitted together where they are stored to see their potential for use in the wall. This visual test allows several rocks to be moved to the wall at the same time with a high probability that they will work together in the wall.

All wall rocks should be laid with their greatest dimension extending into the wall. At least one-quarter of the rocks should be “header rocks” or rocks that extend a minimum of two feet into the backfill behind the wall. These rocks perform a similar function as anchor posts.

Once the initial foundation is complete, the back of the wall is filled with crushed rock. This rock is broken or crushed with a double jack at a distance from the wall, so that the breaking of the rock does not disturb or damage the rocks just fitted in the wall. The smaller fractured rock is then stuffed behind the wall rock, in a fashion that does not move or disturb the wall rocks or compromise their points of contact, so that all voids are filled with crushed angular rock and the back of the wall rocks are fully supported. Once the back of the wall rocks are stuffed and supported, the remainder of the footing behind the wall is filled with crushed rock to the same elevation as the wall rocks. Test the wall rock for stability by walking along the outer (front) edge of the rocks and checking for movement or rocking. When a worker’s full weight is placed on the outer edge, the rocks should not move or tilt. If movement occurs, the cause must be identified and corrected prior to proceeding to the next tier.

Construction must be monitored carefully to ensure that the wall is conforming to the intended design and is structurally sound. Multi-tiered walls over 3 feet high require a minimum batter of 2 inches in 12 inches. The required batter should be accounted for in the initial foundation layout. Rocks placed on top of the first tier need to reflect the prescribed batter. Use a string line to guide the starting point or front of the wall for the second tier. Attaching a line level to the string also allows you monitor how level the top of the wall is.

Installing the second tier is similar to installing the foundation except that there must be solid contact between the top of the foundation rocks and the bottom of the second tier rocks. To ensure wall stability, each rock placed in the upper tier should have a minimum of three contact points with the lower tier. The rocks in the second tier must span the joints between rocks in the foundation tier. The second tier must also maintain the minimum 5% rearward tilt that transfers the weight off the wall and into the hill slope.

Once the second tier is complete, the back of the wall is carefully chinked (hand pressure only) and voids are filled with appropriately sized crushed rock ("stuffed"). Subsequent tiers are constructed in a similar fashion until the designed height is achieved. The top of the retaining wall affects the trail bed drainage design. If the trail bed is outsloped, the top of the wall must be lower in elevation than the outboard hinge of the trail tread. Once the wall is complete, the front of the wall can be chinked by placing rock wedges into the gaps left between rocks to add stability. Chinking is performed only after the wall is complete, because without the full weight of the wall, placing rock wedges into the gaps can wedge the wall apart, eliminate points of contact, and destabilize the wall. Chinking is not intended to fill every gap in the face of the retaining wall; only the largest ones. Gaps are necessary to provide drainage from the back of the wall and to relieve pore pressure.

Fill material should be rock and/or mineral soil, with the final 4 inches consisting of material not larger than 2 inches. All voids should be filled and the material is compacted.

Multi-Tier Rock Approach Ramps
Multi-tier approach ramps to a bridge have the same design and construction standards as multi-tier rock retaining walls and the ramps are at least as wide as the bridge deck. The finished grade of the fill approaching the bridge should meet or exceed the standards for accessible grade whenever possible. The height of the ramp wall is sufficient to ensure the fill material raises to the level of the bridge deck.

Wet Masonry Multi-Tier Retaining Walls

<u>Layout and Construction</u>
The layout and construction of the foundation is identical to that of dry stone masonry walls. However, the initial foundation is laid on top of a wet layer of concrete a minimum of 12 inches thick. Reinforced steel, wire, or fiberglass fabric is also required in this concrete pour. The concrete is used to provide a level and solid foundation for the wall. The concrete should be wet enough that the rocks will partially sink into it but stiff enough to support them. Before rocks are used in the retaining wall, thoroughly wire brush and wash the rocks with water to create a clean surface to which the concrete and mortar will readily adhere. Muriatic acid is sometimes used to clean oily or dirty rocks. When foundation rock is placed on the wet concrete, any irregularities on the bottom of the rock is filled and supported. Good contact between rocks is still required, but full contact is not as critical as any gaps between the rocks will be filled with mortar.

Before the next tier of rock can be laid, some form of drainage to allow water to drain through or around the wall must be installed, since any gaps in the wall are filled with mortar. Drainage can be accomplished by installing a curtain drain that directs water from behind the wall to the outside edges, or with sections of PVC pipe that extend from the porous backfill to the face of the wall.

The second tier of rock is installed in a similar fashion as for dry stone masonry. Once several rocks or the entire tier of rocks that fit together well have been selected and shaped to provide good contact, they are wiped with a damp cloth or sponge so that the dry rocks will not pull the moisture out of the mortar, causing the mortar to fail prematurely. A thin layer of mortar is troweled on top of the foundation rocks to provide a bed for the next tier and provide good contact between the rocks of the two tiers. Use a thicker layer where there are voids and poor contact.

Another layer of mortar is applied to the bottom of the second tier rock before it is set on the foundation tier. Once this rock is set on top of the first tier, it is gently tapped with the butt of the trowel until it is firmly sitting on the bottom tier and rock to rock contact is achieved. Excess mortar that is squeezed out from between the two tiers is scooped up with the trowel.

Mortar is then troweled on the side of the rock where the next one will butt against it. Again, apply a thin layer where there is good contact between rocks and a thicker layer where there are gaps. The next rock is set in the same manner as the first, except mortar is troweled on the side that will butt against the rock previously laid. The second rock is then pressed against the preceding rock and gently tapped with the butt of the trowel until rock to rock contact is made on the bottom and side.

This process continues until the second tier is complete. As the tiers of a mortar retaining wall are constructed, they need to adhere to the tilt back and batter requirements, as for a dry stone retaining wall. The joining of separate walls, alternate overlapping of corners, and the final wall elevations and tread finishing previously discussed also apply.

If there is a distinctive architectural style for the area, follow this style unless planning, environmental review, or permits dictate otherwise. The finishing styles fall into two basic categories - hidden mortar and exposed mortar. The hidden mortar style looks the same as a dry stone wall. All of the mortar is applied behind the wall face where it cannot be seen. This style requires tighter fitting rocks, especially toward the front. The mortar helps compensate for irregularities and gaps behind the face of the wall. The exposed mortar wall has mortar visible between the sides, tops, and bottoms of the rocks. Exposed mortar also has many architectural styles, which have differing thicknesses, widths, finishing, and tooling. Specialized tools are used to create the final appearance of the mortar ("tool out") so that it is either recessed or extruded.

Once the rock has been set and tooled out to the desired finish, a wet sponge is used to wipe off any excess mortar and clean the exposed rock faces. Sometimes a mild acid wash (vinegar) is applied to the wall after the mortar has set, to soften the appearance of the rock and give it a more aged look (patina). Fish oil emulsions and native moss spores can also be applied to expedite the softening and naturalizing of the wall's appearance.

Soldier Pile Retaining Walls with Timber Lagging

Construction

Prior to construction, the size and height of the wall must be determined. These dimensions depend on the area to be contained and the steepness of the slope where the retaining wall will be built. The height or length of the H beam post depends on how deep into the earth it will be driven and the finished height of the retaining wall. The number of H beam posts needed depends on the length of the wall and the layout or frequency of the posts along the wall. Most commercially available soldier pile retaining walls have a maximum spacing of 5 feet on center for the H beam post.

The wall boards are usually 2- x 6-inch or 2- x 8-inch pressure treated Douglas fir, which is ordered from the manufacturer at the finished length so they will not have to be cut. Pre-cut finishes will increase their life span. Once pressure treated lumber is cut, it will not last as long as uncut wood even if later painted with a wood preservative.

Structural grade plastic wood can be used for the wall boards, which will provide more longevity. However, plastic wood has some aesthetic drawbacks and should not be used where it is exposed to direct sunlight.

The number of boards depends on the total square footage of the retaining wall to be constructed. Allow at least one ground anchor for each H beam post. These are typically duck billed anchors for soft soil, and expansion anchors for rocky conditions. Anchors are attached to the post with threaded steel rods and nuts. The H beam post is manufactured in heights from 2 feet to 10 feet. Walls exceeding 4 feet must be engineered.

To achieve a wall height greater than 4 feet, a stepped wall can be constructed. This structure consists of one wall constructed on top of another. The second wall should be set back from the front of the first wall a minimum of 2 feet. If this structure is used then the layout must compensate for the setback of the second wall.

Once the layout is complete and the locations for the H beam posts are identified, a 45 to 50 pound hydraulic or a gas powered hammer with a rebar driver attachment is used to drive 1-inch diameter rebar 3 to 4 feet long into the ground. The H beam post is set over the rebar, with the rebar sliding into the channel in the center of the post. Using a driver attachment fabricated for the H beam post, the post is driven 2 feet into the ground, or until the finished elevation is achieved at the top of the post. A string line is set to identify this elevation and as a guide for the trail workers.

If the retaining structure will be anchored into rock, then a hydraulic, gas, or electric powered drill is used to drill a hole 1 1/8 inches in diameter and 12 inches deep. This hole is cleaned of rock dust, and two-part epoxy glue is squeezed into the hole. A piece of rebar 1-inch in diameter and 2 to 3 feet in length is driven into the hole until it is fully seated. The H beam post is then placed over the rebar.

When the first post is set, wall boards of 2- x 6-inch or 2- x 8-inch and 4 to 5 feet long are placed into the slot on the side of the H beam post. Once the location of the next H beam post is identified, the process is repeated. After two posts are installed, the wall boards can be dropped into the slots on the sides of the posts. If the ground between the posts has not been leveled prior to installation, it may be necessary to do so before the first (bottom) board is installed. The starting elevation where the first board will sit must be consistent with the layout, as it will affect the final elevation of the wall. It is also important to provide a gap between the boards for drainage. The height of the gap in the wall may vary, depending on the anticipated drainage from behind the wall. A 1/2-inch gap between the boards is considered the minimum with a 1-inch gap being preferred. This gap can be established by inserting a piece of metal stock between the wall boards where they set on top of each other inside the post channel.

On soft soil, a hydraulic or gas powered hammer with a gad drive attachment is used to drive an earth anchor (duck billed anchor) into the hill slope behind the wall once the wall boards are installed. The duck billed anchors should have a minimum 3,000 pound capacity. The anchors are driven into the hill slope a minimum of 4 to 6 feet. Use anchors that are designed to attach to 1/2-inch diameter all thread. The all thread is attached to a high lift jack and the jack is used to pull on the all thread and set the duck billed anchor. Setting the duck billed anchor requires pulling it several inches to open the bill. The all thread is run through a hole in the H beam post and attached with nuts and washers. The holes can be pre-drilled, or drilled on-site if the appropriate power tools are available, and placed within 12 inches of the top of the post to provide good leverage once the wall is loaded. Commercially available soldier pile walls will already have these holes drilled through the posts. The all thread is tightened until the wall is pulled two to three degrees past vertical into the hill slope. Once backfilled, the weight of the backfill will push the wall out to where it is nearly plumb.

For working in rock, use a hydraulic or gas powered rock drill to drill a 5/8 inch diameter hole a minimum of 3 inches deep into competent rock. Insert an expansion anchor into the hole and set it with a setting tool. Use an anchor that can be attached to a half inch all thread, and attach the all thread to the posts as described above.

When the anchors are set, 2-inch channel iron is installed on top of the final wall board and H beam post to provide a metal cap. The channel iron is pre-cut to lengths matching the center spacing between the posts, and placed on the wall so that it spans from the center of one H beam post to the center of the next. An electric, gas, or battery powered drill is used to drill a 3/16-inch hole through the channel iron into the post. A 1/4-inch x 1-inch metal screw fastens the channel iron to the post. This screw can be installed with an electric, gas, or battery powered drill.

Once the metal cap is installed, the retaining wall can be backfilled with porous material that allows water to pass through to the front of the wall, where it can seep out through the gaps left in the wall boards. The final 4 inches of fill consists of the desired tread material and should be installed so that the designed surface drainage is achieved.

Synthetic and Gabion Retaining Wall Layout
Prior to construction, determine the desired size of the retaining wall and layout the foundation. Synthetic and gabion retaining walls require a substantial foundation. This foundation must accommodate the retaining wall structure and the soil, organics, and vegetation installed on the front of the wall to hide the synthetic/gabion materials, protect plastic or petroleum-based materials from ultra-violet light, and blend the wall with its natural surroundings. To keep the soil covering the wall in place, it is recommended that the face of the retaining wall be constructed at a slope no greater than one-to-one (45 degrees).

Certain land management regulations, such as those applied to wilderness areas, prohibit the use of synthetic materials. The architectural design and aesthetic qualities of these walls may not be appropriate in some locations. If not covered with soil and re-vegetated, these structures are unsightly and will quickly deteriorate from exposure to ultraviolet light. In some locations, vegetation re-growth may be too slow to consider use of this retaining structure.

Geotextile Fabric Retaining Walls
Geotextile fabric comes in a number of weaves and weights. When selecting fabric for a retaining wall, the fabric should be structurally sufficient to hold up to the rigors of the wall construction and its intended use. Fabrics should have minimum grab strength of 120 pounds, a grab tensile elongation of 50%, and a Mullen burst strength test of 230 pounds per square inch. The fabric can be either woven or non-woven. The non-woven has more initial permeability, but will plug quicker than the woven fabric. However, neither is effective at passing water once clogged with soil or organics. Woven fabric is slick and provides less friction, making it difficult to work with during construction. The non-woven fabric is more pliable, and the felt-like finish makes it less apt to slip when folded back on itself, which is required in constructing geotextile walls.

<u>Construction</u>
Prior to excavating the foundation, any vegetation suitable for transplanting is salvaged from the work area and kept in wet burlap sacks until it can be planted later in the soil placed over the face of the retaining wall. Once excavation begins, all organics and topsoil from the area are saved for later placement over the completed wall. Save all B horizon soil for use as backfill material. When excavating the foundation, the minimum rearward tilt into the hill slope is 10%. This tilt ensures that the weight of the wall is transferred into the hill slope. The excavation must not be longer than the length of the retaining wall. Vertical earthen sides will help retain the fill material placed on top of each fabric tier.

The length of the fabric should correspond with the width of the wall. Add a minimum of 3 feet of fabric on each end of the wall to fold and seal off the backfill at the ends of the wall. Unroll and cut off the length of fabric needed for one tier of the wall. Each tier is 1 foot high and has two layers of fabric - one below the fill material and one above. If the retaining wall is longer than the fabric, additional lengths are cut and laid side by side with a minimum 4 foot overlap.

Rather than having to handle the entire roll, it is easier to unroll what is needed for each tier and cut that length from the roll. Place one end of these pre-cut lengths of fabric at the inboard hinge of the foundation or the back next to the cut bank, and staple by driving in U shaped pieces of rebar every 4 feet along the inboard hinge of the fabric with a single jack to keep the fabric from moving or being pulled forward. Use a utility knife to cut small holes in the fabric to accommodate the staples. The staples are fabricated from 3/8 inch rebar and are approximately 12 inches wide and 18 inches long. Use a rebar bender and cutter to fabricate the staples. When the fabric is unrolled to where the front of the retaining wall will be, it is left there and is filled with a 1-foot deep layer of the B horizon soil from the initial excavation or imported aggregate. Use tampers or plate compactors to compact this fill material in 2 to 3 inch lifts as you place it. The earthen banks at the rear and sides of the foundation will help contain the backfill as it is being compacted. Care must be taken at the front of the wall as that area is open until the fabric is folded back on itself.

Once the layer of backfill is nearly complete, the fabric at the front of the wall is partially pulled back and temporarily pinned to keep the backfill from spilling out. Continue placing and compacting backfill until the designed thickness of the tier is achieved. Carefully unpin the fabric at the front of the wall, and then fold the sides of the fabric (the extra 3 feet) back on top of the fill material. Using a hospital fold or something similar, fold the front of the fabric over the sides and pull the remaining fabric tightly back over the compacted fill to the inboard hinge. U-shaped rebar staples are used to fasten the fabric along the inboard hinge every 4 feet.

The next length of fabric is rolled out toward the front of the wall just as before, but stops 1 foot short of the previous tier to achieve the one to one batter. Once again, this length of fabric is filled with backfill to a depth of 1 foot. The backfill is compacted and the sides and front are folded, tucked, pulled back and stapled. The process is repeated with succeeding tiers “stepped back” 1 foot from previous tiers to achieve the proper batter, until the final tier is installed and stapled with U-shaped rebar at the back of the wall.

If the cut bank cannot be laid back at a 45 degree or less angle, the width of the fabric tiers above the first tier must be shortened to compensate for the steeper cut bank. The layout for this installation must ensure that each tier steps back 1 foot to retain the 45 degree angle and that the top tier is deep enough to provide the designed tread width.

Once the geotextile wall is complete, the top of the wall receives a minimum of 8 inch of backfill suitable for trail tread. The tread material does not extend beyond the outside edge of the top tier of the retaining wall. The surface is shaped and compacted to provide the desired drainage, and the front of the wall is covered with topsoil from the excavation. If the excavation yields insufficient topsoil it may need to be imported from another location on the trail.

A minimum depth of 1 foot of soil is placed over the front of the wall. Organics are spread over the soil, and if necessary, a layer of jute netting is laid over the face of the wall to help contain it. Another way to install the netting is to put it down before the soil is placed on the face of the wall. Once the soil is in place, a stiff wire with a hook is used to pull the netting through the soil to the surface to ensure that the netting it is integrated into the soil for the best retention. The surface is lightly tamped with a McLeod and organics are spread over it again. Vegetation salvaged earlier is transplanted in the soil on the face of the wall to promote re-growth.

Cellular Confinement Retaining Walls

Cellular confinement material comes in heights from3 to 8 inches, 8 to 10 feet in width, and 13 to 66 feet in length. Individual cells are 4 to 12 inches wide. Order strips to the length, width, and height required for the project. Individual strips can be stapled together with staple pliers or clips, which can be purchased from most cellular confinement manufacturers or local hardware store. In terms of strength, the U.S. Army Corps of Engineers recommends minimum cell seam peel strength of 180 pounds. If a cellular confinement wall is planned where drainage is an issue, it can be purchased with holes pre-drilled through the cells to allow water to pass. Holes can also be drilled once you receive the material.

<u>Construction</u>

It is recommended that a cellular confinement wall have a maximum batter of one-to-one or 45 degrees. This angle is necessary for retaining the soil covering the face of the wall more than it is necessary for stability. Cellular confinement walls can be designed to have a much steeper face, but it is difficult to retain the topsoil and plants needed to cover the wall with steeper designs. If required, an angle steeper than 45 degrees may be achieved if the face of the wall is covered with rock rather than soil. A non-structural rock facing is the most stable at angles steeper than 45 degrees. With this type of rock facing, each rock should have a minimum of three points of contact with adjacent rocks. A shallow footing at the base of the rock facing is required to anchor the bottom rocks and keep them from sliding downslope.

Prior to excavating the foundation, vegetation suitable for transplanting is salvaged from the work area and kept in wet burlap sacks until it can be planted in the soil on top of the face of the wall. Once excavation begins, all organics and topsoil from the area are saved for later placement on the completed retaining wall. Save all B horizon soils for use as backfill material. When excavating the foundation, the minimum rearward tilt into the hill slope should be 10% to ensure that the weight of the wall is transferred into the hill slope.

Construction begins by laying out the cellular confinement strip on the foundation. The leading edge of the strip should be at the designed front of the wall. Make sure there is sufficient space for the bench that will be required to support the soil that covers the face of the wall when it is complete. Staple or clip one or more strips together to achieve the designed dimensions, as necessary.

Open the strip to its full dimensions. U-shaped rebar called a “spreader” is placed along the length of the strip at intervals necessary to keep the strip fully spread until it is filled with backfill material. The spreader can be fabricated using 3/8 inch rebar and a rebar cutter and bender. Rebar should be a minimum of 12 inches high and long enough to match the width of the cellular strips being used. Metal tendons, clips, and anchor pins can also be used to reinforce the geocells and secure them to the ground.

If the wall needs to drain water, the material placed into the open cells must be porous enough to allow water to pass through without clogging. If not, the cells are filled with B horizon soils saved during excavation of the foundation. If there is insufficient soil from the excavation to fill all the layers of the wall, soil can be imported from construction or maintenance activities along the trail.

The cells should be filled from the back of the wall to the front of the wall. Once all the cells have been filled, gaps between the cellular tiers and the hill slope are filled with porous material or B horizon soils, depending on the application. The rebar spreaders are removed and the soil is compacted with tampers. Start the compaction at the rear of the wall and move toward the front. Be careful not to over-compact the material in the cells because it could cause the cells to lift if the backfill material is forced out the bottom of the cells. While compacting the fill material, check the top of the cells with a level to ensure the 10% rearward tilt is maintained. The cellular strip for the second tier is laid out similar to the first tier; however, the starting point for the front of the tier is 8 inches further in toward the hill slope to achieve the one-to-one batter. The wall building process is repeated again with succeeding tiers set back 8 inches to achieve the proper batter until the final tier is installed.

Once the wall is complete, the top receives a minimum of 8 inches of soil suitable for trail tread. The surface is shaped and compacted to provide the desired drainage, and the front of the wall is covered with topsoil from the excavation. A minimum of 1 foot of soil is placed over the front of the wall. Organics are spread over the soil, and if necessary, a layer of jute netting is laid over the face of the wall to help contain it. Another way to install the netting is to put it down before the soil is placed on the face of the wall. Once the soil is down, a stiff wire with a hook is used to pull the netting through the soil to the surface. This method ensures that the netting comes to the surface sporadically so it is integrated and can better hold the soil. The surface is lightly tamped with a McLeod and organics are spread. Vegetation salvaged earlier is transplanted in the soil to promote the re-growth of the face of the wall.

Gabion Basket Retaining Walls

Construction

Gabion panels are joined to form a single unit. The minimum required tensile strength of the wire should be 60,000 pounds per square inch and the minimum galvanizing is 0.80 ounce per square foot.

Most gabion panels (twisted mesh or welded mesh) are manufactured from 11-gauge wires or 9-gauge wires, depending on the application. Tie wires should be galvanized and no smaller than 13.5 gauge. Alternatively, galvanized spiral binders of the same gauge as the panels are used, with a 3-inch separation between loops.

Individual units are divided into cells of equal length, none greater than 3 feet, with diaphragms made of the same construction as the main panels. Wire mesh panels (base, ends, sides, diaphragms, and lid) are assembled so that the strength and flexibility at connections is equal to a single panel.

Prior to construction, determine the size of the retaining wall and the layout of the foundation. Gabion basket retaining walls require a wide foundation. The width of the footing must be equal to one and a third times the height of the wall. In addition, there must be a bench in front of the wall that is wide enough to support the soil that will cover the face of the structure. This additional bench width should be a third of the wall height. A gabion basket wall should have a minimum batter of one-to-one or 45 degrees. This angle is necessary for retaining the soil covering the face of the wall more than it is necessary for stability. Gabion basket walls can be designed to have a much steeper face, but it is difficult to retain the topsoil and plants needed to cover the wall with steeper designs. If required, an angle steeper than 45 degrees may be achieved if the face of the wall is covered with rock rather than soil. A non- structural rock facing is the most stable at angles steeper than 45 degrees. With this type of rock facing, each rock should have a minimum of three points of contact with adjacent rocks. A shallow footing at the base of the rock facing is required to anchor the bottom rocks and keep them from sliding downslope. The lift for each tier should not exceed 3 feet.

Prior to excavating the foundation, vegetation suitable for transplanting is salvaged from the work area and kept in wet burlap sacks until it can be planted in the soil on top of the face of the wall. Once excavation begins, all organics and topsoil from the area are saved for later placement on the completed retaining wall. Save all B horizon soils for later use as backfill material. When excavating the foundation, the minimum rearward tilt into the hill slope is 10% to ensure that the weight of the wall is transferred into the hill slope.

Each style of gabion is assembled by the following method. Rotate the panels into position and join the vertical edges. Welded wire panels are joined along all vertical edges with spiral binders or tied. When tied, the tie wire passes through each mesh opening along the joint and is secured with a locked loop. Twisted wire panels are joined along the vertical edges with tie wire or spiral binders. When the panels are joined with tie wire, use 4-inch nominal spacing, and alternate single and double-locked loops. The end of each binder is crimped to secure the spiral in place. There should not be any openings greater than 4.75 inches (line dimension) along the edges or at corners of tied or spiral bound gabions of either mesh style. Insert wire stiffeners (4 per exposed face) into the baskets to maintain their shape and keep them from deforming when filled with rock. The empty gabions are set in place and each is connected to the adjacent gabion with tie wire along the top and vertical edges. Tie each layer to the underlying layer along the front, back, and sides. The tying is done in the same manner as for assembling the baskets.

Before filling each gabion with rock, remove all kinks and folds in the wire fabric and properly align the baskets. Rock for filling the gabions should vary in size and conform to the following graduation:

Carefully place the rock into the gabions to ensure proper alignment, avoid bulges, and provide a minimum of gaps. All exposed rock surfaces should have a smooth and neat appearance, with no sharp edges projecting through the wire mesh.

The rock is placed in lifts to allow installation of internal connecting wire. Internal connecting wire is used to maintain a relatively flat, smooth external surface for the 3-foot high baskets. Internal connecting wires are galvanized, at least 13.5 gauge, and fastened at the vertical 1/3 points.

The top layer of rocks fills the gabion so that the lid will lie on the rock when it is secured. The lid is secured to the sides, ends, and diaphragms with the wire in the same manner as for joining the vertical edges.

Once the gabion basket wall is complete, the top receives a minimum of 1 foot of soil suitable for trail tread. The surface is shaped and compacted to provide the desired drainage, and the front of the wall is covered with topsoil from the initial excavation. A minimum of 1 foot of soil is placed over the front of the wall. Organics are spread over the topsoil, and if necessary, a layer of jute netting is laid over the face of the wall to help contain it. Another way to install the netting is to put it down before the soil is placed on the face of the wall. Once the soil is down, a stiff wire with a hook is used to pull the netting through the soil to the surface. This method ensures that the netting comes to the surface sporadically so it is integrated and can better hold the soil. The surface is lightly tamped with a McLeod and organics are spread. Vegetation salvaged earlier is transplanted in the soil to promote the re-growth and naturalization of the face of the wall.

Chapter 14. Drainage Structures

Understanding Drainage Patterns

A properly laid out trail will maintain the natural drainage patterns of the landform and minimize interruption of the natural flow. There are many elements that affect natural drainage 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 drainage gradients, and size of the area being drained (watershed). These factors need to be considered when evaluating drainage patterns.

Estimating Channel Flow Area

Understanding the amount of water or 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. The minimum flow that a trail designer should use for evaluation purposes is the 100-year event.

Use one of the modeling methods (Rational Method, USGS Magnitude and Frequency Method, or the Flow Transfer Method) and field observation to estimate 100-year event flow levels. Field observation methods include the Triple Bankfull and Double Peak Flow.

The size of a culvert also must account for the loss of flow rate through the culvert. Once water flowing through a culvert reaches about 90% of the culvert's capacity, there is an increase in the amount of friction that reduces the flow rate by approximately 10%. To compensate for this loss, the cross sectional area should be increased by 10%.

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.

Crossing sites and structures should be sustainable, have the least environmental impact, and meet the needs of trail users. When selecting stream crossing sites 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. Stream drainages are complex systems and subtle changes easily disrupt the equilibrium of a watershed. Therefore, it is important to consult a qualified hydrologist or engineering geologist when locating, designing, or constructing these structures.

Selection and Accessibility
Whenever possible, the drainage structure should not be a barrier to hikers 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.

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 down slope of the excavated area to prevent sediment from entering the watershed.

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

Excavated material must be exported to a stable location far enough away from the crossing site that it cannot re-enter the stream channel. Additional silt fences are 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 fences or waddles 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 coffer dams are removed and disturbed areas are rehabilitated.

Drainages Without Structures
The most effective method of facilitating overland sheet flow is to design and layout the trail to follow curvilinear alignment. Design and construct the trail tread with a full bench on a side slope with greater than 20% gradient and an outslope. 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.

The percent of outslope needed for a trail varies. The percentage of outslope needed to facilitate sheet flow across the trail tread depends on the steepness of the linear grade, soil strength and durability, amount and magnitude of rainfall received, amount of surface area (watershed) above the trail, percent gradient of hillslope the trail is traversing, amount of canopy cover above the trail, mechanical wear associated with user types, and the volume of traffic. The outslope of a trail should not be less than 1.5 times the linear grade. This ratio of outslope may need to be increased on trails with high mechanical wear.

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.

Simple Open Structures

Drain Swales
A drain swale is an appropriate structure for maintaining natural drainage patterns. 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. 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.

Armored Drain Swales
Sometimes a drain swale receives high flows that warrant the hardening of the trail tread within the crossing. 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.

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. 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 and coarse 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 or gradient of the watercourse crossing so that the finished elevation will match the channel's elevation. If the top of the armoring structure does not match the existing channel grade, this structure will alter the stream morphology, which could result in lateral scour, head cutting, streambed 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. 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. 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. 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. 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.

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 larger volumes of water during storm events. 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.

Because larger watercourses receive more water than those where armored drain swales are used, armored stream crossings require deeper excavations 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. More dynamic streams may require increasing the stone size to 2 feet deep and 1.5 feet wide.

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 flows that are 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. If the spring has a low flow volume and is confined to a small area or a single location, then a drainage lens could be prescribed. 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. 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. In addition, inboard drainage ditches must be used in conjunction with a drainage structure to carry the water across or under the trail.

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.

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. 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 it will retain its position without sliding down the slope and even further if needed for stability and eventual 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 ditch water velocities 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 reduce 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.

Culverts

Open and Step Through Culvert Construction

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.

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

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. 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.

Close Rock Culvert Construction
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 crib walls are installed along the outside edges of the culvert to contain the soil covering the top stone or stones.

Open and Closed Wooden Culverts Construction
Open culverts constructed of wood are sized and installed in the same way as rock culverts. However, given the limited size of planking material, this style of culvert is

used primarily on small, ephemeral watercourses or seeps. When selecting lumber for a wood culvert, use a species that is resistant to rot, such as cedar or redwood. Pressure treated wood is not acceptable, as the culvert will convey stream or spring water, and preservatives will leach into the water.

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 bottom of the outside planks are flush with the top of the tray plank. 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. Rock headwalls are required to seal the culvert inlet and support the crushed backfill.

Metal and Plastic Culverts

Closed metal and plastic culverts have 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 natural watercourse underneath the trail or in conjunction with ditches. The latter is referred to as a ditch relief culvert.

Culverts should not be used to cross a watercourse that is habitat for fish or sensitive or 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 natural 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.

To properly size a culvert requires careful evaluation of the stream channel above the inlet to identify the presence and quantity of aggregate, sediment, branches, or large woody debris. If a significant quantity of aggregate or woody debris is observed in the channel, the culvert’s size should be further increased to accommodate the passage of that material. 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.

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.

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 coffer dam 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.

Given that culverts are only recommended for low-flow drainages, 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 back to an angle that the banks are stable, shoring can be avoided.

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, which reduces the depth of the trench. An oval culvert may also better accommodate a stream channel that is shallow and wide. Its lower profile can reduce trenching excavation and the amount of 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 inlet and deposition or head cutting at the outlet. 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.

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

Culvert Headwall

Prior to backfilling the trench, headwalls are installed at the inlet and outlet. 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, but concrete, wood, and burlap bags filled with Ready-Mix are also used for headwall material. 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.

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. 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. 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. 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. 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.

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. Hand heavy metal plate tampers and the flat end of digging bars 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 drainage 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.

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.

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 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 drainage feature already exists.

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 hydrologic 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 feature, 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.

Because relief culverts drain inboard ditches, they are 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. 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.

Relief culverts must have headwalls and energy dissipaters. Headwalls are 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. 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.

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 culverts 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.

Step Stone Crossings
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. 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 step stone crossings. 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 modification 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.

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 step stones will not be undermined by bed load movement.
- 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 proper conditions 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.

Installation of step stones is performed during low flow periods in perennial streams and during dry periods in ephemeral streams. 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 largest 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 of 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 are 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.

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. Sometimes a ford is located adjacent to a bridge crossing because equestrians often prefer using a ford.

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 course 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 both horse and rider. Widening the channel reduces the water depth, 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.

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.

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.

Drain Lenses

The use of a drain lens is restricted to low flow seeps and springs that have a narrow discharge. High volume springs and springs that cover a broad area are better served by other drainage structures, such as inboard ditches, culverts, or armored drain swales.

Installation begins with excavation of the trail bed to the depth of the saturated soil and extending beyond the trail bed width into the back slope and fill slope. 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. 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 minimum inward batter of 3 inches for every 12 inches of height.

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 4-inch thick and compacted. In applying the tread, make sure the material will not filter down and contaminate 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 sustainability without the fabric working its way to the surface.

<u>Drain Lens with a Culvert</u>
In certain conditions, the effectiveness of a drainage lens can be improved by adding a culvert. 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. To protect the culvert from sharp rock faces (especially an ABS culvert), the culvert is wrapped with geotextile fabric when installed.

Other Trail Drainage Structures
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 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 in site conditions that meet the criteria of a wetland. In these locations, less intrusive structures such as puncheons and boardwalks are more suitable.

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.

Turnpikes

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. 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 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. 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. 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. Water can be collected on the native grade and dispersed in its natural pattern if the structure does not significantly interrupt flow. Depending on the amount of runoff, the water is collected by parallel ditches and channeled to culverts that carry the flow under the turnpike to escapement ditches down slope.

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 inch but 4 x 8 inch 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 in more expensive but may have more longevity than wood products. The structural characteristics of plastic lumber make it more susceptible to warping, twisting, expanding, and contracting due to the effects of ultraviolet light. The use of plastic lumber in a turnpike will need to compensate for this weakness 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 when exposed to ultraviolet light.

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. The lap joint is cut and pre-drilled for pinning prior to being laid in the footing. Once placed into the footing, the ends of the lumber are pinned with 5/8-inch x 3-foot rebar. The span between rebar pins is typically 4 feet but should not exceed 6 feet. Additional pinning will be required for longer lumber.

<u>Rock Causeways</u>
A rock causeway is the same as a log turnpike, except the fill material is contained by rock walls. This structure is most suitable in rocky environments, where materials are plentiful and aesthetic compatibility can be maintained.

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 from 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.

When constructing a causeway on an accessible trail hardened with crushed rock, the inside of the wall rock needs to be nearly vertical so the crushed rock will have an even and uniform depth and prevent differential settling. A causeway wall is laid in the same manner as a single tiered rock wall. When completed, the wall is filled and chinked with rock from 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 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.

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.

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.

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 coupling of watercourses, inter-basin water transfer, impacts to plant and animal communities, slope instability, soil erosion, and mass wasting.

<u>Drain Dips</u>

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 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.

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.

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.

Rolling Grade Dips

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. When designing a trail with a rolling grade dip, you must 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 the linear grade between control points substantially.

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.

Water Bars

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.

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. For example, a trail with a 15% grade requires a water bar at an angle of approximately 35 degrees.

Look at the natural drainage of the area to determine the appropriate placement. A water bar should mimic the natural flow of water across the trail. If the trail has altered the natural pattern and water runs down the trail, determine the most direct path of travel and build the water bar to emphasize that path. If you can observe the trail with water on it during spring runoff or a cloudburst, the drainage pattern will be more evident.

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

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

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.

Chapter 15. Timber Planking, Puncheon, and Boardwalks

Installation of these drainage structures in wet areas should occur during the time of year when ephemeral streams and springs are dry or at the lowest flow. Sediment control devices, such as silt fences or straw waddles, are installed down slope of the intended excavation area to prevent sediment from entering the watershed. All excavated material should be exported to a stable location far enough away from the construction site that it cannot re-enter the watercourse. Additional silt fences should be installed between the watercourse and the excavated material if there is any chance of that material migrating back into the watercourse.

Once the structure installation is completed, all excess excavated soil or any soil trapped in the silt fence or waddle should be hauled away from the influence of the watercourse and used as backfill on trail structures or sidecast on appropriate slopes. All sediment retention structures are removed and any disturbed areas are re-vegetated and rehabilitated.

Timber Planking

Timber planking structures represent a minimalist approach. They are primarily used in remote settings where primitive conditions are expected by the user. These structures are not suitable for Class 1 or 2 trails.

Where soil conditions allow, the earthen foundations for the sills should be level front to back and side to side. The sill foundations should also be level to each other to avoid uneven loading of the structure. In fens with tussocks or in dense tundra mat, precise leveling and squaring of the sills may not be possible. Excavation may also need to be kept to a minimum to reduce disturbance to vegetation and permafrost. The builder needs to make the sills as level and square as the site conditions allow.

The sills should be comprised of the most rot-resistant tree species available, such as redwood or cedar. The bark and sapwood should be removed from the sill logs to reduce rot and increase their lifespan. The diameter and length of the sills will be determined by the strength of the underlying soil and the intended width of the planking. The sill will also need sufficient height to provide an air gap between the wooden planks and the surrounding soil. The maximum distance between two sills should not exceed 8 feet. If possible, the sills should be level and squared to each other.

A 5/8-inch diameter piece of rebar is then driven through each hole to pin the sill log to the ground. The length of the rebar should be sufficient to have it penetrate through the sill and into the ground a minimum of 30 inches. If the underlying soil is subject to severe freeze thaw or frost heave conditions do not pin the sills. Pinning will not allow the timber planking structure to freely move with the undulating ground.

Once the sills are anchored, the planking is installed. These planks should be a minimum of 4 x 12 inches in dimension and have a maximum free span of 8 feet. They should also be constructed of rot resistant wood. The planking can be installed either as a single plank or two planks side by side. If an individual timber plank structure is being constructed, the plank should be installed so that the ends are flush with the outside edge of the beginning and end sills. With a multiple timber plank structure, the ends of the first planks are placed flush with the outside edge of the beginning sill and approximately halfway on (or center of) the next or second sill. The next set of planks will butt against the first planks and rest halfway on the second sill and halfway on the third sill.

The planks should be fastened to the sills by drilling a 5/16-inch pilot hole through the planking and driving in 7-inch galvanized spikes or 7-inch timber lock screws until they are flush with the planking's surface. A punch or drift pin should then be used to recess the head of the nails a minimum 1/8-inch below the surface of the planking. A minimum of six nails or screws should be used for each piece of planking (three on each end of the planking). The two outside nails are located approximately 1 1/2 inches in from the edge of the planking.

Where multiple timber planking sections are constructed, it is important that the planking structure conform visually to the surrounding setting. Long, straight sections of planking on a trail that is curving around the hillslope will look out of place and contrast to the natural setting. In these settings, the timber planking structure should be laid out and constructed to curve with the terrain. To achieve the desired curve, the ends of the planking must be cut at an angle. The angle will vary depending on the amount of curve desired. Once the planks have been cut, the sills are set to match the angle of the end cuts on the planking.

Puncheons

Puncheons are used when the trail alignment traverses through saturated or chronically wet soils. Sometimes landform limitations may require traversing through this type of ground, especially in marshes, boreal forests, temperate rain forests, or low wetland areas associated with stream or river valleys. They may also be required when the trail alignment unknowingly intercepts sub-surface ground water flows or when a small ephemeral watercourse needs to be crossed and there is no suitable wet crossing location. In the Pacific Northwest they are also used to span over exposed tree roots that are associated with the redwood, fir, spruce, and hemlock trees.

Puncheons are designed to be low to the ground. When used to traverse saturated and wet soils or tree roots, they are no more than 2 feet above the ground. These structures are not intended to be used where water is flowing across a low flat area without a defined channel because they do not possess the necessary free board and may disrupt the flow. They should not be used in applications where railings are required (i.e., decking elevations of 48 inches or higher above the channel).

Puncheons are a very good design solution to providing an accessible trail surface when native soils are too weak to meet the firmness and stability standards and site conditions prohibit the use of trail hardening, turnpikes, or causeways. They also can be used to bridge over obstacles such as roots and rocks that are in excess of accessibility standards.

Puncheons can be used by horses but due to a horse’s sensitivity to vibrations, noise, and confinement, puncheons are not ideal for equestrian trails and should be used sparingly. The span of a puncheon on an equestrian trail should also be kept minimal since the more time a horse is on a puncheon the more likely it is to become spooked.

Construction of a puncheon begins by laying out, excavating, and leveling the mudsill foundation. This layout and leveling process is usually performed with an Abney hand level or clinometer, McLeod, form stakes, ledger boards, and tape measures. The simple but effective layout method is a common practice when constructing less complex trail structures in the field. At the completion of this process, the mud sills will be anchored to firm and stable ground and level and square to each other.

There should be a minimum of two 6- x 8-inch select structural Douglas fir joists attached to the top of the mudsills. If using redwood or cedar, the joist size needs to be sufficient to meet the 100 pounds per square foot live load requirement. The joists should be squared to the mudsills, centered, and spaced so the two outside joists are 48 inches apart (outside to outside) for a puncheon without bull rails. The joist spacing should be 60 inches if bull rails are installed. The maximum free span of these joists should be 12 feet.

When installing the decking, it is important that the boards are laid with the crowned side up. The decking should be fastened to the joists by drilling a 7/32-inch pilot hole through the decking and into the stringer. The depth of the pilot hole should leave at least 1 1/2 to 2 inches of un-drilled wood in the joist to firmly grasp the fastener. When using long decking screws (5-6 inches), it may be necessary to drill the hole deeper because screws this long shear easily. With 3-inch decking, drive in 60D galvanized nails until they are flush with the decking surface. A punch or drift pin should then be used to recess the head of the nails a minimum 1/8-inch below the surface of the decking. Stainless steel deck screws 6 inches long can also be used to fasten the decking to the joist. If the decking used is 6 inches wide or less, then two fasteners are used per board. These fasteners should be placed approximately 1 1/2 inches from the edge of the boards to keep the boards from curling or cupping. If the boards are wider than 6 inches, then three fasteners per board are used; two approximately 1 1/2 inches from the edge of the board and one in the center.

Soil dams are attached to each end of the puncheon to provide separation between the puncheon structure and the surrounding soil. They should be con heart redwood, cedar, or pressure treated Douglas fir. The soil dams should be a minimum dimension of 3 inches thick and the same length as the mudsills. The number of boards will be dictated by the overall height of the puncheon. The soil dam should span from the bottom of the mudsill to the top of the decking. It is fastened to the ends of the joist and the mudsills.

If the puncheon is for an accessible trail, bull rails can be attached to the outside edge of the decking to provide edge protection. Bull rails can also be used on equestrian trails. The bull rail should be redwood, cedar, pressure treated Douglas fir, or plastic wood. The bull rail is attached to the decking by placing 2- x 4-inch wooden or plastic lumber blocks between the bull rail and decking. These blocks are required to elevate the bull rail off of the decking to allow water to drain and reduce the buildup of organic material that will increase rot. These blocks should be inset from the ends of the bull rail by approximately 2 inches and have a maximum spacing of 48 inches. The bull rail should be a minimum of 4- x 4-inches with 4- x 6-inches preferred. The bull rails and blocking are attached to the decking by drilling a 3/8-inch hole through the rail, bock, and decking, and fastening all three together with 3/8- x 12-inch galvanized carriage bolts.

Curved Puncheons

Where multiple puncheons are constructed it is important that they conform to the surrounding setting. Long, straight sections of puncheons on a trail that is curving around the hillslope will look out of place and in contrast to the natural setting. In these settings the puncheons should be laid out and constructed to curve with the terrain. There are two basic methods for obtaining this curve: installing the mudsills parallel or flared to each other.

Equestrian Puncheons

While the basic structural design is the same for hiking and equestrian puncheons, there are some design modifications to accommodate horses. The joists must be a minimum of three 6- x 8-inch pressure treated Douglas fir to reduce the deflection (bounce) in the joists as a horse crosses the puncheon.

The decking should have a minimum thickness of 4 inches, a minimum length of 72 inches, and a minimum space of 60 inches between bull rails. Note, with 4-inch thick decking, 7-inch galvanized spikes should be used to nail it down. The bull rails should be a minimum of 4 x 8 inches. Bull rails should be installed in the same manner as those on pedestrian puncheons except the carriage bolt should be longer to accommodate the 8-inch bull rail and 4-inch decking. The approach to both ends of the bridge should be level, if possible.

Boardwalks

Boardwalks can be designed to be low to the ground or relatively high off the ground. When used to traverse sandy soil, saturated and wet soil or tree roots, they usually are no more than 24 inches above the ground. When used to cross ephemeral watercourses or ponding water, they can be more than 24 inches from the decking to the lowest point in the watercourse. They also can be used in applications where railings are required (e.g., decking 48 inches or greater above the channel). These structures are not intended to be used where water is flowing since they do not possess the necessary free board and may restrict water flow. They are, however, an effective structure for spanning across ponding water where high flows and associated debris do not occur.

Boardwalks are primarily used on pedestrian and accessible trails but they are also appropriate on mountain bike trails. Due to their high elevation off the ground and a less robust design, most boardwalk structures are not suitable for equestrian use.

There are numerous boardwalk designs that can be used on trails. The basic differences between these designs regard the foundations and the types of materials used to construct the boardwalk's superstructure. The most common foundations are wooden and plastic wood mudsills, concrete pier blocks, diamond piers, and helical piers. The superstructure materials are wood, fiberglass, metal, wood composites, and plastic lumber.

Foundation Layout

Prior to constructing the foundation for the boardwalk, layout the structure. At the completion of the layout process the location of each mudsill or pier and their finished elevation should be identified to ensure they are level and square to each other.

Boardwalk Construction

Wooden Posts
Once the piers have been installed, the construction of a boardwalk using pier blocks is nearly identical to one using diamond piers. Either of these structures may use wooden post depending on the finished elevation of the boardwalk. The wooden posts are secured to the concrete pier blocks by toe nailing the posts to the wooden blocks seated on top of the pier blocks with 16d galvanized nails or by using pier blocks with a manufactured galvanized bracket, such as a Simpson Post Base, embedded into them. With diamond piers, the wooden posts are bolted directly to a metal bracket that is imbedded into the top of the diamond pier. The posts should be fastened onto the concrete pier blocks and diamond piers so that they are parallel to the headers that will be placed on top of them.

Header Installation
Headers span across the post and are perpendicular to the path of travel. They should be a minimum of 4- x 8-inch redwood, cedar, or pressure treated Douglas fir. Headers are attached to the top of the wooden posts either by toe nailing them 16d galvanized nails or using a manufactured galvanized bracket such as a Simpson Cap/Base.

With helical anchors, wooden posts are not used and the header is bolted to a metal beam seat bracket that is attached to the helical pier extension.

Joist Installation
Once the headers are installed, wooden joists are attached to the headers. Pedestrian boardwalks require a minimum of two 6- x 8-inch joists of pressure treated structural grade Douglas fir. If composite lumber or non-structural plastic wood is used for decking, the number of joists should be sufficient so that the space between the joists does not exceed the manufacture's recommendation. The maximum free span for all these joists should be 12 feet unless appropriately sized joists are used.

The joists are fastened to the header by either toe nailing with 16d galvanized nails or using a manufactured galvanized bracket, such as a Simpson Hurricane Tie. Joists can also be attached to the header at the face of the header so that the top of the joist and the header are at the same elevation when joined. The layout process is the same except it occurs on the face of the header instead of on the top of the header. The joists are fastened to the header via a galvanized metal bracket such as a Simpson Double Shear Joist Hanger.

Railing Post Installation
If handrail posts are required they are through bolted to the side of the joist and header with 3/8- x 10-inch carriage bolts. The post material should be rot resistant wood with a minimum dimension of 4" x 6". The length of the post is determined by the designed finished railing height. Pedestrian railings are 42 inches from the top of deck to the top of the rail. Accessible trail railing height should accommodate an unrestricted viewing

area between 32 and 51 inches from the top of the deck at each distinctive viewing location determined along the railing.

Decking

After the posts have been fastened, the decking is installed. The decking is cut so that it extends beyond the outside joist by a minimum of 6 inches. The overhang is necessary to cover the exposed sides of the joists for aesthetic purposes. It also ensures that the decking extends beyond the bull rail, posts, and railings, if they are installed, and prevents trail users from stepping off the end of the decking when walking next to the bull rail or railing.

The decking should be laid perpendicular to the direction of the joists. As each piece of decking is laid down, it is centered on the joists by measuring the length of the overhang on each end. Once a decking board is centered on the joists, the next piece of decking is laid down next to it. A gap is left between the two pieces of decking to allow for future swelling and shrinkage. Normally, a 1/4-inch gap is sufficient, but some materials and climates may require 3/8 inches or more. In cool, wet climates where the decking never dries out, no gap between the decking boards is required. In these climates, the gaps will accumulate organics between the boards, which may increase rot in the decking and joists. In a very hot and dry desert climate, board shrinkage can be substantial. In these conditions, decking should be installed without a gap, otherwise the gap may become too wide especially by accessible trail standards.

Prior to fastening the decking to the joists, pilot holes for the fasteners are drilled to reduce the risk of splitting or splintering the decking boards. If the decking is 6 inches wide or less, two fasteners are used per board, placed approximately 1 1/2 inches from the edge of the boards to keep them from warping. If the boards are wider than 6 inches, three fasteners per board are used: two at approximately 1 1/2 inches from each edge of the board and one in the center. For wooden decking, the pilot holes should be one drill bit size smaller (i.e., 1/32 to 1/16 inch smaller) than the diameter of the fastener. For composite and plastic wood, the bit should be the same diameter as the fasteners because this material is very hard and deck screws would likely shear before passing through. The depth of the pilot hole should leave at least 1 1/2 to 2 inches of un-drilled wood in the joist to firmly grasp the fastener. If using long decking screws (e.g., 5-6 inches), it may be necessary to make the hole deeper because screws this long shear easily. When the decking wood is hard and dry, it may also be necessary to lubricate the nails or screws when installing them. Liquid hand cleaner (in a can) works well for this purpose and is easy to use. Only decking screws should be used on composite lumber and plastic wood. All fasteners should be stainless steel or galvanized steel for maximum longevity.

If nails are used, they should be driven with a hammer until they are nearly flush with the deck surface. Then, a hand punch and hammer should be used to drive them approximately 1/8 inches below the surface of the deck to prevent hammer marks on the decking and eliminate tripping hazards. Deck screws should also be screwed approximately 1/8 inches below the surface of the deck.

Decking and Soil Dam Installation
The decking and soil dam are installed on boardwalks the same as on puncheon structures.

Railing Installation
If the top of the decking is 48 inches or more above the channel or ground below, a railing is required. The railing should be 4- x 6-inch redwood or cedar. The finished height of the railing from the top of the decking to the top of the railing should be 42 inches for pedestrian trails. At vista points along an accessible trail, ensure that the railing does not restrict the view between 32 and 51 inches from the top of the deck. The railing is notched to rest on top of the post and is fastened to the post using galvanized 40d nails. Pilot holes are drilled through the railing and post to reduce splitting. The twist bit for the pilot hole should be 1/16 inch less than the shank of the fastener. The fasteners are driven in at an angle to provide better attachment to the post and reduce splitting. The heads of the nails are set flush with a drift punch and the screws are set just below the surface of the wood. If two rails join at the top of a post, the railings are notched and joined at the center of the post.

Bull Rails
If required, bull rails are installed as previously described in the section on puncheon construction after the posts and top railings are assembled.

Diagonal Rails
The diagonal rail provides an additional safety barrier under the top railing and between the posts. These rails are installed diagonally from the intersection a top railing and post to the intersection of a post and the decking on an adjacent post. The railing is cut to rest flush against the posts and is fastened to the posts by toe nailing with 40d hot dipped galvanized nails.

After all the railings are installed, the posts and railings are sanded to remove splinters and rough areas that might injure the trail users.

Chapter 16. Trail Bridges

A trail bridge is a structure along a trail that spans over a waterway, precipitous slope, or other unstable ground that cannot support trail construction. Typically, a trail bridge is longer than a single span puncheon or boardwalk. If the height from the deck of the bridge to the ground or watercourse below is 48 inches or more railings are required for safety. In addition to horizontal railings, a mid-rail or diagonal mid-rail is also necessary for edge protection.

Bridges are expensive to build and maintain. They also can have significant impacts to park aesthetics and resources. Before deciding to build a bridge, consider other crossing designs first.

Bridge Site Evaluation
Bridge sites represent major control points designed within a trail alignment. A brief summary of the criteria used to identify the most appropriate bridge location are listed below:

- Narrow channel width to reduce bridge span;
- Straight channels to reduce bank erosion;
- Stable watershed to reduce stream bed aggradation or channel scour;
- Stable banks to provide a long term foundation for bridge abutments; and
- High banks to place bridge elevation above high flows and associated floating debris projecting above flood waters.

In evaluating the watercourse to be crossed, several potential bridge crossing sites are evaluated. Some of these sites may require substantially more trail construction and resource impacts to use. Even if a site has good physical attributes, the feasibility, cost, or resource impacts of building the trail to the site might eliminate it from consideration.

The length of the bridge span is another factor to consider when selecting a bridge site. Selecting a site with a short span increases the options for bridge design and material selection. It also potentially reduces resource impacts, improves aesthetics, minimizes material transportation, and reduces construction and maintenance costs. When identifying the required bridge length, identify both the “free span” and the “total span.” The “free span” is the length of the bridge stringer that is not supported by the abutment sills.

Access to the site is another concern. Bridge stringers, along with abutment and superstructure materials, will need to be transported to the bridge site. Generally, this transport is via hand carrying, pushing or pulling bridge components attached to trail carts or other wheeled carriers, or high lead and/or skyline rigging. These methods can be tremendously time and labor intensive, especially if the distance to be traversed is great or the ground is difficult.

Desirable features of a bridge crossing site might be appropriately sized and located trees, large boulders, or bedrock outcrops that that could serve as high anchor points. These anchors are essential for securing a high lead or skyline rigging that may be required to transport, place, and assemble the bridge.

Bridges often serve as a focal point for trail users. People usually stop on these structures and contemplate their surroundings. Selecting a crossing site that provides pleasing views of the stream or vistas of the surrounding countryside can have a dramatic impact on the user’s experience.

Bridges are usually located within the inner gorge area of a watershed. The inner gorges of most watersheds are inherently dynamic and unstable. Building a bridge in these locations requires careful examination of the potential site. Geomorphic features, such as landslides, debris flows, and scarps, are obvious indicators of unstable areas.

It is always desirable to support abutments on bedrock. When bedrock is not possible, evaluate the substratum intended to support the bridge for structural integrity and water intrusion and saturation. Saturated or loose, unconsolidated soil may not provide suitable support for a bridge abutment. Weak soil may require some type of retaining structure to become a suitable foundation. However, before entertaining construction of a retaining wall to contain abutment materials, the potential effect of the wall on the hydrology and morphology of the stream has to be carefully evaluated. Sites with weak or unstable substratum should be avoided.

Ensure that the approaching trail grade is within the design standards and avoid sudden grade changes by identifying the finished elevation of the bridge deck. Keeping the approaching trail elevation the same as the deck elevation eliminates the need for steps, improving accessibility and use by equestrians and bicyclists.

Selecting a Bridge Design
Using all the information developed during the bridge site assessments, select a bridge design that is the most appropriate for the site conditions, trail standards, user types, and management policies. Regardless of the chosen design, it must be properly engineered to be considered safe for public use. The design must accommodate the Department's minimum live load rating (100 pounds per square foot), dead load (weight of the bridge's superstructure), snow load (maximum anticipated snow fall on the bridge), wind shear (wind force against the bridge), and seismic conditions (level of seismic activity in the geographic area of the bridge). The ability of a bridge to accommodate these engineering requirements is dependent on the design of the bridge and the materials used to construct it.

Another important consideration in selecting the bridge design is the predominant architectural style used by the agency managing the trail system. State and national parks and forest agencies often have a particular style of architecture that is applied uniformly throughout their management areas. The style is often based on historical practices or the need to comply with a historical setting. The bridge design may need to correspond with the surrounding architecture, which often can be accomplished simply by using the appropriate materials and finishing techniques on the bridge's superstructure.

Selecting an Abutment Design
Once the bridge site and design are selected, you must determine the abutment type. Abutments are the foundation upon which the bridge sills rest. The type of abutment used will be based on the site conditions and the selected bridge design. Among the site conditions to be considered, are the strength and stability of native soil; surface and sub-surface drainage conditions; the elevation difference between the right and left banks; the amount of free board required to keep the bridge above future flood events; the availability and suitability of local building materials; the steepness of the hillslope; and the elevations and configurations of the approaching trail alignments. The bridge design will influence the abutment loading requirement, surface contact (displacement),

finished elevation, building materials, architectural design, and number of required anchors.

Abutment Sills
An abutment sill is the structural member on which the bridge stringer is set and to which the stringer is fastened. The sill is usually constructed of wood, plastic wood, or concrete. The abutment sill anchors the bridge stringer to the abutment and provides a barrier and air gap between the stringer and the surrounding soil and vegetation.

Regardless of the style of sill selected, it must be adequately sized to support the weight of the bridge and all its components (dead load), as well as the weight of the bridge users (live load). The live load for trail bridges in the California state park system is 100 pounds per square foot. The sill for a bridge at a high elevation may also need to be designed to support the additional dead weight associated with snow. The size refers to the total surface area of the sill that comes into contact with the abutment. As the load bearing capacity of the native ground decreases, the sill's surface area contact must increase. The larger and heavier the bridge structure, the more surface area contact is required of the sill.

Initial Best Management Practices
Prior to laying out the bridge abutments, it is important to undertake several measures that will minimize potential impacts to resources. To layout the abutments, you must be able to cross the watercourse, often numerous times, which can result in the destruction of riparian vegetation, bank erosion, and stream bed disturbance. The best way to eliminate these problems is to establish a temporary crossing that can be used for the entire project. Although the layout activity represents a minor issue in terms of disturbance, it is just the precursor to the destruction that can occur when personnel and materials are moved across the watercourse once construction begins.

If high anchors are available, installing a wire rope skyline directly over the abutments will provide a means of transporting both personnel and materials across the watercourse. A temporary bridge, such as a pipe bridge, will also facilitate the movement of personnel and materials across the watercourse. In a small watercourse, scaffolding and planking can be assembled to facilitate a temporary crossing, for example. The goal is to keep personnel away from the riparian vegetation, streambanks, and streambed.

In addition, appropriate erosion control measures must be installed between the abutment layout area and the watercourse to prevent the migration of disturbed soil into the watercourse. A well-planned and executed bridge construction project will avoid unnecessary resource damage and add credibility to the environmental review and permitting processes.

Abutment Layout
Since the abutments serve as the foundation for the bridge, they should be constructed square and level to each other. The stringer tables and engineered bridge plans in this

handbook and the pre-engineered bridge stringers purchased from manufacturers are sized for level bridges. Constructing a bridge “out of level” means more of the total weight (“dead load” and “live load”) is born by one end or side of the bridge. The force of gravity will unequally distribute the weight to the downhill end or side of the bridge. Sometimes a bridge structure is intentionally designed and constructed with a moderate linear grade (end to end). Such a structure must be specifically engineered to compensate for uneven loading. Also, a bridge deck with even a moderate linear grade can be difficult if not hazardous to traverse in wet or icy conditions. A level bridge is much easier for trail users with a mobility impairment to traverse.

Layout the bridge abutments prior to construction. The layout of simple earthen/rock abutments with mudsills is usually performed with an Abney hand level or clinometer, McLeod, form stakes, ledger boards, and a tape measure. Most bridge abutments are more complex and require the use of an auto level, stadia rod, tape measure, framing squares, form stakes, batter boards, and builder’s string. Establish a center line, abutment footprint, beginning and end of bridge batter board stakes, end and side batter boards, and string lines for the location of the bridge abutments, sills, beam seats, and beam seat brackets and anchors. Square the abutments and sills and ensure the finished elevations are level to each other.

<u>Excavating Earthen Abutments and Abutment Foundations</u>

Earthen abutments with sills must be excavated to the designed footprint and elevation. For soil/rock retention or concrete abutments, the abutment foundation must be excavated to the designed footprint and elevation to support the abutment structures.

During the excavation process, regularly monitor the excavation with the auto level and stadia rod to keep the trail crew informed on their progress and how much material remains to be removed. Elevation readings should be taken throughout the excavation area, not just the initial elevation stations. In addition, a 4-foot carpenter’s level attached to a long straight board can be used to evaluate the leveling process and ensure that over-excavation does not occur. Over-excavation will result in having to use earthen fill or aggregate to elevate the low areas. Even when properly compacted, fill areas will lack the load bearing qualities of undisturbed native soil.

All excavated soil must be exported away from the influence of the watercourse. Normally the approaching trails on each end of the bridge are constructed in a manner that will facilitate the removal of soil by the trail crew. If possible, the exported soil should be used for fill material behind a cribbed retaining wall or similar structure or scattered on a hillslope outside of the influence of the watercourse.

On most trail projects, plate compactors and jumping jacks are the most effective compaction equipment. It is important that the on-site native soil has good strength and cohesion or be supplemented with high-quality aggregate to ensure that it is capable of supporting the abutments. Having near optimum soil moisture is also critical to achieving the desired soil compaction. Time the bridge construction project around good soil moisture conditions or import water to achieve those conditions. Soil that is too dry will not bind well and have relatively large voids. Soil that is too wet will be soft when wet and will have many voids after the soil dries.

Concrete Abutment Construction
A concrete abutment requires a solid foundation. If the abutment is to be poured on top of native soil, the foundation must be properly excavated and compacted.

A simple concrete abutment usually has a footing to provide a stable base. The base of the footing must have sufficient area to support the load of the bridge. The footing must also be long and wide enough to accommodate the depth and width of the stem wall. The footing can be formed and poured separately ("cold joint") or it can be formed and poured as a unit with the rest of the abutment.

A stem wall is formed and poured on top of the footing. It must be wider than the outside to outside measurement of the bridge stringers and high enough to be level with the top of the decking. Formed within the stem wall is the beam seat upon which the bridge stringers will rest. The rest of the stem wall extends above the beam seat and acts as a soil dam. This section of the stem wall provides the barrier between the surrounding soils and the bridge superstructure.

In locations that freeze during winter, the footing must be excavated below the frost line (i.e., excavate below the depth to which the soil will freeze). Local building codes usually specify this depth.

When receiving transit mix, a slump test should be performed to check the consistency of the concrete. The consistency is the relative stiffness of the concrete. It also indicates how much water has been used in the mix. Too much water and the concrete will be weak. Too little water and the concrete will be difficult to work and will set-up too fast.

Use sacks of dry ready mix concrete in remote locations. Ready mix concrete comes in 60 or 80 pound bags. The size of the bag selected for use should depend largely on the method of transport. For bridge abutments, the standard 4,000 PSI mix is adequate for most jobs. When greater strength and quicker curing are required, the 5,000 PSI mix is preferable. When pouring bridge abutments in areas with freeze/thaw conditions, an air entrainment additive is recommended.

Once the ready mix is on-site, it should be placed on a water-proof tarp and covered with another tarp to keep moisture from setting up the concrete prematurely. Straw waddles or silt fences must be placed around the bags of concrete to prevent the cement from migrating into the nearby watercourse. Additional straw waddles must be installed around the abutment forms and concrete mixing sites to contain concrete spilled during the mixing or pouring processes.

To mix the concrete, a steady supply of water must be available. Usually a hose can be used to pipe water from an upstream site to the abutment. The use of local water supplies and the method of transportation must be approved in the environmental review and permitting process.

After the concrete has cured a minimum of seven days, the forms can be removed.

Wooden Trestle Construction

Being a load bearing structure, trestles require a strong and stable foundation. Unless the underlying soil is very firm and stable, a concrete footing usually serves as the foundation. The slab is formed and poured on level and compacted mineral soil or rock. It is recommended that the concrete slab be a minimum of 1 foot longer than the mudsill, which varies depending on the height of the trestle. It should be a minimum of 2 feet wide for a single trestle and 4 feet wide for double trestle. The slab should have a minimum thickness or depth of 1 foot. For additional structural strength, the slab should be reinforced with 5/8-inch rebar. Galvanized 1-inch J bolts are inset into the concrete slab. These bolts anchor the galvanized or stainless steel metal brackets used to secure the mudsill to the concrete slab.

The trestle should be constructed of con heart grade redwood, Alaskan yellow cedar, or pressure treated Douglas fir. The trestle consists of three components: the mudsill, the columns, and the trestle sill. If a single free span of the bridge exceeds 32 feet, a double trestle should be used to distribute the additional load.

The trestle sill must be installed square and level to the trestle sill(s) supporting the opposite end of the bridge stringers. The bridge stringers should be attached to the trestle sill via galvanized or stainless steel brackets and through-bolted. If the trestle is joining two spans with stringers of different dimensions, fabricated metal supports may be placed beneath the smaller stringers to bring them level to the top of the larger stringers. The trestle sills should be centered over the mudsill with respect to both length and width.

Abutment Sill Construction

<u>Wooden and Plastic Wood Sills</u>

Wooden and plastic mudsills are usually purchased pre-cut to the prescribed dimensions. Although redwood, cedar, and plastic wood can be cut to the desired lengths, pressure treated wood should be purchased at the prescribed lengths because cutting pressure treated wood compromises the preservative treatment.

Prior to installing the mudsills, the earthen or soil/rock retention abutments are constructed, leveled, compacted, and squared. Batter boards and string lines or ledger boards are installed to identify exactly where the mudsills will be placed. The mudsills should be prescribed equal distance apart and square and level to each other. Carefully pin the mudsills to the abutments by driving 5/8-inch x 3-foot rebar through the pre-drilled holes in the mudsills. Pinning the mudsills prevents them from being inadvertently moved when the bridge stringers are placed and squared.

Once all the mudsills are installed, the beam seat brackets are installed. The brackets secure the bridge stringers to the mudsills. They are commonly made of galvanized or stainless steel. They are attached to the mudsills with lag screws. The bridge stringers are attached to the metal brackets by a bolt that runs through the bracket and stringer.

Concrete Sills

When constructing a concrete sill on top of an earthen or soil/rock filled abutment, the concrete sill is framed and poured on top of the earthen or soil/rock filled abutment to separate the bridge stringers from the surrounding soil. The top of the sill is flat and does not have a soil dam incorporated into the concrete pour. J bolts for the beam seat brackets are installed in the sill using the same methods as those used in concrete abutments. The end-of-bridge stringer will sit flush with the back of the sill and is through-bolted to the metal bridge stringer bracket. The soil dam is attached separately.

When constructing a concrete sill on top of bedrock, the native surface must be cleaned of all loose rock, soil, and vegetation. If side and end batter boards and string lines were established during the layout of the abutment, they can be set to identify the outside edges of the sill as well as the elevation. If the bedrock upon which the sill will sit is nearly level, a gas-powered jack hammer and Roto hammer can be used to finish leveling.

If the surface of the rock is not suitable for leveling, an elevation graph of the surface of the rock is developed using a tape measure and an auto level. That graph is then used to develop a template that matches the bottom of the form boards to the surface of the rock.

To anchor the reinforcement steel into the rock, drill 5/8-inch diameter holes into the rock approximately 6 inches deep with a powered Roto hammer drill. Once the holes are drilled, remove all the rock dust from the hole with a small bottle of compressed air. Once the holes are cleaned, mix a batch of two part epoxy glue (Hilti) and pour several inches into each hole. Then, use a sledge hammer to drive the vertical pieces of 5/8-inch rebar into each hole. J bolts for the beam seat brackets are installed in the sill using the same methods as those used in concrete abutments. The end-of-bridge stringer will sit flush with the back of the sill and is through-bolted to the metal bridge stringer bracket. The soil dam is attached separately.

Bridge Stringers

Placing the Bridge Stringers

Some steel bridge manufacturers will specify the use of an elastomeric pad between the beam seat brackets and the bridge stringers. The pad cushions the load from the superstructure to the beam seat or sill. It also accommodates movement of the bridge associated with load and temperature changes (e.g., expansion and contraction). If required, place the elastomeric pads on the beam seat brackets before placing the bridge stringers.

Prior to placing the bridge stringers, be sure they are properly oriented. Log and milled stringers usually are slightly arched or have a “crown”. The crown side should be up when placed on the sills. Similarly, glulam, steel, and fiberglass bridge stringers may have an engineered camber. The camber also must be up when the stringers are placed. If the stringers have pre-drilled holes for diaphragms or posts, etc., make sure they line up to each other.

Make sure all the stringers are the same length. Even manufactured stringers can be off as much as 1/4-inch. Have the stringers on hand and measure them prior to starting a bridge project. Avoid cutting pressure treated stringers to because it can compromise the wood treatment. When using log stringers, be sure to alternate the small ends of the logs so the strength of the combined stringers is nearly equal on each end of the bridge.

Bridge stringers can be placed on the sills by hand by a trail crew, by rigging techniques such as high leads and skylines, or by a crane, excavator, or helicopter. During this operation, the trail on either side of the bridge should be closed, barricaded, and manned by a trail crew worker to keep the public out of the hazardous zone.

Manually lifting and placing the bridge stingers is limited to small light weight stringers and site conditions where the stringers can be carried across the watercourse. Although this option may be appropriate in the right setting, it requires the trail crew to climb the streambanks and walk across the stream channel. In many locations, these activities are not be appropriate. Carrying bridge stringers also increases the risk of injury to trail crew workers especially when traversing uneven ground with awkward and heavy loads.

Rigging techniques, such as high leads and skylines, allows the stringers to be lifted, moved, and placed without touching the ground, trampling the streambanks, or entering the channel. With the right rigging set and experienced crew, even the largest bridge stringer can be placed with a high degree of control and precision. These techniques reduce resource damage and vastly improve worker safety. A skyline is especially utilitarian because it can also be used to transport workers and materials across the watercourse, help assemble the bridge, and provide workers with a safety line.

When rigging and winching large bridge members such as sills or stringers, nylon strapping is used to protect the trees used as anchors. When a strap is used as a choker, the wide nylon prevents the tree bark from being crushed. If the bark is crushed, it can injure the tree’s vascular system. Before the rigging is set, determine if the tree is suitable. Small trees or trees with poorly developed root systems can be uprooted during a winching operation.

Regardless of the method used to place the bridge stringers, if they cannot be anchored to the abutment sills right away, then 2- x 6-inch boards should be fastened across the top of the stringers to keep them from moving and falling over. Wooden braces against the outside of the stringers may also be required.

Although the trail should have been already closed and barricaded, it is important to place closure signs and install caution tape across the ends of the bridge at the end of each workday. The closure needs to be in effect until the bridge is completed and opened for public use.

Securing and Squaring the Bridge Stringers

Inspect the bridge stringers to ensure that they are resting fully against the sills, and the ends of each stringer are flush with the backs of the sills. Before bolting the stringers to the beam seat brackets, check if they are square to each other by measuring diagonally from the outside end of one stringer across the bridge to the outside end of the other, then repeating this measurement on the opposite side. Squaring the bridge stringers is critical to assembling the rest of the bridge. If they are not square, the decking will not be square and will have to be custom fit to the bridge. In addition, posts and railings will not be the located in the same positions on both sides of the bridge.

Once the bridge stringers are squared to each other, they must be anchored to the beam seats by through bolting to the beam seat brackets. Manufactured glulam, steel, aluminum, and fiberglass stringers will have pre-drilled holes for this purpose. A milled wood stinger will need to have holes drilled using the beam seat bracket holes as guides and drilling through the stringer as it is resting on the brackets. Pressure treated wood stringers will need to be treated with a wood preservative after the holes are drilled or reamed. Apply copper naphthenate with a bottle brush for this purpose.

Installing a Drop Cloth

After the bridge stringers are placed and anchored, a geotextile fabric drop cloth should be installed under the area where the bridge will be assembled. The drop cloth is installed to catch any debris that falls from the bridge as it is being assembled. The cloth prevents fasteners, wood chips, and pressure treated materials from entering the watercourse. It also catches tools and other valuable items that might otherwise be lost in the channel if they are dropped.

Bridge Scaffolding and Skyline

Once the bridge stringers are anchored and the drop cloth is installed, some type of temporary scaffolding must be installed so workers assembling the bridge have a safe platform from which to work. . Standard stair tower scaffolding can be assembled in the channel if the channel morphology and water conditions allow. The Department has developed a bridge scaffolding system that hangs from the bridge stringers. This scaffolding is easy to transport, set-up, and operate. Because it hangs from the bridge, there is no need to enter the stream channel or disturb the streambanks. When used in conjunction with an overhead skyline, this system is safe and highly efficient. The skyline can be used to transport, lower, and secure heavy or awkward bridge components, such as diaphragms or post sills.

Straightening the Bridge Stringers

Bridge stringers need to be plumb (vertical and at a right angle to the abutments). If they are not plumb, they will not have full load capacity. Twisting and warping of the stringers can even result in the stringers not fully resting on the beam seats. Being out of plumb also will make it difficult to install diaphragms or bridging. The posts and handrails will also be affected. The unintended flare will reduce their strength, make them difficult to assemble, and visually obtrusive.

Warping can occur after the bridge stringers have been delivered to the bridge site, usually from being laid on their side on uneven ground. Sometimes it only takes a couple of days in this position to warp the stringers. Even metal and fiberglass bridge stingers can develop a subtle twist if not properly stored or transported. Proper transportation, placement, and storage are critical to keeping bridge stringers straight and plumb.

Diaphragms, bridging, and post sills are cross braces that are installed between the bridge stringers or are bolted to them to unitize, stabilize, and strengthen the stringers. They also act as spacers to ensure that the stringers are the correct distance apart. Post sills also provide structural support for posts and post braces when wooden bridge stringers lack sufficient height to secure posts.

Some manufactured bridge stringer packages have diaphragms that come with sway braces. A sway brace provides additional stability to the bridge by reducing lateral movement. It is attached from the bottom of the diaphragm to the beam seat bracket. The braces are crossed over each other to form a cross brace. There are turn buckles at the end of the sway braces that are attached to the beam seat brackets. The turn buckles are tightened until they are taut. If the sway braces are too loose, they will slap or clang together when you jump up and down on the bridge. Tighten the turn buckles until they are too taut to slap against each other.

Posts

Posts are the structural members of the bridge used to anchor the railing. They provide structural support for the railing both vertically and horizontally. Railing is required on all bridge or boardwalk structures higher than 48 inches from the deck to surrounding ground. Posts are 4- x 6-inch con heart redwood or cedar.

When purchasing wooden glulam, all weather steel, aluminum truss, or fiberglass I beam bridge stringers from a manufacturer, it is important to provide the manufacturer with a simple set of plans that identify the post layout. The manufacturer will then pre-drill the post attachment holes in the stringers. Any time holes are drilled through a bridge stringer, its load capacity is reduced. If the manufacturer knows the locations of the holes, the stringer can be engineered to compensate for the load reduction. If the bridge stringer is to be made of pressure treated wood, it can be drilled prior to being injected with wood preservative.

Note, the engineered all weather steel I beam, aluminum truss, and fiberglass I beam bridge designs in this handbook were developed with drill holes factored into the calculations. However, the layout for the post attachments will need to be submitted to the manufacturer.

If all weather steel I beam stringers are ordered, metal gussets can be welded to the sides of the beam where the posts will be attached. The gussets are pre-dilled for bolting the post.

Fiberglass I beam stringers can be ordered with pre-drilled holes for post attachment. The holes also can be drilled on-site. To fill the void between the I beam and the post, a 4- x 6-inch wooden block is inserted between the post and the I beam (between the flanges). The pre-drilled holes in the I beam are used as templates for drilling through the wooden blocks and the posts.

Post Braces

Post braces are used in conjunction with post sills. A post brace is 4- x 6-inch con heart redwood or cedar. It provides additional lateral support for the post. The post brace spans from the top outside edge of the post sill to the side of the post above the decking at a 45-degree angle.

Decking

Deck boards for bridges should be a minimum of 3 inches thick for pedestrian bridges and 4 inches thick for equestrian bridges.

If using pressure treated lumber, it is best to order the decking lumber in the required lengths so the ends of the boards are pressure treated. If pressure treated lumber is cut, the wood preservative is compromised.

Once the decking material is selected, it is cut to the appropriate length. The decking should extend beyond the outside stringers by a minimum of 6 inches. The overhang is necessary to cover the exposed sides of the stringers for aesthetic purposes. It also ensures that the decking extends beyond the posts and railings and prevents trail users from stepping off the end of the decking when walking next to the railing.

On some all-weather steel I beam, aluminum truss, and fiberglass I beam bridge designs, a 4- x 6-inch nailer will be attached to the top of the stringers. The decking boards should be laid with the crown side up to help prevent the sides of the board from warping upward (cupping) in the future.

A gap is left between two pieces of decking to allow for future swelling and shrinkage. Normally, a 1/4-inch gap is sufficient, but some materials and climates may require 3/8 inches or more. In cool, wet climates where the decking never dries out, no gap between the decking boards is required. In these climates, the gaps will accumulate organic material between the boards, which may increase rot in the decking and stringers. In a very hot and dry desert climate, board shrinkage can be substantial. In these conditions, decking should be installed without a gap, otherwise the gap may become too wide especially by accessible trail standards.

When placing the decking, it is important to periodically measure from the end of the bridge where the decking installation began to where the last piece of decking was placed. This measurement should be made inside the posts along both sides of the decking. If one measurement is longer than the other, the decking boards on the short side need to be spaced further apart until the two measurements are the same. In this manner, the decking is maintained square to the structure and won't have to be tapered at the end of the bridge.

Use a drill with a twist bit to drill pilot holes into the decking and stringer or nailer. Pilot holes will reduce the risk of splitting or splintering the decking boards. If the decking is 6 inches wide or less, two fasteners are used per board, placed approximately 1 1/2 inches from the edges of the boards to keep them from warping. If the boards are wider than 6 inches, three fasteners per board are used: two at approximately 1 1/2 inches from the edge of the board and one in the center. For wooden decking, the pilot holes should be one drill bit size smaller (1/32 in. - 1/16 in.) than the diameter of the fastener. For composite and plastic wood, the bit should be the same diameter as the fasteners because this material is very hard and deck screws would likely shear before passing through. The depth of the pilot hole should leave at least 1 1/2 to 2 inches of un-drilled wood in the joist to firmly grasp the fastener. When using long decking screws (e.g., 5-6 in.) it may be necessary to make the hole deeper because long screws shear easily. When the decking wood is hard and dry, it may also be necessary to lubricate the nails or screws when installing them. Liquid hand cleaner (in a can) works well for this purpose and is easy to use. Only decking screws should be used on composite lumber and plastic wood. All fasteners should be stainless steel or hot dipped galvanized steel for maximum longevity. Hot dipped galvanized nails also have a rougher surface, which enhances their grip and makes them less likely to pull loose.

For 1 1/2- to 2-inch decking, 40d nails or 5-inch decking screws should be used. For 3-inch decking, 60d or 6-inch decking screws should be used. For 4-inch decking, a 70-d or 80-d nails should be used.

If nails are used, they should be driven with a hammer until they are nearly flush with the deck surface. Then, a hand punch and hammer should be used to drive them approximately 1/8-inch below the surface of the deck to prevent hammer marks on the decking and eliminate tripping hazards. Deck screws should also be screwed approximately 1/8-inch below the surface of the deck.

A common practice in decking a horse bridge is to install running planks on top of the decking. Given the traction problems associated with this design, thick decking installed perpendicular to the flow of traffic is preferable.

Soil Dam

Soil dams have two functions: (1) they prevent soil and organics from coming into contact with the stringers and decking; and (2) they support the fill material installed against the end of the bridge when the approaching trail tread is brought level to the bridge's decking. Soil dam materials should be con heart redwood, cedar, pressure treated Douglas fir, or plastic lumber. It is recommended that plastic wood be used when installing a soil dam on a bridge using non-wood stringers since it will have a similar lifespan.

Railings
Railings are required on all bridge structures where the distance from the top of the decking to the stream channel or ground is 48 inches or more. The railing should be 4- x 6-inch redwood or cedar. The finished rail height is measured from the top of the decking to the top of the upper-most horizontal handrail. This height is 42 inches for pedestrian and bike trails. The minimum handrail height for equestrian trails is 54 inches. Accessible trail railing height should accommodate an unrestricted viewing area between 32 and 51 inches from the top of the deck at each distinctive viewing location determined along the railing.

Bull Rails
If required, bull rails are installed once the posts and top railings are assembled. They are installed as previously described in the section on puncheon construction.

Diagonal Rails
The diagonal rail provides an additional safety barrier under the top railing and between the posts. These rails are installed diagonally from the intersection of the top railing and post to the intersection of the decking and the adjacent post. The railing is cut to rest flush against the posts and is fastened to the posts by toe nailing with 40d hot dip galvanized nails.

After all the railings are installed, the posts and railings are sanded to remove splinters and rough areas that might injure trail users.

Chapter 17. Trail Steps

When the maximum linear grade or less between control points cannot be achieved through curvilinear alignment or turns, steps can be an appropriate design solution. Steps may also be required when the parent material is not stable enough to retain its position on the landform without some means of containment, or where obstructions such as large rocks and roots must be constructed over rather than through. If there is a significant elevation difference between the starting and ending points of the trail or between major control points, as well as a limited landbase, steps can be the only possible solution to providing public access in a sustainable way.

Steps can create a barrier to a user with a mobility impairment and cause problems for equestrians and mountain bikers. Steps should be avoided when designing a new trail or reroute. When steps are required, design and construct steps that are user-friendly and not hazardous.

Carriages and Landings
Steps should be constructed in sections of three or more steps. The installation of multiple steps in sequence is defined as a step carriage. A single or double step on a

trail can create a trip hazard since trail users do not typically adapt their gait to one or two steps as well as they do to a series of steps. When the hillslope dictates multiple carriages of steps due to changes in the slope grade, there should be a break or landing between the carriages. Landings should be a minimum of 3 feet in length, provide a noticeable break in the step carriage, and provide a rest area for users. Landings are important when the step tread depth changes between carriages, due to a change in the hillslope grade. Trail users need to adjust their gait or stride to compensate for the tread depth, and the landing helps them reset their stride.

Handrails

Handrails on steps are recommended in many situations including when the steps are narrow or experience high usage; when there is an adjacent steep drop-off; or where accessibility or resource protection are a concern. Handrails aid hikers in ascending and descending steps. Handrails also give trail users a sense of security. Handrails must have a structurally sound design and be constructed with materials that match the local architecture and are aesthetically pleasing.

Step Layout

To improve user safety, increase accessibility, and reduce the number of users traversing around steps, each step must have the same rise and run. The rise should be either 7 or 8 inches and the run (tread area) should between 13 and 18 inches deep to facilitate a smooth and predictable gait. Properly designed and constructed steps can be negotiated without the user having to look at the steps and where their feet are placed. Each tread must be firm and have a uniform surface to provide secure footing. Treads also need to be slightly insloped or outsloped to provide proper drainage.

Step Construction

Wooden Steps

For durability and ease of construction, wooden steps are constructed with rough sawn redwood, cedar; pressure treated lumber, or plastic lumber. The length of the lumber needs to be no less than 6 inches longer than the desired step width and have a minimum end dimension of 4- x 8-inch for a 7-inch rise and 4- x 10-inch for an 8-inch rise. Wooden steps must have an angular face to provide more secure footing for the trail user.

If the steps are being installed straight up the hillslope (through cut), the footing excavation needs to extend into the hillslope 6 inches on both sides of the step. Burying the end of the steps 6 inches into the hillslope prevents the end of the step from being exposed, which can divert sheet flow and erode the uphill side of the trail. Once the step is placed in the trench, it is pinned with 5/8- x 36-inch rebar.

Curved Steps

Sometimes it is not practical or desirable to install a step carriage in a straight line. Features such as rock outcroppings or trees may prohibit installing a step carriage in a linear fashion. For aesthetic purposes, it may also be preferable to have the steps curve up the hillslope in keeping with the outdoor setting.

With a curved step layout, the depth of the tread will need to be tapered so the inside of the step is narrower than the outside. Since the minimum step tread depth is 13 inches, the depth of the inside of the step tread cannot be less than 13 inches. Since the maximum step tread depth is 18 inches, the outside of the step tread cannot be greater than 18 inches.

To achieve a more acute curve to the step carriage, a tapered landing is used between step carriages. The use of a landing is limited to where there is an appropriate change of grade in the hillslope. At the change in grade, install the landing. The minimum landing width is 36 inches. Thus, the inside of the landing is 36 inches and the outside of the landing is determined by the desired acuteness for the curve of the step carriage. The deeper the outside of the landing is the more acute the curve will be.

Rock Steps

Rocks for step material should weigh between 200 and 300 pounds for pedestrian trails and 300 to 500 pounds for equestrian trails. Larger rocks can be used, but require greater effort to move and place. Additional time and increased safety risks exist if rock is not moved properly. Rigging such as skylines can be employed to move rock, which increases the size that can be used safely and efficiently. Smaller rocks lack the mass needed to achieve the desired stability and durability. Ideally, rock for pedestrian steps should be large enough to provide stability but small enough that a single worker can move them by piss anting (rolling or maneuvering rock without lifting) or using a rock bar.

Rock must also have the proper shape and dimensions. Individual rock steps set in the ground must have at least one flat surface to serve as a tread and one 90-degree face from that surface to serve as the front of the step. Rocks used in an overlapping rock step design must have two flat sides - one for contact with the rock below and one to serve as the tread and provide good contact with the rock above. Rock used in steps must also have a thickness consistent with the desired rise of each step.

Rock and Riser Steps

Rock and riser steps are individual rock steps that are not structurally connected. They are a good design for stable slopes with low to moderate user traffic.

Installation begins at the bottom of the carriage. The first step is the keystone that buttresses the entire carriage. This step is well-anchored and has the mass to support the steps above it. Before placing the rock, a footing is excavated so that approximately one-third of the mass of the rock is below grade and tilted into the hillslope by approximately 5%. The rock lies back into the hillslope and produces an inward and downward force, rather than outward and downward. The excavation must match the bottom of the rock so it sits snugly in the ground. If backfill is required to adjust the elevation of the footing or fill voids, use well compacted aggregate to prevent settling.

Once placed into the footing, the rock must have the required rise above the approaching trail tread. The top of the step must be level from front to back or tilted slightly backwards by approximately 5%. If a cross slope is required for drainage, the rock is set to have the appropriate cross slope.

The excavation for the next step is such that once the second step is placed, the top of the rock is the required rise above the first rock step and the front of the rock is the required distance from the front of the first step rock (i.e., provides the required tread depth). The face of the rocks should not overhang the lower steps. The overhang provides leverage for displacing the rock if the front of the overhanging rock is stepped on.

Rock Framed Steps

Rock framed steps are a good design on steep or unstable slopes where additional structural support is necessary. They are also a good design for high-use pedestrian and equestrian trails due to their structural integrity.

In addition to the rocks that serve as risers and treads, wall rocks are installed on both sides of the step to help lock it into the hillslope. The wall rocks are placed in an excavated footing that accommodates the size of the rock, starting at the bottom of the carriage and simultaneous to placement of the step rocks. The bottom wall rocks are placed on both sides of the step rocks and serve as keystones for the wall rock above. Therefore, the mass of the bottom wall rocks must be large enough to perform this function.

Wall rocks are wedged tightly into the trench using rock wedges to fill voids and increase contact (“chinking”). Good contact between the upper and lower wall rocks and the step rock is critical to provide the friction that locks these stones into place. As in dry stone construction, all joints are broken and good contact is made between all rocks.

Overlapping Rock Steps

Overlapping rock steps are a good design for stable slopes with low to moderate pedestrian traffic. Overlapping rock steps are installed in a similar manner to rock riser steps, but instead of being placed independently, the steps are interlocked with the front of the top step over the back of the bottom step. The overlap of the two steps should be a minimum of 25% of the depth of the step tread. Contact between the two rock surfaces must be sufficient to fully support the upper step.

This style of step requires rocks that have adequate thickness for the designed rise and are rectangular and uniformly shaped for good contact. The top of the rock needs a relatively flat and uniform surface, especially toward the back where the next step is to rest on top of it. The bottom of the rock needs to have a flat and uniform surface toward the front of the rock where it overlaps with the rock below it. Although a rock with uniform rectangular shape works well for this purpose, rocks that are thicker at the rear bottom half are more desirable as they add more mass to the back of the step and anchor it better into the hillslope.

Equestrian Steps

For an equestrian trail, it is best to avoid linear grades or other situations where steps will be required. When determined to be necessary, equestrian steps should follow the same layout procedures as for wooden or rock steps, except the step treads must be 48 inches deep. The extra depth allows a horse to have at least half of its body on a step at a time. This spacing also accommodates the gait of the horse and minimizes tripping and stumbling while ascending or descending. Transition landings must be 96 inches deep so the horse can have its entire body on the landing. The step width on equestrian trails should be a minimum of 48 inches with 60 inches being the optimal width.

Additional requirements for construction of equestrian steps include the use of erosion-resistant backfill material and the placement of barriers along the trail edge.

Interlocking and Cribbed Steps

Ordinary wooden steps may be unsuitable at some sites. The ground may be full of large rocks or roots, making excavation impossible, or the site may be too steep to allow installation of steps with 13-inch treads. In these cases, partial or full crib steps are a solution. They are also a good design for pedestrian and equestrian high-use trails due to the structural integrity.

Interlocking Steps

Partial crib steps, called interlocking steps, are built with an additional crib wall or walls that frame the step tread. When the step carriage traverses the hillslope at an oblique angle, the steps require a crib wall on the outside of the trail. In a carriage, the steps are interlocked as the crib wall is notched and pinned to both the bottom step and step above it with a 5/8-inch piece of rebar.

When the step carriage traverses straight up the hillslope, it requires a crib wall on both sides of the steps (double interlocking steps). The inside crib wall is installed in the same manner as the outside crib wall to provide additional structural support to the carriage and help contain the material used for the tread.

Full Cribbed Steps

Some situations call for a more complex structure, such as full cribbed steps. There are four common reasons for full cribbed steps.

- Grade too steep;
- Grade not steep enough;
- Large obstructions; or
- Extremely steep or unstable sidehill.

A full cribbed step is a retaining structure with steps and its construction is similar to a wooden cribbed abutment. The two outside cribbed walls are unitized (connected) by steps and anchor posts. The step member spans between the two cribbed walls and serves the function of the step riser as well as a facer. The anchor post also spans between the two cribbed walls (further into the structure, behind the steps). It ties the two cribbed walls together and provides additional rigidity and structural integrity to the carriage. The steps and anchor posts are notched into the cribbed walls.

Both the step/anchor post and the cribbed wall are notched to a depth that when the two members are seated together a 1/2-inch gap remains between the cribbed wall members. Fill material placed inside the cribbed walls consists of 2- to 3-inch washed drain rock.

Cable Steps

Cable steps are a series of steps strung together with galvanized wire rope. They are draped over the surface of highly unstable material such as sand, or seasonally eroded surfaces such as ocean bluffs exposed to storm waves. This step design is only used for pedestrian trails.

Use an 8-inch rise per step when determining the number of steps and the depth of the treads. The 8-inch rise between steps is achieved by increasing the fill material behind the step so the back of the step is 2 inches higher than the front of the tread. Once the layout has been determined, “dead man anchors” are installed a minimum of 18 inches into the ground at each end of the step carriage. These anchors are 6- x 6-inch timbers cut to the same length as the steps.

The cable step material is made from 6- x 6-inch construction heart redwood or cedar, with the edges cut at a 45 degree angle for an even-sided octagon. A table saw with a fence and a ripping blade set at a 45 degree angle is used to create the octagon shaped steps. The octagon shaped step is used to provide increased traction for the user. Round peeler core timbers used for this purpose do not provide adequate traction and can be slippery.

Cutout Stringer Stairways

To provide adequate clearance above high water flows, many bridges are constructed with cribbed abutments. These abutments result in a significant elevation difference between the trail grade and the bridge deck or tread. One method of access from the trail grade to the bridge tread is a stairway. The most common stairway design is the cutout stringer stairway.

The layout for cutting out the step stringers is performed with a steel framing square. The body or large end of the square is placed on the side of the stringer and moved up and down until the 13-inch mark is at the top edge of stringer. The tongue or small end of the square is then moved until the 8-inch mark is on the top edge of the stringer. Once the square is placed in this manner, lines are scribed along the outer edges of the body and tongue of the square until they meet at the heel of the square. The tongue represents the rise of the step (8 inches) and the body represents the tread depth (13 inches).

The width of the steps is the same as the bridge tread. Tread on the stairway carriage is constructed level in all directions to reduce the chance of slipping when the surface is wet. Water drains off all four edges of the tread.

Hardening the Step Approach
All step structures will create increased mechanical wear to the trail tread approaching the bottom step of the carriage. This area often becomes eroded over time, resulting in the vertical rise of the first step being greater than the designed rise, which can create user discomfort and safety issues. A solution to this problem is to harden the trail tread approaching the bottom step so that it is more resistant to mechanical wear. Hardening can be accomplished by framing the trail tread with wood or rock and installing aggregate surfacing, or by installing a rock armoring (stone pitching) in front of the bottom step. Regardless of the hardening technique used, the hardened approach is installed at trail grade.

Chapter 18. Railings

Railings are horizontal or diagonal structural members attached to vertical posts for the purpose of delineating the trail, protecting vegetation, and providing a barrier for users at precipitous locations.

Types of Railings

Wooden Railings (Other Than Bridges)
Railings are constructed by placing two upright 4- x 6-inch posts in the ground a minimum of 24 inches deep and 8 to 10 feet apart. An alternate method of post installation, is using a fabricated steel post bracket. By minimizing ground contact, this post bracket method increases the post's longevity and allows for easy post replacement. The posts are then spanned by one or two rails. The top of the completed railing should be 42 inches above the trail tread for bicycle and pedestrian trails and 54 inches for equestrian trails.

The standard posts for railings are 4- x 6-inch con heart redwood or cedar. The top rail is fixed to the upright posts with 40d galvanized nails. If required, the diagonal rail is cut flush at the appropriate angle for firm fit against the upright posts. With multiple rails, splices are made at the center of the top of the post to ensure a secure, durable attachment.

Post Sill Design
Sometimes the ground conditions prohibit digging 24-inch deep post holes. An alternative design is to use post sills with diagonal braces. A footing is excavated into the trail bed, perpendicular to the path of travel. The footing is a minimum of 20 inches deep and 12 inches wide. The bottom of the footing must be in undisturbed mineral soil and level in all directions. A 6- x 8-inch sill is laid into the footing and pinned with two pieces of 5/8- x 30-inch rebar.

The length of the sill depends on the designed trail width. The sill must extend beyond the outside edge of the trail sufficiently to install a post brace at a 45-degree angle. The 4- x 6-inch post is attached to the sill by toe nailing it into the sill with 40d galvanized nails. A post brace is then installed to support the post. The 4- x 6-inch brace is installed at a 45-degree angle and must be long enough to span from the end of the sill to half way up the post. The post brace is toe nailed into the sill and post with 30d galvanized nails.

A 3- x 12- x 20-inch soil dam is installed in the footing, up against the post. It is notched around the post sill and is the same width as the 12-inch footing. This soil dam is required to contain the backfill material placed on top of the sill. It is nailed to the post and toe nailed into the sill with 30d galvanized nails. Once the soil dam is installed, the footing is backfilled with crushed aggregate in compacted 3-inch lifts until the designed trail surface is achieved.

Masonry

Masonry railings are used for aesthetic or historic design purposes. When this material is selected, the same principles for placement and design are followed. The minimum height of a masonry wall railing is 42 inches and the minimum thickness is 12 inches.

Railing Design Specifications

Equestrian Trails

On multi-use trails and areas such as overlooks and trails where sufficient room is available for the passage of two horses, the height of the rail is 54 inches and a diagonal mid-rail of equal size is used for additional structural support and user safety.

Accessible Trails

If a railing is located along an accessible trail, a railing height of 32 to 51 inches should be considered for use at vista points to allow users in wheelchairs to see above or below the railing. The height is measured from the top of the trail surface to the top of the railing. When a railing is planned for an area that is considered hazardous, incorporate a mid- or diagonal rail so a person in a mobility assistive device cannot accidentally travel under, over, or through the railing. On accessible trails, bull rails are installed on puncheon, bridge, and boardwalk structures.

Chapter 19. Trail Camps

With the exception of frontcounty administrative spike camps, trail camps are camps that are typically only accessible by foot, horse, boat, or bicycle. Trail camps include visitor camps, trailside shelters, equestrian camps, and administrative spike camps designed to accommodate overnight use on a trail. The planning and development of trail camps require all of the environmental review and permitting processes required of a trail project.

Public Trail Camps

Site Selection

When selecting a location for a trail camp, the following criteria should be considered:

- Establish a relationship between the site, the trail system, and other overnight camping facilities. A trail camp should be placed along an extended trail at a maximum of one-day hiking distance from the trailhead or other camping facility.
- A trail camp should be located within 800 feet of the main hiking trail, but positioned to provide as much privacy and seclusion as possible.
- A trail camp should be located within 500 feet from a water source, to accommodate water access, but no closer than 150 feet to open bodies of water to preserve water quality.
- Topography and exposure of the site to the elements are important considerations, particularly the slope, surface drainage characteristics, water table depth, solar orientation, prevailing wind direction, and severity of typical rain storms. Sites for trail camps are relatively flat (ideally less than 5% slope) and have good drainage or water escapement. Tent pads should have slopes less than 3% and may require minor grading to comply.
- Soil should be evaluated for characteristics such as drainage, erosion, percolation (for human waste disposal), and resistance to compaction.
- Vegetation should be evaluated for resistance to trampling, overstory protection (shade), screening capabilities, and erosion control effectiveness.
- Water sources should be evaluated for potential use as drinking water and for recreational opportunities.
- Potential hazards from tree failures, landslides, flooding, animal encounters, insects, and noxious plants should be evaluated to assess visitor safety concerns.
- Isolation of the site should be considered. A trail camp should be free from vehicle or logging noise and visual contact with highways and other developed areas. A sense of isolation is important in a trail camp.
- Evaluate the availability of on-site building materials such as stone, downed logs, and gravel. The ability to haul or pack in building materials to the site should also be considered.
- Evaluate accessibility for park personnel to patrol and maintain the site. Although remote locations are desirable, basic housekeeping, maintenance, visitor safety, and resource protection activities must be performed on a routine basis. Contingency plans should be developed for emergency evacuation of ill or injured visitors.
- A facility for disposal of human waste must be considered, especially since trail camps are designed for overnight use. Soil conditions must be analyzed, if a leaching system is used for a pit toilet or a composting toilet. Frequency of camp use should also be considered in the waste disposal method. Other factors to be considered include privacy, odor control, and groundwater contamination.
- If trash receptacles are not provided, users must pack out their trash. This requirement needs to be in all the literature pertaining to the camp and signs must be posted at the trailhead and at the camp.

- When feasible, trail camps should be located to maximize views and sounds of desired landscape features such as lakes, streams, mountains, rock outcrops, meadows, and canyons.
- Consider the potential carrying capacity of the camp. How much use can the site receive before resource degradation occurs, the maintenance and operational cost becomes excessive, or the visitor experience is diminished?

Site Design

A trail camp's design, amenities, and administration will be dictated by the type and quantity of use. A large group requires a large facility and more amenities than a small group. Horseback riders will require facilities and amenities specific to the care and feeding of their animals. Boat-in campers will require mooring or dock facilities as well as access from the shore to the campsite. The type of use needs to be identified prior to site selection, design, and administration.

The type of amenities provided may include a fire ring or grill that is protected from prevailing winds; a food box or hanging pole to keep food away from animals; and picnic tables, toilets, and/or shelters. Design should not exceed the minimum necessary to meet user needs so as to maintain the minimalistic experience users expect from a trail camp.

Accessibility

All new public trail camps need to address access for persons with disabilities pursuant to the Department's Accessibility Guidelines and the Architectural Barriers Act Accessibility Guidelines for Outdoor Developed Areas. These guidelines require that accessibility of trail camps be addressed regardless of whether or not the trail leading to them is accessible.

Signage

Campsites and amenities should be clearly marked to direct users and avoid the development of volunteer trails that result when users wander around a trail camp.

Latrines

A human waste facility should be located within a short distance of the trail camp. If a toilet is located too far from the campsite, it discourages use and promotes unsanitary conditions within the immediate vicinity. Toilets should be located downwind from campsites and positioned to provide privacy.

There are numerous designs for backcountry toilets; the most commonly used are the pit toilet and the self-composting toilet. Before selecting an outdoor toilet design, contact the local health department to determine if there are any requirements that will affect the design selection and to confirm that your design options are consistent with local ordinances. Also consider frequency of use.

Pit Toilets

The most familiar toilet facility in backcountry is the pit toilet. A pit toilet is an unsealed hole in the earth, 3 to 6 feet deep, with a small privy placed on top. Several important criteria must be adhered to when installing this type of facility.

- A pit toilet should not be installed on a floodplain and should be at least 200 feet from waterways.
- A pit toilet should be located at least 50 feet from campsites or shelters.
- A pit toilet should be no deeper than 6 feet below the original grade. The bottom of the pit is at least 2 feet above the highest seasonal groundwater level, impervious layer, or bedrock.
- A pit toilet should be air-tight, except for the vent stack and waste entry hole.
- The area around the privy and pit should be banked to direct surface water away from the hole. The drip line of the privy roof should extend outside the mound surrounding the hole.
- The waste entry hole should have a self-closing lid and a ringed or semi-ringed toilet seat.
- A vent stack of at least 12 inches in diameter should be installed. This vent should extend into the seat box and reach a minimum of 2 feet above the highest point on the roof. The vent stack should have a rain cap to prevent precipitation from entering.
- The privy should have adequate ventilation and a self-closing door. It should also be screened and sealed against flies, rodents, and other vermin.

Self-Composting Toilets

A self-composting toilet is another human waste facility that has a backcountry application. Although it is larger and more expensive than a pit toilet, it has several advantages, such as less groundwater contamination, less odor, and a longer period of use before it needs to be removed or dug out. The disadvantages are that they operate only in temperate environments (average of 65 degrees Fahrenheit) and are so sensitive to temperature, humidity, and air movement that they often fail to work properly.

Two common designs are the "continuous composting toilet" and the "batch or bin composting toilet." The batch or bin composting toilet requires regular attention and maintenance. Waste must be transferred from the toilet to the bin, periodically mixed, and organic compost material added on a regular basis.

Public Trailside Shelters

Structure and Site Design

Regardless of what kind of design is selected, the shelter should not place undue pressure on or damage to natural or cultural resources and should match the anticipated volume and type of use.

Trailside shelters have a minimum of three vertical walls and a roof, and are positioned so that the open side faces away from prevailing storms and wind. This orientation enhances the structure's ability to provide a warm, dry shelter.

The surrounding vegetation and topography will influence design selection, along with available stone, wood, gravel, or soil that can be used in construction. The architectural design employed throughout the park or district may also be a factor in the design of a trailside structure.

Whenever possible, a foundation of native stone should be used to prevent earth to wood contact. If native stone is not available, imported stone or concrete may be an alternative. The building materials for a trailside shelter should be consistent with the local area. For example, redwood should be used on the north coast, cedar in the Sierra, and stone in the desert. Pressure-treated materials should not be used in parts of the structure that can be contacted by the public.

Minimum amenities for a trailside shelter typically include a warming/cooking campfire pit or ring; pegs to hang packs or clothes; a table or elevated platform for eating and cooking; sleeping platforms or bunks; shelving; and a food storage facility that is secure from rodents, birds, and other wildlife who are often attracted to campsites. If the shelter is in bear country, a bear-proof storage locker or bear pole should be provided.

Equestrian Camps

Site Selection

An equestrian trail camp shares many of the site location and facility-planning criteria used for trail camps and trailside shelters. The difference between planning for an equestrian camp and other types of trail camps is accounting for the impact of stock, mainly horses and mules, on natural resources. Horses and mules are large animals that, if not staged and confined properly, can severely impact fragile soil, plants, and waterways.

To select a site for an equestrian camp, soil in the area must be carefully evaluated. The scuffing, scraping, and treading of hooves quickly erode thin loamy soil and can turn wet clay and silt into a quagmire. Firm, well-drained soil with protective ground cover is the most suitable for equestrian camps. The side slope in a stock holding area should not exceed 5% to minimize the mobilization of loose, unconsolidated soil during a rain event.

Vegetation within the equestrian camp must also be evaluated. Trail stock can trample or overgraze fragile plants if left unattended, and can also introduce competitive exotic plants through their feces. Cultural landscaping, including historic orchard trees, should also be protected. Areas with predominantly native plants (especially grasses) should not be used for equestrian camps. Vegetation that is resistant to trampling or grazing is preferable.

Bodies of water such as streams and lakes are also susceptible to damage by stock. Stock that is watering or grazing near water can trample riparian vegetation and erode the bank. Stock also contaminates potable water sources by urinating and defecating directly in the water or its immediate watershed. Stock feces also accelerate the eutrophication of lakes by adding nitrogen-rich organics to the water.

Hitching Rails

Hitching rails should be provided to restrain stock and reduce conflicts between them. When not being used, stock is tied to the rails to prevent them from wandering out of the designated holding area. Sufficient hitching rails should be provided to accommodate the maximum number of stock allocated for the camp. The rails should be located at least 150 feet from campsites and 300 feet from the nearest waterway. Short, well-spaced hitching rails (10 to 12 feet long) are preferred to long, tightly-spaced rails.

Corrals

A corral to contain stock not in use can also be provided at an equestrian camp. A corral confines stock to a designated holding area, reducing impacts to the surrounding soil, vegetation, and waterways. A corral should be large enough to accommodate the maximum number of stock allowed in the camp and be located at least 200 feet from the nearest campsite and 400 feet from the nearest waterway.

A corral site must provide ample shade or shelter. Limbs from overhanging trees must have a minimum clearance of 10 feet, and all brush must be removed from within the corral. If a natural shelter is not available, a small lean-to should be constructed.

A corral can be constructed with a variety of materials, such as wire, metal, or wood. The material selected should be compatible with the surrounding environment. For example, split rail or log fencing blends into a backcountry setting and provides a more rustic appearance. Wire and metal fencing is longer lasting and requires less maintenance, but is more obtrusive on the landscape.

The safety of livestock and their handlers is important. Sharp corners should be avoided and nail or bolt heads should be set flush with the rails. Rails are cut flush with the post and have no protruding ends, or are designed so that overlapping ends are on the outside of the corral.

Water Troughs

Since stock requires water in large quantities and because stock must be kept away from natural bodies of water, watering troughs should be provided in the holding areas. Water should be piped in from a nearby spring or by installing a sand point pitcher pump.

Feed

Stock feed should be limited to grain carried in by the user, unless grazing or pasturing areas are identified and approved through the appropriate permitting process. Many government agencies require the use of certified weed-free feed to reduce the introduction and spread of exotic plants. When grazing is allowed, stock must be hobbled and tended. Picketing or tying animals to a tree is discouraged since it usually results in vegetation being denuded as well as scarring and breakage of the tree.

Administrative Spike Camps
When determining whether to use a spike camp, consider the cost of the crew's time spent commuting as well as the additional project time needed to accommodate the commute.

Establishing a spike camp may not only reduce the total project cost but it can shorten the project length by eliminating the extra commute time and improving crew productivity. A long project timeline may result in conflicts with wildlife restrictions, crew availability, visitor use, weather, etc. When a trail crew's workday is truncated by an excessive commute, it is more difficult to train and organize the crew. Many trail construction activities require time to set up and break down each day. In addition, when a crew has more time each day to work on a given task, skill development improves significantly and the crew experiences a greater sense of accomplishment.

<u>Site Selection</u>
Administrative spike camps should be established and operated in a manner that has minimal impact on the park's resources and facilitates, efficiently implements the trail project, and provides a healthy and enjoyable environment for the trail crew.

A site is selected according to many factors, among them proximity to the trail and worksite. With a clear understanding of the environmental problems and the effects of human use on the backcountry, as well as anticipated future use, spike camps are chosen based on the following criteria:

As terrain permits, a 150-foot minimum distance between bodies of water and camp is required. A camp should be located at least 150 feet from the trail if possible and never less than 100 feet. Human waste and gray water must be buried not less than 200 feet from a body of water, campsites, and the trail.

New spike campsites are selected in conjunction with the trail supervisor and must be part of the project's environmental review and permitting process. Avoid constructing a new site unless there are problems with existing sites, such as the environmental impacts caused by a large crew, or no site is located close to the project.

The following factors are considered when locating a spike camp:
- Proximity to project worksite
- Proximity to developed facilities and re-supply locations
- Stock/helicopter access
- Stock pasture/feed
- Access to water for stock and camp use
- Proximity to and visibility from the trail
- Local environment including the presence of bears or sensitive species

- Ability to have a campfire and firewood availability
- Fire danger
- Sun/shade
- Dry site for cook tent or fly
- Human waste control and disposal
- Proper food storage for bear and corvid control
- Evacuation options

Site Design
The size of the crew and the length of time it will occupy the site will determine the size of the camp. Set-up a camp that is sufficient to meet the cooking and living needs of the crew. An elaborate camp takes more time to set-up and break down, and has greater potential for impacting the environment. Spike camps are intended to be a spartan temporary home for trail crews. A simple camp is the best choice.

Within the project's environmental review and permits, camp set-up depends on the location and the preferences of the crew. Sleeping tents are normally the lightweight backpack variety, fast to set up and take down. They are pitched outside of the camp's common area (e.g., cooking, dining, campfire, dish washing, and relaxation areas). Kitchen and dining areas should be covered with a large, heavy-duty rain fly stretched across a long skinny pole or tight rope. Cooking is usually done over a campfire with Dutch ovens or over white gas or propone camp stoves. Wall tents are often set up to provide shelter for the kitchen and the crew's community tent (a warm dry location to relax, read, and play cards or board games during time off). The community wall tent can also be used as a dining area. When cold weather is anticipated, the community wall tent can be outfitted with a light weight wood stove to warm crew members in the mornings and evenings. A clothes line can also be set up inside the tent to dry wet clothes and gear during inclement weather. Lighting can be provided by white gas or propane lanterns.

Water
If municipal or well water is unavailable then potable water may need to be made by filtering water from a nearby stream or lake. In-line or large volume base camp bag filters can be used to purify water by eliminating harmful bacteria and cysts. Any water system that extracts water from a stream or lake must be identified in the project's environmental documents and permits.

Where permissible, a campfire can be used to sterilize water for washing via a jungle can (i.e., a 35 gallon can on a metal stand over the fire). Boiled water is used for washing hands and faces, filling solar showers, and washing dishes.

Kitchen
Discard used dishwater and other grey water into shallow sumps on the edge of camp, always more than 200 feet from water. Dig a pit 12 to 18 inches deep and filled partially with large crushed rock, so the water will not be standing in the bottom of the pit for long periods. Place a wire screen over the pit to collect any silverware or food scraps that

may be inadvertently thrown out with the dishwater. Use a similar sump for laundry water.

<u>Showers</u>
Providing a shower facility at a spike camp is important for proper sanitation and good crew morale. Showering helps reduce reactions to noxious plants, such as poison oak, poison ivy, or cow's parsnip. After a hard day of sweating and toiling in dust or mud, a hot shower greatly improves a crew member's morale. It also makes being around fellow crew members a lot more pleasant.

Shower facilities should be located a minimum of 200 feet from the nearest water, campsite, or trail. Locate showers on porous soil or over a shallow sump similar to the grey water sump. A wooden pallet with open slats can be laid out to stand on while showering to keep feet clean. A rope or some other device can be used to hang a solar shower over the wooden pallet. A privacy tarp is hung around the shower. Solar shower bags are set out in the sun each day to heat the bath water. If solar heating is insufficient, hot water from jungle cans can be used.

<u>Latrine</u>
If plumbed, vault, chemical, or pits toilets are unavailable or impractical, then a latrine (i.e., a large pit dug in the ground) may be required to dispose of human waste. Dig the latrine 200 feet or more from campsites, water sources, and trails. The pit should be at least 3 feet deep and large enough to accommodate the number of crew members for the length of their stay, so that the waste is buried at least 12 inches under the surface when the camp is closed. A tarp should be hung to screen off the latrine and provide privacy. A toilet seat is installed for the comfort of the crew. Two parallel logs or a forked tree branch can be substituted for a toilet seat. Spread chlorinated lime and ashes from the fire in the latrine daily to control odors and insect activity.

Spike Camp Operations

It is important to remember that a spike camp is a community where people set up temporary residence. These camps may be occupied for several months at a time and support five to 15 or more people. As in all communities, there needs to be simple guidelines that maintain order and efficiency and eliminate conflicts. The larger the trail crew and the longer the operation the more important these guidelines are. Trail crew leaders (if an in-house crew) or project leaders and crew supervisors (if an outside agency crew) should provide to and review with the entire crew the established guidelines on a routine basis.

<u>Bears</u>
Take precautions to protect food, gear, tack, and stock feed from bears. Bears are persistent and bear-proof storage facilities and negative reinforcement methods will not prevent some bears from entering the spike camp and attempting to break into any facility containing food or the smell of food. The best practice is to camp in an area without bears whenever possible. Deterrent methods to consider are:

- Bear pole/cable (permanent or temporary)
- Bear boxes
- Electric fencing
- 24-hour camp watch and intimidation
- Bear-proof pack boxes or canisters

Garbage

Garbage should be a major concern of the trail crew. Whether it is trailside litter, burned trash from campfire pits, or garbage from spike camps, it is essential to pack out all trash. Never bury anything in the backcountry, except for cleaned campfire ashes and human waste. Buried garbage will not stay buried for long, because animals will dig it up and spread it around. Clean the backcountry whenever and wherever it is needed to give the public a positive impression of park management and protect resources.

Meals

Perhaps the most important element of operating a spike camp is ensuring the crew is provided with plenty of good, healthy food. To ensure that the crew is provided with a well-balanced diet and no one goes hungry, a menu must be prepared for each day and the corresponding food must be purchased and transported to the camp. The menu should take into account how long certain foods will last in the backcountry.

Prior to any person being assigned or contracted to perform the duties of a backcountry cook, they must be tested for Hepatitis A, a viral liver infection. Hepatitis A is highly contagious.

Good backcountry cooks need to be skilled in planning nutritious meals and determining the quantity of food needed for the crew, and able to prepare a delicious and healthy meal with the barest of kitchen appliances and supplies. They must be able to cook with camp stoves, propane burners, propane ovens, Dutch ovens, open flames or coals, and/or radiant/reflective heat ovens.

Sanitation Protocols

Spike camps must be maintained in a clean and sanitary condition for the health and safety of the occupants. Extra precaution must be taken to control the growth of bacteria and the spread of disease. These precautions must be taken seriously by every crew member due to the isolation of the living situation and the close proximity of the crew.

The camp is to be left neat and clean on a daily basis. Before going out on the trail each day, dishes are washed, garbage burned, food secured, and the camp area policed and left in an orderly manner. These activities are for the safety and sanitation of the camp, to present a positive image to the public, and to discourage marauding animals.

Each crew member must keep their personal space clean and sleeping bag aired out to prevent mice and other vermin from nesting in it. Wash clothes as needed. It is the crew leader's (if an in-house crew) or crew supervisor's (if an outside agency crew) responsibility to monitor the crew and set a good example.

Kitchen

Hand Washing Station
Wash basins with hot water, soap, and clean towels must be located near the kitchen and dining areas so that crew members can wash upon entering camp and prior to handling food. There must be sufficient washing facilities to accommodate the number of people occupying the camp.

Lunch
Prior to making their lunch, crew members must thoroughly wash and dry their hands. Disposable plastic gloves may also be used to eliminate the potential for contamination. Utensils for serving food must be provided and used. Care should be taken to keep the handles of these utensils free of the food items being served or spread. People must take care to not spill food containers. Handing food with bare hands is prohibited. People should be aware of the amount of food available and not take so much that there is not enough left for the rest of the crew.

Breakfast and Dinner
Prior to serving or eating breakfast and dinner, everyone must thoroughly wash their hands. The food is set out on a table and the cook or their designated assistant(s) serve the crew to help keep food distribution orderly and avoid over-consumption of food before all crew members are served. Note, a good cook will ensure there is plenty of good food for everyone and no one will go hungry.

Dish Washing Station
The dishwashing process involves four stations after the food is wiped off. At the first station, the dishes are washed in warm soapy water. The amount of soap used should be small because all soap on the dishes must be rinsed off and the less soap used, the easier it is to rinse. Soap left behind on the dishes can sicken the crew. After the dishes are washed they are rinsed in a container of clean water at the second station. At the third station, the dishes sanitized in a container of water with a small amount of bleach. Dishes should be left in this water for at least 10 seconds. At the fourth station the dishes are rinsed in clean water to eliminate the chlorine residue. The dishes are then dried and put away.

Common Areas
Areas of the camp that are shared by everyone, such as the dining area, campfire, and community tent (for reading and relaxing), must be free of personal gear, such as packs, safety gear, or clothing. When the crew gathers in the morning or after work, a location adjacent to these areas must be designated for storing packs and other personal gear to keep the common areas free of tripping hazards and less congested.

Latrine
To ensure the privacy of the crew, a flag or some other signal is hung by the latrine to let people know when it is occupied. Once someone is finished with the latrine, it is their responsibility to take the occupied flag down. They should also ensure there is sufficient toilet paper and restock it as necessary. Each day a member of the crew must be assigned to clean the toilet area and (depending on the latrine type) dump ash from the fire into the latrine to help eliminate odors.

Showers
It is the responsibility of the crew leader (if an in-house crew) or crew supervisor (if an outside agency crew) to ensure that crew members regularly shower and maintain good personal grooming. To maintain the crew members' privacy, a flag or some other signal is hung by the shower to let people know it is occupied. Once someone finishes showering, it is their responsibility to take the occupied flag down and leave the shower ready for use by the next person, which includes refilling the solar shower as necessary and returning it to the appropriate location.

De-Mobilizing Camp
Break camp by dismantling structures such as tents, benches, and tables. Do not burn or destroy poles or other materials that are in good shape and can be re-used in the future. Stash them near camp for the next crew.

Leaving behind a meticulously clean camp is the responsibility of all workers and cannot be overlooked in the rush to break camp. Always leave a campsite cleaner than you found it. Minimize the size and number of holes or pits in and around camp, and always refill them with native soil when breaking camp. Police the campsite for non-native material such as bits of plastic or foil. If using an established campsite, the entire camp, including the campfire ring, should be left clean as an example to the public of minimum impact camping.

The campfire ring must be picked through to remove all foreign material. Allow the fire to thoroughly cool before picking through it. Ash from the fire should be buried in the latrine or grey water pits. Only thoroughly burned material should be buried. There should be no organic material that will attract curious animals.

If a temporary spike camp was established, rehabilitate the site to natural conditions, obliterating signs of tent pads, fire rings, temporary structures, latrines, sumps, foot trails, and areas where stock have been tied or picketed. Aerate the soil, transplant appropriate native plants, and scatter duff over exposed soil.

Crew Behavior

Quiet Hours
Trail crew workers are normally exhausted at the end of every workday. A good night's sleep is critical to their performance and morale. If a crew is to begin work at 7:00 am, they are usually up by 5:30 or 6:00 am to allow enough time to dress, pack personal

gear, wash up, make lunch, eat breakfast, wash dishes, use the latrine, stretch, and gather tools before hiking to the project worksite. To get in 8 hours of sleep, they need to turn in by 9:30 or 10:00 pm. To facilitate good sleeping conditions, the camp needs to be quite by 9:30 or 10:00 pm. Loud noises such as yelling and music should not be permitted after these hours so crew members can sleep without being disturbed. The crew leader (if an in-house crew) or crew supervisor (if an outside agency crew) is responsible for establishing and enforcing quiet hours.

Smoking

Smoking in the backcountry may be prohibited due to wildfire or other resource management concerns. Before allowing crew members to smoke on the grade (i.e., worksite) or in camp, check with appropriate staff to determine if smoking is allowed or appropriate.

If allowed, rules for smoking must be established and followed. These rules may include that smoking on the grade may only occur during breaks or lunch. Smoking in camp is allowed only in a designated smoking area. The designated smoking area must be in a location free of material that could be accidentally ignited. The smoking area must be downwind from the non-smoking crew members. Cigarette smokers must not litter used butts and matches. If smoking is allowed, the butt should be packed out by the smoker with other crew garbage. It is a good idea to bring a small container with a tightly fitting lid to store cigarette butts until they can be properly disposed of in the frontcountry.

Alcohol

Youth corps such as the CCC typically prohibits their crews from consuming alcohol while on a spike. Do not indulge in drinking alcohol when camped with or next to a youth corps. Drinking in front of these young people sets a bad example. It is not a matter of whether drinking alcohol is bad, it is a matter of respecting the youth corps policy and not setting yourself apart from the crew that is working for you.

Agency crews drinking at a spike camp can also be problematic. Trail work is difficult and exhausting. At the end of a hard day's work, many crew members would like to relax with a beer or a mixed drink. The problem comes when the consumption of alcohol begins to affect the behavior of the crew or their work performance. Once alcohol is permitted in a camp it is difficult to regulate. For this reason, some agencies prohibit crews from drinking alcohol in camp. If drinking is permitted, the trail crew leader or supervisor must ensure that the privilege is not abused and take corrective action immediately when an abuse occurs.

Chapter 20. Materials

Native vs. Non-Native Materials

"Native" materials, sometime referred to as "on-site materials", are those materials that occur naturally within the environment or landform through which the trail passes. Native materials enhance the appearance of a trail structure and reduce the visual impact of the trail by blending it into the surroundings. When native materials are used, they should be of a sustainable quality.

Materials for trail construction that are imported to the worksite and not gathered or produced locally are considered “non-native.” Use of non-native materials is appropriate when native materials are unavailable, harvesting of native materials is detrimental to the resources, or non-native materials are more cost effective or provide a safer, more durable product. Imported rock, gravel, and soil must be durable and an appropriate color that blends with the area the trail traverses. All material must be free of invasive and exotic weeds, pathogens, and organisms.

<u>Cost Benefit Analysis</u>
Prior to determining whether to use native materials, perform a cost benefit analysis between the use of native and non-native materials. Utilizing native resources may reduce material and labor costs, particularly in remote locations where materials have to be transported over a long distance. Consider costs related to the purchase, harvest, and transportation of materials and restoration of the harvest site. In addition, evaluate the potential resource impacts of using native materials. Finally evaluate the durability, longevity, aesthetic, and architectural characteristics of the material.

<u>Environmental Analysis and Permits</u>
The use of any on-site materials must be disclosed in the project’s environmental documents, reviewed by natural and cultural resource specialists, and approved during the environmental review process. The use of native materials may require mitigation measures and control agency permits. All approvals and permits must be secured before native materials are harvested. Prior to the start of the trail project, all CEQA documents, mitigation measures, and permit conditions must be reviewed with the trail crew, including the location of all approved and permitted native materials and the marking or flagging of those sites.

Soil

<u>Native</u>
Soil should be harvested from sources in the following order:
1. From performing maintenance and construction on trail facilities:
    a. Excavated soil from trail or trail structure construction;
    b. Slough and berm material produced from restoring back slopes and/or outsloping the trail bed; and
    c. Cleaning of silt deposits from drainage structures.
2. Silt from point bars in streams or rivers where vegetation is not disturbed.
3. Soil borrow pits.

It should be noted that native soil types can vary widely depending on location. When using native soil, care should be taken to match the appropriate soil type with the purpose for which it is being used. If necessary, it may be better to use non-native materials for longevity and sustainability.

Non-Native
When importing soil to a project, select soils that have the appropriate color and texture. A thorough review and evaluation must be performed to determine the appropriate soil to be imported. The soil should be sterile and free from pathogens, as well as invasive and exotic plant seeds. If the soil is being used to augment aggregate surfacing, it should have sufficient quantities of clay to bond the aggregate together.

Aggregate

Native
Aggregate or gravel in any amount should be harvested from sources in the following order:

1. Trail or trail structure construction;
2. Trail reconstruction and trio maintenance activities;
3. Scree slopes (rock smaller than fist size);
4. Beach area of lakes and oceans;
5. Point bars on streams or rivers; and
6. Excavation borrow sites.

Non-Native
Imported aggregate should have a texture and color similar to the soil in the area through which the trail traverses. It should not produce a sharp contrast to the surrounding environment. 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 free of contaminants. Imported rock must be evaluated for invasive, noxious seeds and pathogens. 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 rock should also be checked for its serpentine content, which could expose trail workers and users to asbestos dust. Additionally, aggregate must have the following qualities:

- Fractured faces are necessary to minimize the space between individual rocks so they fit tightly together. Rocks with these characteristics are produced from open pit or rock quarry sites. The rock is excavated from the earth and ran through a crusher to produce the fractured faces. Rock formations such as shale and chert (a hard, dark, opaque rock composed of silica) provide excellent fractured faces. Rounded aggregate produced from river or stream deposits should be avoided. Even when run through a crusher, this material will have smooth rounded faces that are prone to slippage and will leave gaps between rocks. This material does not lock together and does not produce firm, stable, and durable trail tread.
- Proper gradation is necessary so there is a good matrix of rock sizes. Different sizes ensure there are minimal voids or spaces between rocks. The absence of voids bonds the aggregate tightly together, increasing its strength and durability. The matrix must also include a good percentage of rock dust, silt, and clay. Having a mixture of clay in the aggregate is very important because clay bonds to the fractured aggregate and essentially glues it together. Clay retains the moisture that

is necessary to keep the aggregate from drying out, losing its structure, and becoming friable.

For pedestrian, mountain bike, equestrian, and multi-use trails, the rock should be 1.5 inch minus. For accessible trails, it should be 0.75 inch minus. Rock should be from an open pit or quarry, 100% crushed, and free of vegetable matter and other deleterious substances. It should be readily compactable when watered and rolled to form a firm and stable surface. The crushed rock should be inspected prior to delivery to the worksite to ensure the quality of the material.

Rock

<u>Native</u>
Rock can be used to construct retaining walls, bridge abutments, steps, causeways, drain lenses, armored watercourse crossings, step stone crossings, water bars, culverts, and energy dissipaters. It should be harvested from sources in the following order:

1. Clearing and excavation of the trail;
2. Trail reconstruction and trio maintenance;
3. Talus slope rock (fist size or larger), including beaches and ocean shores;
4. Forest floor;
5. Streams or rivers; Forest floor; and
6. Quarry sites.

<u>Non-Native</u>
Imported rock must have the appropriate color, texture, shape, size, structural strength, and durability to construct the intended trail structure. Selecting and importing the appropriate rock is critical. The time and effort to locate and select the proper rock is well spent if the resulting rock structure is sound and blends with the environment. Rock fill that is encapsulated within the structure and not visible from the trail does not require a type and color that complements the native environment.

Vegetation for Restoration

<u>Transplanting</u>
Rehabilitation of disturbed areas should include transplanting and seeding of native plant species found in the same watershed. Such vegetation is placed where it would grow naturally. Transplanted vegetation is selected and harvested from areas abundant with the desired species. When completed, the harvested area must be restored to a natural-looking appearance. Do not repeatedly use the same access point when gathering vegetation to limit disturbance to the habitat or altering its appearance. Transplants should blend naturally with the surrounding habitat. Consider the soil type, drainage, and amount of direct sunlight when transplanting.

Types of Vegetation for Transplanting

Hardy Plants
Hardy plants for transplanting vary by geographic areas. Consult a qualified resource specialist before developing a vegetation transplanting proposal. Transplanting is most successful when performed during winter months and more successful in forested areas.

Natural Humus
Humus taken from downed logs provides a diverse vegetation mix when placed on the ground or on other logs. Natural humus and organic duff layers exist in many environments. Harvest and use of natural organic duff is preferable for introducing native seeds, as it protects from the loss of soil moisture and erosion of disturbed soil due to precipitation.

Young Conifers
Use young coniferous trees only if the entire root ball can be obtained and the transplanting takes place during the winter months. Trees should be no larger than four feet tall (five gallon size) for optimum transplant success. Transplanting a nursery log (a downed log in a state of decomposition with small shrubs and trees sprouting from it) is an excellent way to reintroduce conifers to an area.

Seeds
Use seeds of native species that are harvested in the project area or have been purchased and approved as a native seed source for the area.

Logs
When using native logs, consider the durability and life span of the species of wood selected. Do not over-harvest at sites with decades of harvesting or with a limited amount of suitable logs. As with any work in the forest, signs of disturbance must be restored to a natural state.

Stringers and Retaining Structures
Logs should be harvested from sources in the following order:
1. Trees cut or logged during clearing;
2. Downed trees:
   a. Trees out of sight from the trail corridor where removal would cause no damage to natural or cultural resources;
   b. Trees within sight of the trail, but removing them would cause no damage to the natural or cultural resources and would leave minimal scars that can be easily restored to a natural state; and
3. Standing trees when appropriate for timber stand management or hazardous tree removal.

Split Products
Certain species of trees, including coastal redwood, giant sequoia, and cedar, provide outstanding split wood products. Harvest logs for split products in a manner that leaves minimal scars that can be easily restored to a natural state. Split wood should be harvested from sources in the following order:

1. Trees cut or logged during clearing; and
2. Downed trees off the trail and out of sight of the trail.

Beach Driftwood Logs
The following criteria are applied when using beached logs:

1. Logs must be removed and transported to the worksite in a manner that will not damage sensitive beach or dune vegetation or leave visible scars.
2. Logs should be displayed to provide an ocean-washed look with little or no exposed, freshly cut ends.
3. Structures should be engineered and built to sustain tidal or wave action.

Riverbank Downed Logs
Due to the importance of these structures in stream and river systems, they should not be removed for trail projects unless they are at imminent risk of being poached or pose a threat to park resources, property, or facilities.

Glue Laminated Wood Beams

A variety of species of wood is used to create the individual wood lams in a laminated beam. One of the strongest species is Douglas fir. Because of its superior strength, it is often used in fabricating glulams for use in trail bridges

One of the most important factors in designing glulams is camber. Camber is the curvature of the laminated beam. The top center of the beam is higher than the ends of the beam, which compensates for the deflection in the beam caused by dead load (weight of the superstructure), live load (weight of the user) and snow load (weight of the snow where applicable). Camber for glulam beams is specified as either inches of camber or as a radius of curvature used in the manufacturing process.

In environments with high humidity or significant rainfall, mildew, fungi, and decay are a common problem in laminated wood beams. To protect laminated wood beams and prolong their lifespan, the beams in these environments should be treated with a wood preservative or be constructed of rot resistant wood such as Alaskan yellow cedar, Western red cedar, or Port Orford cedar.

If the laminated beams are to be pressure treated with a wood preservative, it is important that beams be ordered to the exact dimensions required and all holes drilled before the wood is pressure treated. Cutting and drilling into beams after treatment will leave exposed wood that will be subject to decay and rot. Topical wood preservatives applied to these exposed surfaces are not as effective as pressure treatment.

Milled Lumber

<u>Natural Wood Products</u>
Determine the origin of all lumber so as to not support the destruction of old growth forests. Use lumber companies that practice sustainable harvesting.

<u>Treated Wood Products</u>
If lumber that is naturally resistant to rot and decay is not available or is cost prohibitive, the use of pressure treated Douglas fir may be appropriate. Its use is dependent on its application and the agency's policy. This lumber is suitable for retaining structures, abutments, soil dams, bridge stringers, bridging, and post sills. Treated lumber should not be used in areas where the public may come into contact with the wood or where it is in contact with a spring or stream (e.g., a wooden culvert).

<u>Lumber for Posts, Handrails, and Benches</u>
Lumber used for surfaces that come into contact with the public, such as posts, handrails, and benches, should be con heart redwood, cedar, or other non-treated wood that is naturally resistant to rot and decay.

<u>Decking Lumber</u>
Decking material should be con heart redwood, cedar, or pressure treated Douglas fir select structural grade. In addition, decking material should be quarter-sawn (vertical grain).

<u>Bridge Stringers</u>
All milled wood stringers and joists for bridges, puncheons, and boardwalks should be Douglas fir select structural grade. It can be either pressure treated or non-pressure treated lumber, although pressure treated lumber is preferable due to its relative longevity. If another species of wood is used for stringers or joists, the structure must be approved by a structural engineer to meet dead load, live load, seismic, and wind shear specifications.

Composite and Plastic Lumber

<u>Composite Lumber</u>
This material is not yet suitable for certain structural applications that require tensile strength (the capacity of a material to withstand longitudinal force), such as longitudinal free spanning structural members like stringers or joists for bridges, puncheons, or boardwalks, cribbed abutments, or interlocking retaining walls and handrails. When used as decking, it has less free span capability than wooden products of the same dimensions, and, therefore, requires less spacing between stringers and joists.

Evaluate the appropriateness of using composite materials as follows:

- Aesthetics (how the material will blend in with the landform or park setting).
- Meeting specific structural design requirements.
- Sustainability and maintenance requirements.

Plastic Lumber
Non-structural plastic lumber has less structural strength than traditional wooden, metal, or fiberglass materials and has limited use in trail structures. It lacks the tensile strength for free span applications but is very effective when fully supported by the ground and the load is bearing straight down (e.g., mudsills and steps) or used in a vertical position (non-safety railing applications such as sign posts). It can be used for decking, but like composite lumber, it requires additional joists to shorten the free span length. The structural lumber is reinforced with fiberglass or fiber reinforced polymer rods to give it additional strength.

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. Climatic conditions should be a factor when considering the use of plastic lumber. When storing plastic lumber, it should be stacked flat, banded tightly, and stored out of the sun. When used in cool, wet climates, plastic lumber decking can leave a very slippery surface. Some manufacturers offer a textured surface to improve traction.

Concrete

Portland Cement
The type of Portland cement that should be used depends on the application. Type I Portland cement is used in most trail construction. Type II Portland cement is used for extremely large abutment pours where concrete temperature control and curing time must be moderated. Type III Portland cement is used when concrete is being poured in extremely cold weather or the forms need to be pulled (removed) as soon as possible because it requires less curing time.

Aggregate in Concrete
Two classifications of aggregates are utilized in concrete: fine and coarse. Fine aggregate consists of sand graded in size from 1/4-inch maximum diameter to near dust size. Coarse aggregate consists of crushed stone or gravel that is well-graded for size and conformance with specific project plans and specifications. When selecting coarse aggregate, the largest permissible size is used. The larger the aggregate, the less water and cement required to produce quality concrete. The maximum size for coarse aggregate depends on the size and shape of the pour and the distribution of reinforcing steel. The size of coarse aggregate should not exceed 1/5 of the minimum thickness of the pour and 3/4 of the clear spacing between reinforcement bars.

Water in Concrete
Water in concrete converts dry cement and aggregate into a plastic, workable mass, and then chemically reacts to harden the mass into a solid, strong unit. The amount of water used determines the strength of concrete. Too much water thins or dilutes the cement paste and reduces its strength. Water used in concrete must be free of decayed vegetable matter and other organic material.

Proportions

Abutments and sills require a minimum five-sack mix (five sacks of cement for every cubic yard of concrete). Concrete slabs used for accessible trails require a minimum six-sack mix. The quantities of cement, and fine and course aggregate depend on the richness of the mix (the higher the ratio of cement the richer the mix).

The proportion of cement and fine and coarse aggregate for a five-sack mix are:

1 part cement
3 parts fine aggregate
4 parts coarse aggregate

The proportions of a six-sack mix are:

1 part cement
2.5 parts fine aggregate
3.5 parts coarse aggregate

The quantity of water used depends on the desired consistency and strength. Usually concrete is mixed with the minimum quantity of water to permit proper handling and placement. The stiffness or consistency of concrete is measured by a "slump test." The desired slump for concrete used in abutments and slabs is a maximum of 3 inches and a minimum of 1 inch.

Placing Concrete

When pouring concrete into forms, always start in a corner and use a square point shovel to spread or move the concrete out from the corner. If a hoe or rake is used, it may segregate the aggregate in the concrete and thus weaken it. Concrete is placed in a maximum lift (depth) of 18 inches. Achieve proper consolidation and avoid honeycombing (voids in the concrete) by spading and/or vibrating (using a stinger) the concrete thoroughly. Don't over-vibrate, because it can lead to segregation of aggregates. When using chutes, let the concrete drop freely but no more than 3 to 4 feet. Long, free drops can cause segregation of the aggregates.

When placing concrete on a slope, start at the bottom to provide support for the mix all the way up the slope. Avoid ricocheting concrete against the form boards and reinforcing bars, which can also causes segregation of aggregates and honeycombing.

Finishing

On concrete trails, contraction joints to control cracking are placed perpendicular to the trail. These joints should be 1/4-inch wide, cut 25% of the way through the concrete's depth (typically 3/4 to 1 inch deep) and should be spaced no more than 24 times the thickness of the slab (e.g. a 4-inch slab should have joints spaced no more than 8 feet apart). Finish trail surfaces by pulling a damp stiff bristled broom over the floated surface to produce a non-skid finish. Concrete trails should not be finished with a steel trowel as it will create a slick walking surface.

Curing
Allow concrete to cure slowly. Cover the surface with water, add a layer of plastic sheeting, or cover the surface with burlap and wet frequently. Temperatures must be kept moderate and water loss must be controlled. Rapid drying can result in cracking and a loss of strength. Concrete should be allowed to cure a minimum of seven days before use. If possible, allow concrete to cure a full month before use. In 28 days, concrete will reach nearly its full strength.

Air Entrainment Additives
Concrete trail structures at high elevation or in a cold climate can be damaged by water expansion inside the concrete. To mitigate this situation, air entrainment additives are mixed into the concrete. These additives create many small air bubbles that are dispersed throughout the concrete. These air bubbles increase the freeze-thaw durability of concrete.

Asphalt Concrete
When selecting asphalt concrete, the size or scope of the job should be taken into account. Any new construction or large asphalt repair patches (one cubic yard or greater) require the use of asphalt concrete hot mix. Small repairs, such as potholes, root damage, or edge fractures, require asphalt concrete cold mix. When purchasing asphalt, the following criteria are used:

- Asphalt concrete must be produced in a central mixing plant and conform to Section 39-3 of the California Department of Transportation's Standard Specifications.
- Aggregates must conform to specifications of half-inch maximum, medium grading, Type B, as specified in Section 39-2.02 of the Standard Specifications.
- Asphalt binder must be AR-2000 to AR-8000 steam-refined asphalt, conforming to Section 92 of the Standard Specifications.
- The amount of binder to be mixed with the aggregate should be between 4% and 7% by weight of the dry aggregate.

Soil Sterilants
In some locations vegetation, especially equisetum (horsetail), can grow through asphalt creating eruptions or deformities in the trail's surface. These deformities can accelerate the deterioration of the asphalt and take the trail out of compliance with accessibility standards. To resolve this issue, the soil and aggregate base under the asphalt can be treated with a soil sterilant prior to installing the asphalt. A geotextile fabric treated with a soil sterilant can also be placed beneath the asphalt to prevent vegetation from growing through the asphalt. Where these treatments are prohibited, an alternative trail hardening method such as concrete or aggregate surfacing may be appropriate.

Paving
Paving begins at the furthest point on the trail to eliminate the need to haul materials over freshly placed asphalt. Apply asphalt deep enough to produce the planned thickness after compaction (generally 1/4 inch of compaction per inch of asphalt).

Spread the asphalt so that no separating of coarse and fine aggregate occurs. Lumps of hardened asphalt should be raked out and discarded. When conforming to existing surfaces, the asphalt is feathered to achieve the correct transition between surfaces. When the asphalt is put down in two or more applications, the joints receive a tack coat and are lapped and not butted together. The finished surface must provide adequate drainage and sheeting of water.

Compacting Asphalt
Initial rolling is completed before the asphalt's temperature is below 200 degrees Fahrenheit. Rolling is performed so that cracking, shoving, or displacement does not occur. A minimum of three complete rollings are performed after the initial rolling. The final rolling is completed before the asphalt temperature is less than 150 degrees Fahrenheit. The completed surface must be thoroughly compacted, smooth, and free from ruts, humps, depressions, or irregularities.

Metal

All Weather Steel
All weather steel is suitable for use in most locations. However, there are certain environments that can lead to durability problems. All weather steel will not perform in extreme environments and should not be used. Exposure to high concentrations of chloride ions, originating from seawater spray, marine fog, or coastal airborne salt, is detrimental. The hygroscopic nature of salt adversely affects the patina by maintaining moisture on the metal’s surface. In general, all weather steel should not be used for bridges within 2 kilometers (1.32 miles) of coastal waters.

Alternating wet and dry cycles are required for the patina to form on all weather steel. In an environment that is continuously wet or damp, such as submersion in water, buried in soil, or covered by vegetation, a corrosion rate similar to that of ordinary structural steel must be expected. If all weather steel is used in such cases, it should be painted and the paint should extend above the level of the water, soil, or vegetation. Damp conditions may also be experienced under a bridge if it is low over the water. For this reason, it is recommended that bridge stringers have a minimum freeboard of 8 feet over water.

Galvanized Steel
Galvanized steel is used when the structure will be exposed to corrosive natural elements, such as salt air in coastal areas; however, it also can be submerged in fresh and salt water, buried in soil, and embedded in concrete.

When selecting a galvanized steel product, it is important to use only steel that has been batch hot-dip galvanized. Batch hot-dip galvanizing produces a zinc coating by completely immersing the steel product in a bath (kettle) of molten zinc.

When bolting hot-dip galvanized I beams together, bolting the I beams to the beam seat brackets, or attaching diaphragms and sway braces, it is good practice to use hot dip galvanized bolts, nuts, and washers. Using fasteners made of dissimilar metals, such as carbon steel, all-weather steel, or some types of stainless steel, can cause corrosion. When using stainless steel fasteners with galvanized metal, use austenitic stainless steel (300 series).

Aluminum Alloys

Aluminum alloy is a chemical composition where other elements are added to pure aluminum to enhance its properties - primarily to increase its strength. There are two principle alloy classifications: wrought and cast. Wrought alloy's primary appeal is its exceptional strength-to-weight ratio. Aluminum is 66% lighter than steel. It is also far less susceptible to brittle fractures. Whereas steel becomes brittle at low temperatures, aluminum increases in tensile strength at low temperatures. Aluminum naturally produces a protective oxide that coats the exterior and regenerates when scratched. This oxide layer is highly corrosion-resistant, which minimizes maintenance costs and makes it a good option in marine environments.

The wrought alloy commonly used in trail bridge construction is 6061-T6. This alloy is versatile, can be strengthened with a heat treatment, is highly formable and weldable, and has moderately high strength coupled with excellent corrosion resistance.

Fasteners used with aluminum structures should be ASTM F593 Type 316 stainless steel to prevent galvanic corrosion.

Although aluminum alloys have a good weight-to-strength ratio, compared to steel their tensile strength is such that the use of I beam bridge stringers is limited. Long bridge spans require additional structural support in the form of a truss assembly.

Hardware

Bolts, lag screws, nuts, washers, and nails in non-coastal environments should be hot-dipped galvanized to prevent rust and corrosion and increase longevity. Often, electroplated and mechanically zinc-plated fasteners are sold as "galvanized," leading to the assumption that they are hot-dip galvanized. It is important to use products that have been hot-dip galvanized because they have a life expectancy of 35-55 years, while electroplated and mechanically plated nails have a life expectancy of 10-15 years. Hot-dip galvanized bolts have a life expectancy of 50+ years while electroplated and mechanically plated bolts have a life expectancy of 15+ years. In coastal environments, stainless steel hardware should be used because it is the most resistant to salt air corrosion. Rods should be cold-rolled steel. Plate or sheet steel should be hot-dipped galvanized or all-weather steel. Repairs to galvanized steel components should be coated with a zinc-rich paint.

Nails should be hot-dipped galvanized to reduce corrosion and increase longevity. Wood screws or deck screws used on trail structures should be hot-dipped galvanized or stainless steel to prevent corrosion and increase longevity.

Wire Rope

Wire rope used in non-rigging applications is pre-stretched, galvanized, and engineered for proper tensile strength. When used in barrier applications, wire rope should have a plastic coating to eliminate loose strands of wire puncturing the user's hands. Only rope of good quality and suitable size should be used. All metal components should be rust resistant.

Paints, Sealants, and Preservatives

When appropriate, paints, sealants, and preservatives are applied to wood, as well as metal components of trail structures. Sealants and preservatives must not contain pentachlorophenol, creosote, or other restricted substances. Recommended sealant for exposed wooden structural members is boiled linseed oil, cut 50% with paint thinner and a Japan dryer additive. A recommended preservative for non-exposed wooden components is copper naphthenate. A wood preservative is not advised unless warranted by insect or fungi infestations. Preservatives can be avoided through the use of con heart redwood or cedar, prevention of earth to wood contact, and/or by providing a proper air gap.

A number of non-toxic wood preservatives have become available. Some of the more promising products are internal wood stabilizers. These are clear liquids that when applied to bare wood have a chemical reaction with the free alkalis that exist naturally in wood. When the liquid and alkali meet, a waterproof gel forms within the pores of the wood. Over time, that gel hardens to silicate glass crystals, which harden and densify, preventing the wood from absorbing water, reducing the chance of rot and increasing the longevity of the wood. The glass crystals remain permanently imbedded deep within the wood. Note, this product does not contain UV inhibitors, so the wood will eventually turn silver in color if exposed to sunlight. It can also push excess tannin out of the wood as the crystals form, turning the wood very dark or even black if it is redwood.

Metal primers and paints must not contain lead or other restricted substances. A recommended primer for ferrous metals is a red oxide, synthetic, alkyd-based industrial primer. A recommended finish is synthetic alkyd-based enamel. The use of metal primer and paint should be avoided on trail structures if possible as they require cyclical re-application. On large structures such as bridges, re-application may require sand blasting. Control agencies typically require that all sand and material removed by sand blasting be captured, which can be very expensive.

Fiber Reinforced Plastic

On trails, fiber-reinforced plastic (FRP) is generally only used in the construction of bridges including I beam stringers and associated channels (diaphragms). It is also used in the fabrication of pony truss bridges. FRP (also called fiber-reinforced polymer) is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, aramid, or basalt. The polymer is usually an epoxy, vinylester, or polyester thermosetting plastic.

These lightweight and corrosion-resistant I beams are ideal for bridges in coastal environments. They also are a good solution for bridges located in difficult to access areas because they are light weight and therefore easier to transport out the trail than other materials. FRP I beams have a limited span length (30 feet maximum) due to the lower tensile strength of this material. They are not fire- or ultra-violet light- resistant. They can be ordered in a variety of colors but dark grey, charcoal, or black are the least obtrusive. Placing them in shaded locations and increasing the decking overhang can mitigate ultra violet light concerns.

The pony truss FRP bridges are manufactured and sold as a complete bridge package. They are also a good design for bridges located in a coastal environment. These bridges are manufactured in lengths up to 100 feet. They are lightweight, easy to transport out the trail, and do not require a lot of skill to assemble. Some of these pre-manufactured bridges are only rated with 80 pounds per square foot live load, so their load rating must be verified prior to purchase. Seismic, wind shear, and snow load rating requirements must also be provided to the manufacture.

Culvert Materials

Culverts are constructed of corrugated steel, aluminum, acrylonitrile butadiene styrene (ABS), concrete pipe, rock, or wood. Each material has its own advantages depending on the application.

<u>Corrugated Metal Pipe (CMP) Culverts</u>
CMP is constructed of corrugated galvanized steel or aluminum alloy. The corrugations (ribbing) are annular or helical. For trail applications, the wall thickness of corrugated metal pipe should be a minimum of 16 gauge. Metal culverts are strong, durable, and comparatively inexpensive. When used properly, they can last between 25 and 40 years. The bottom and sides are subject to abrasion when used on watercourses that transport aggregate, which can lead to a shorter life expectancy. The ribs project above the culvert wall and are struck by the aggregate as it is carried through, especially in an aluminum culvert, which is a softer and more easily abraded metal. Steel culverts are more fire resistant and less apt to burn or melt in a wildfire than aluminum culverts, but are heavier and more difficult to transport. Due to salt corrosion in coastal environments, galvanized steel culverts have a shorter life span than aluminum. Both galvanized steel and aluminum culverts come in round and oval shapes. Oval-shaped pipes are desirable when a large diameter is required but difficult to install in locations where the required dip at the crossing and minimum fill required over the culvert can't otherwise be achieved. An oval culvert has a greater capacity and less pipe height than a round culvert, making it ideal in these situations.

<u>Acrylonitrile-Butadiene-Styrene (ABS) Culverts</u>
ABS culverts, often referred to as plastic culverts, are lighter in weight and more flexible than metal culverts, and available in single- and double-walled forms. The life expectancy is unknown, since they have not been in use as long as metal culverts. If properly located and installed, the longevity may be equal to that of metal culverts. The

exterior of single- and double-walled culverts is corrugated and similar to annular corrugated metal culverts. Single-walled ABS culverts are very lightweight and easy to cut, shape, and transport. Due to the corrugated interior, the pipe is also subject to abrasion when used on streams that transport aggregate. Double-walled culverts have an additional wall inside the corrugation, which gives the inside of the pipe a smooth appearance. The advantage of a double-walled culvert is added strength, added ability to efficiently transport water, aggregate, and debris, and resistance to abrasion. Disadvantages include increased weight and decreased flexibility. Lack of corrugation on the inside wall can also result in higher velocity flows, which can make the discharge from the culvert more erosive if an appropriately designed energy dissipater is not provided. These higher velocities may also impede the upstream movement of fish and amphibians through the culvert. ABS culverts are not fire resistant and burn or melt at a very low temperature when compared to metal culverts. ABS culverts are supposed to be UV resistant, but experience has shown that these culverts will degrade quickly when exposed to direct sunlight.

Concrete Culverts

Concrete culverts in trail applications are rare due to the heavy weight, lack of flexibility, and difficulty in transporting. They are appropriate near a trailhead where vehicular support is available. Concrete is very durable and the smooth walls of the pipe's interior give it similar performance to the double-walled ABS culvert. When properly located and installed, these culverts last between 40 to 100 years. Concrete culverts do not burn but will fracture and crumble when exposed to intense heat. This type of culvert is installed in short sections (approximately 4 feet long) due to the heavy weight. The major drawback is the likelihood of failure at the joints between pipe sections. This failure can occur with ground swelling, ground settling/movement, or root intrusions. Failed joints leak water, which erodes the material around the culvert.

Chapter 21. Workforce Management

Management Basics

Regardless of the workforce used, there are a number of important procedures and rules of conduct that should be followed by crew members, crew leaders, project leaders, trail supervisors, and trail program managers.

Leadership/Supervision

No crew, regardless of its experience or skill, should perform trail work without qualified direction or supervision.

Project Orientation

Before the start of each new trail project, the trail crew is given a thorough orientation to the project including the reason or need for the project, the desired outcome, the individual tasks required to complete the project, the order in which the tasks will be performed, and the time anticipated to complete each task and the entire project. If possible, this orientation should occur at the project worksite. Linear projects, such as a trail reroute, will require hiking the crew across the new alignment.

During orientation, solicit questions and comments from the crew to clarify project details and provide an opportunity for the crew to suggest ideas. It is important that the crew have a clear vision of what they will be doing and have an opportunity for input. This kind of information exchange increases the crew's ownership and investment in the project.

Training

With each trail project there is going to be a need for specialized training. Training is essential to improve worker safety, productivity, morale, and the quality of the work performed. It is a good investment not only for the immediate project but for future projects. It is especially critical for in-house crews because they will be working on many projects for a long period of time and are a source of future crew leaders and supervisors.

Leading/Supervision

When leading or supervising, be open to questions and ideas from the crew. Engaging with the crew is an opportunity to impart information and further the crew's knowledge. Crew members deserve an honest and well thought-out answer. No one has all the answers or always knows the best way to perform a task or resolve a problem. Crew members sometimes come up with ingenious methods or solutions to a problem encountered during a project. Listen to the crew member and if their idea won't work, explain why, and, if they have a good idea, use it and give them credit.

Project Review

During the course of a project there should be several reviews conducted by the trail supervisor and program manager. It is important that the project be reviewed frequently enough that trail construction, production and project cost issues are identified and corrected before a significant investment in labor and materials occurs. Correcting problems that have been overlooked for a significant amount of time can be costly in terms of funds, time, and crew morale.

Chain of Command

It is important that during project review all work-related comments from the supervisor go through the chain of command. When a supervisor corrects the crew and redirects the crew's work, it undermines the crew leader's authority and credibility. It also can demoralize the crew and add general confusion to the project. Comments to the crew by the supervisor during project review should be positive or simply conversational in nature. This protocol applies to all types of crews. If working with a non-park crew, these comments are from the project leader to the crew's supervisor.

Similarly, it is important that project-related questions and comments from the crew go through the chain of command. If a crew member has a pointed question or a concern about a project, it needs to go through the crew/project leader or the supervisor of the non-park crew. If a trail supervisor starts addressing questions and concerns directly to crew members, the trail supervisor may inadvertently give out information that conflicts with what the crew/project leader provided or give information not yet provided to the crew/project leader. Contradictory information erodes the credibility of the crew/project leader and potentially sets up a conflict between the trail supervisor and the crew/project leader. Following the chain of command and maintaining close communication between crew/project leaders, trail supervisors, and trail program managers will prevent this problem from developing.

Workforce Selection

There are several different workforces available for trail work; each has its advantages and disadvantages. When considering which workforce to use, keep in mind the following criteria.

- Cost
- Level of supervision/support required
- Safety concerns
- Skill with basic tools and/or power tools
- Knowledge and experience
- Physical capability (fitness and strength)
- Agency policies regarding the use of power tools
- Availability (long vs. short term)
- Work ethic and motivation
- Ability to be trained
- Preferred types of projects
- Length of workday
- Contracting requirements
- Labor force work history

Remember that every crew member deserves respect. Any crew is capable of out-performing (or being out-performed by) another on any given day. Recognize the strengths of each type of workforce and match it to the appropriate project, supervision, and support.

Crew Conduct

<u>Uniforms and Image</u>

All crews, regardless of the source, must have a professional image. Being dirty, smelly, and sweaty at the end of the day is a mark of honor among hard working trail crews. Being dirty and smelly at the beginning of the day is inexcusable.

Trail work thrashes clothing more than most jobs. Pants and shirts will become torn and stained. Replacing uniforms can become costly, so it may not be possible to always have a uniform that meets agency standards. Working in the backcountry on an extended spike also makes it difficult to keep appearances up to standard. However, uniforms can be washed, sewn, or replaced as feasible at camp or when the crew comes off a spike.

Latrines

A common issue on trail projects is sanitation. In many locations, it is not feasible to provide sanitary facilities at the worksite. Crews should take advantage of trailhead facilities before hiking out to the worksite. Portable toilets can be hauled to the trailhead if there is room for the vendor's vehicle to unload and service the toilets and a place to locate the toilets out of vehicle or user traffic. If a toilet is not available within easy walking distance of the worksite, crew members can carry a mobile toilet (a bucket lined with a plastic bag) or a plastic bag (WAB BAG) for defecating, or follow backcountry protocol (e.g., dig a "cat hole").

Crew members should never defecate or urinate within 200 feet of a water source, trail, or campsite. All feces must be buried in a hole that is a minimum of 6 to 8 inches deep and 6 to 8 inches wide into top soil. Feces are buried with soil excavated from the hole and organic material (duff) is spread on the surface. If the site lacks adequate topsoil depth, the "cat hole" method should not be used.

Trash

Litter on a project is inexcusable. The only way for litter, including food waste such as orange peels and apple cores, to arrive on a trail project is via the crew. The crew must remove their trash. Trash is packed out, not stashed or buried. Even if garbage and food are carried out each day, they should not be left unattended in camp or at the worksite for any period of time. They can attract bears, corvids, and other wildlife. If animals gain access to garbage, significant resource management and public safety issues can develop. Crews must keep food and trash within sight or stored in appropriate containers.

Smoking

Smoking on the worksite may be prohibited due to wildfire or other resource management concerns. Before allowing crew members to smoke on the grade (worksite) or in camp, check with appropriate staff to determine if smoking is allowed or appropriate. If allowed, rules for smoking must be established and followed. These rules may include that smoking on the grade may only occur during breaks or lunch. Smoking in camp may be allowed only in a designated smoking area. The designated smoking area must be in a location free of material that could be accidentally ignited and downwind from the non-smoking crew members. Cigarette smokers must not litter used butts and matches. If smoking is allowed, butts should be packed out by the smoker with other crew garbage. It is a good idea to bring a small container with a tightly fitting lid to store cigarette butts until they can be properly disposed in the frontcountry.

Dealing with the Public

Even when working in an area closed to the public, crews will likely encounter the public and must project a professional image. Being dirty and sweaty after working is acceptable, but loud and vulgar language is not. Crews should be friendly to the public; they are the reason the trails are built. Engage the public politely and answer questions. (Note, for this reason, it is wise to learn about the project area.) Treat the public well and advise them of any dangers or risks. In an area legally closed by a closure order, crew members should advise hikers of the closure and the reason for it, but not challenge or argue with them. If necessary, advise law enforcement. Crew members should be prepared to escort hikers through a dangerous work area, and halt all dangerous activity until the public has left the area.

Natural and Cultural Resources

Natural and cultural resources of a park take precedence over trail facilities. Every decision regarding design, layout, and construction of a trail is based first on what is best for the park's resources. Sensitive, rare, or endangered natural and cultural resources should never be jeopardized by a trail facility.

The mere presence of a trail crew can have disruptive effects on natural and cultural resources. These impacts are detailed in the resource documents related to the project, and every effort must be made to minimize them. A trail crew can be the largest, most focused human occupation that has ever occurred or will ever occur in the worksite. Be certain the crew, regardless of the source, is advised and respectful of any resource concerns. In addition to proper management of trash and sanitation, the crew must stay on the trail alignment unless going off the trail as part of an assignment. Train the crew to recognize and avoid rare or threatened plants. The crew must recognize indications of cultural sites (e.g., dark earth and shell fragments, or cans, bottles, or other historical cultural artifacts),halt excavation when these are encountered, and consult the appropriate park cultural resources staff before proceeding.

Chapter 22. Worksite Safety

Environmental Considerations

There are many potential hazards associated with working in the outdoor environment. Heat, cold, rain, wind, and extreme dryness can cause or contribute to illness and injury. A heavy rain can generate a flash flood; high winds can present a danger from falling trees or limbs; and thunderstorms can create lightning hazards. The crew must have a plan for safe evacuation or retreat until the hazard passes

Wind

Windy conditions in a forested environment can be lethal. Falling trees or branches can cause serious harm to trail users and workers alike. Consider the following precautions if caught in a wind storm.

- No crew should enter a forested area during high winds and the crew leader should evacuate the crew if high winds develop.
- If caught in a forest during a wind storm, crew members should plan a possible escape route away from potential tree failures, and look up and listen for breaking trees and branches during wind gusts.
- The first storm of the winter may produce more windfall hazards under mild wind conditions due to the accumulation of dead material during the relatively calm summer and fall months.

- Gusting winds move in different directions and have a tendency to cause more windfall and breakage of treetops than steady wind.
- If working in one location for a long period of time, identify possibly hazardous limbs or trees and possible impact zones in the work area.
- If taking a break during windy conditions, continue to wear hard hats and stay aware of potential hazards.

Lightning

Lightning can be potentially hazardous to a trail crew, especially on high, open ground. Crew members should be aware of their surroundings and avoid high open areas if the conditions for lightning are present. If caught in a lightning storm, consider the following precautions.

- If caught on an open ridge, seek a mid-slope location so that projections such as trees or rocky outcrops are above you or protrude into the sky higher than you.
- If unable to evacuate from a ridge, quickly move below the top of the ridge and then off the ridge to low ground as soon as possible.
- In a dense forest, avoid groups of tall trees that can attract lightning. Instead, position yourself below a clump of short trees.
- If lightning strikes are close enough to produce a ground current, avoid positioning yourself in a gully, depression, overhang, or cave, and keep hands close to the body and off the ground.
- When lightning strikes are close, stop using hand-held tools and place them away from you.
- If unable to find a safe location when lightning strikes are close, the ideal position is crouch into a ball with only your feet touching the ground.
- Do not lie on the ground surface when lightning strikes are close. Have the least amount of contact with the ground as possible. If in a tent during a spike, do not lie down on the ground.

Rain

Working on trails while it is raining usually requires crew members to wear heavy, bulky, waterproof garments that restrict body movement and agility. Keep in mind that wearing rain gear may reduce visibility and impair hearing. If caught in a rainstorm, consider the following precautions.

- All crew members must ensure that they have properly fitting and functional rain gear when working in an area that may receive rain.
- Always be aware of slippery footing, especially when crossing wood or rocks. Use appropriate foot wear when working in the rain.
- Remember that when wet, tools are more difficult to control.
- Even though it may not be cold, crew leaders and members alike must be able to identify signs of hypothermia and its treatment. Most cases of hypothermia occur when the air temperature is 30 to 55 degrees Fahrenheit. Also, be aware that hypothermia can become a problem in windy conditions when the temperature is warmer than 55 degrees Fahrenheit.
- Rain gear traps body heat and can causes workers to sweat more than normal. Monitor water intake and ensure that the crew stays hydrated.

<u>Noxious Plants and Animals</u>

Noxious plants and animals, such as poison oak, stinging nettle, and ticks, can exist in many work locations. It is important that all crew members are advised as to types of noxious plants and animals that may be encountered on a worksite and how to identify them. Infections caused by noxious plants and animals can be very uncomfortable and can even result in lost work time or even hospitalization.

<u>General Considerations</u>

When working around noxious plants and animals, consider the following precautions.

- Crew leaders should be made aware of any crew members with special sensitivities or who have had previous adverse reactions to noxious plants and animals.
- Always protect exposed skin from contact with noxious plants by wearing gloves, a long-sleeve shirt with cuffs buttoned, long pants with cuffs closed around boots, and a face shield, if necessary.
- Avoid touching your face after handling noxious plants and animals and always be sure to wash skin after working around noxious plants. Skin should be washed in cool or like warm water within 30 minutes of exposure with a mild detergent such as dishwashing soap to remove the oils associated with noxious plants.
- Check your body for ticks frequently when working in an area where they are known to occur. Crew members should also check each other for ticks, especially on the back and head.

<u>Poison Oak</u>

Poison oak (*Anacardiaceae rhus diversiloba*) produces urushiol, an oily substance that causes mild to severe skin irritation. The plant is native to California and frequently found in state park units. Poison oak causes the most common Workers Compensation injury in trail work and is especially prevalent in trail construction. People have different degrees of sensitivity to poison oak that can change from one year to the next. Just because a crew member has never had a reaction to poison oak does not mean they should be careless about contact with the plant or should not take the same precautions as everyone else. To minimize exposure, consider the following precautions when working in and around poison oak.

- Prevent skin irritation from poison oak by learning how to avoid contact with the plant. Crew members should be able to identify the plant by its leaves, stems, and roots. When cut, the stems and roots ooze a black, oily looking sap that contains urushiol equally potent as that in the leaves.
- Those with a known sensitivity to poison oak should avoid working in close contact with the plant. For example, do not run brush cutters through poison oak patches.
- Wear appropriate personal protective equipment (PPE) including gloves, disposable coveralls of impermeable fabric, and a helmet with face shield when operating a brush cutter.
- A barrier cream can be applied to exposed skin before starting work and re-applied every four hours, although you must wash the skin before reapplying. Reapplying cream without washing may spread the oil from any poison oak that has been encountered, increasing the likely hood of a reaction.

- Use rakes and pitchforks to collect and carry cut brush to minimize contact.
- Give the crew members time to wash thoroughly with an appropriate cleanser immediately after working in an area of poison oak. If possible, also allow crew members to wash at periodic intervals during the day. Read and follow the instructions on the cleanser before use. Be aware that cleansers, such as Tecnu, specifically for minimizing the rash from poison oak are solvents (i.e., mineral spirits) that break down the oil and make it easier to be removed from the skin with water and detergent. If the cleanser is not removed, the urushiol, which was thinned and spread when using the cleanser, will affected a greater surface of skin than originally affected by the initial contact with the plant. Even if a crew member is not sensitive to poison oak, maintaining good hygiene will prevent them from contaminating those that are more sensitive.
- Clothing can absorb the urushiol oil from the plant. Therefore, isolate contaminated clothing and gloves, and dispose of the coveralls.
- Be aware of contaminating the inside of vehicles after working around poison oak. Disinfect vehicles periodically or after prolonged projects in poison oak to reduce the chance of contamination.
- All tools used around poison oak are likely contaminated and precautions should be followed in handling them, especially wire ropes and associated rigging pieces.
- Avoid burning poison oak because the smoke can cause severe respiratory as well as skin reactions.

Injury and Illness Prevention Plan
According to the California Occupational Safety and Health Act of 1973, every employer has a legal obligation to provide and maintain a safe and healthful workplace for employees. As of 1991, a written Injury and Illness Prevention Program (IIPP) with mandatory workplace protocols is required for all support facilities (e.g. workshops, warehouses, material storage yards, fuel storage tanks, etc.) and trail projects. The following elements are typically required in an IIPP.

- Management commitment/assignment of responsibilities
- Safety communications system with employees
- System for assuring employee compliance with safe work practices
- Scheduled inspections/evaluation system
- Accident investigation
- Procedures for correcting unsafe/ unhealthy conditions
- Safety and health training and instruction
- Recordkeeping and documentation

Trail projects must have a proactive program to identify, prevent, and respond to safety issues. Simply put, trail work is dangerous. The remote settings and difficulty of getting help to injured parties compound the danger. A manager must include safe working practices into every component of a trail program. Safe working practices should be so much a part of the culture of the program that employees do not have any other option but to work as safely as possible at all tasks. Review the basics, but keep safety meetings and discussions relevant to the realities the crew faces. Give the crew ownership of their safety but guide them to meet their obligations and hold the crew accountable for their actions and safety record.

Task Hazard Analysis
Trail crews should be made familiar with the Task Hazard Analysis process. Agencies other than the Department, such as the US Forest Service, refer to this as the Job Hazard Analysis. Although it is not the only means of addressing safety, this process lends itself well to trail work. A Task Hazard Analysis helps give the trail crew a clear vision of the project they are about to perform and requires the crew to participate in developing a plan to prevent injuries.

At the worksite before each trail project begins, the crew leader should walk the crew through the project to be sure they have a good understanding of why the project is being performed, the tasks required to perform the project, and the order in which those tasks will be performed. Upon completion of the project review, the crew leader facilitates the crew in the development of the Task Hazard Analysis and records the findings. Crew members identify all the tasks required to complete the project, the risks or hazards associated with those tasks, and the prevention methods they are going to implement to avoid or eliminate those hazards. Through this process, each member of the crew assumes responsibility for their own safety and that of others on the crew. A Task Hazard Analysis, with its references to real work situations and specific safety measures, gives the crew a plan to maintain safe working conditions.

Accident Reporting Procedures
Instruct employees to report all accidents and “close calls” to the crew leader. A “close call” is a situation or action that did not result in an injury but could have. Such reports are essential for monitoring where things go wrong, where additional training is needed, or where conditions make a project too dangerous to complete. If several crew members report slipping and falling on a muddy hillside, wait until conditions dry out before continuing with that phase of the project, or provide equipment such as caulked boots to enable the crew to maintain footing. Without reports, the crew leader and trail supervisor may be unaware of impending problems until something serious occurs. Once potential hazards are identified in a report, appropriate preventative measures can be developed and discussed with the trail crew at a project safety meeting.

<u>Crew Injuries</u>
All injuries, no matter how minor, must be reported to the crew leader immediately. Many agencies have a form and a process for reporting injuries. In the Department, minor injuries that don’t result in lost time or require medical attention must be submitted on form DPR 761 "Report of Minor Injury," which is retained for two years from the date of the incident. Minor injuries include tick bites (if the crew member chooses not to seek medical attention), poison oak rashes (if not severe), blisters from tools or boots on feet or hands, and sunburn. Any accidents that result in professional medical treatment must be reported on form SCIF 3067 "Employer's Report of Occupational Injury or Illness" within five days from the date of the incident unless the injury requires hospitalization of more than 24 hours. In that case, the trail supervisor must also notify

the nearest Worker’s Compensation office by telephone. Similarly, for any injury requiring medical treatment, the employee must complete form SCIF 3301 "Employee's Claim for Worker's Compensation Benefits."

Backcountry Emergencies

A backcountry injury is treated as an emergency if the injured person requires professional medical care. When an emergency occurs, the entire crew halts operations until the emergency is addressed. In case of an emergency, a well-drafted and accessible emergency response plan becomes vital. Elements of the emergency response plan should include procedures for emergency communications and emergency medical care (first aid or higher), and an evacuation plan. All backcountry projects must have a plan for dealing with injuries, so that the crew is prepared when one occurs and the injured person can receive treatment to prevent the injury from becoming more serious. When working in a backcountry trail crew, keep in mind the following precautions and procedures.

- Due to the remoteness and isolation, backcountry trail projects require more preparation and supervision than normal trail projects. A crew leader must be assigned to reside at a backcountry project 24 hours a day, seven days a week for the duration of the project. A radio signal capable of reaching an area repeater shall be set up at the spike camp. Individual crew members shall be selected and trained to operate the radio and communicate with park staff. If coverage is available, a cell phone or satellite phone shall also be provided.
- A rotation system shall be developed to provide fresh batteries for communication equipment. Reserve batteries shall be available to ensure continuous communication at all times.
- A backcountry trail crew shall be provided with a portable, hand-held radio to be carried and used by the crew leader to communicate with the backcountry camp and the park.
- A backcountry trail crew shall be provided with a radio-equipped four wheel drive vehicle to be stationed as close to the backcountry camp as possible to provide back-up communication and ensure the expedient transport of an injured or ill crew member.
- Arrangements shall be made with park staff and other agencies as appropriate to monitor potential after-hours radio transmissions from the backcountry camp and ensure that emergencies are responded to as quickly as possible.
- If possible, have a person with Advanced First Aid, First Responder, or Emergency Medical Technician training assigned to the backcountry operation. There shall be a complete first aid/first responder kit available at camp and at the worksite. A litter and blanket shall also be assigned to the backcountry camp to transport injured crew members.
- A good practice is for the crew to use a satellite phone to check in each morning and evening with park headquarters to obtain fire or storm warning information. The satellite phone also allows park headquarters to leave messages that can be checked by the trail periodically throughout the day.

Backcountry Wild Fires

Crews in the backcountry often work the entire day with no outside communication. For this reason, it is important to notify the crew of any dangerous conditions that develop during the workday. A wildfire that starts off-site can entrap a crew working or living in a remote site. Crew members must evaluate the risk of fire based on the local fuel load, weather conditions, and type of work being performed. The trail crew must cease operations when trail work presents a significant risk of wildland fire. Guidelines for identifying hazardous conditions are issued and communicated by the relevant fire suppression authority (federal, state, or local) with jurisdiction over the project area. The trail supervisor should initiate contact with the relevant agency to ensure adequate communication.

Visitor Safety

The top priority while performing trail work is to address visitor safety. Trail work must not endanger visitors. Whether or not an area is open to the public, assume that visitors will find their way to the worksite no matter how remote. Visitors do not have the awareness, experience, or training to deal with worksite hazards.

Trail Closed for Maintenance

If conditions on the trail prevent users from passing through the worksite safely, the trail should be closed to park visitors. These types of conditions include bridge failures or precipitous slopes along landslides. Obvious advantages occur when the crew has the opportunity to completely close a trail that needs work. However, within the Department proper trail closure requires that several tasks be accomplished.

Notification to District Office

If it is determined by the trail supervisor that a trail is too hazardous for public entry and controlled public access is not feasible, inform the local park staff and notify the District Office that an official trail closure order is required. The trail supervisor then prepares a draft closure order for the superintendent’s review and signature.

Public Notification

Every attempt should be made to provide users with advance notification of a closure. A public service announcement via radio and TV stations, newspapers, and park-generated publications is appropriate. Other government agencies, chambers of commerce, local neighborhoods, and user groups should also be contacted. A centrally located bulletin board can assist in providing trail users with up-to-date information on current trail conditions.

Signage and Monitoring

All entry points to a closed trail should be signed appropriately. The Department’s standard metal signs may be adequate, but lighter weight Carsonite-type posts with decal strips or other temporary signage might be easier to install and remove. Consider including the estimated date for re-opening the trail and any alternative routes on the signage. Areas of extreme hazard should be signed and barricaded with caution tape, construction fence, or other physical barrier to keep visitors out. Promptly remove all the closure signs when the work is completed.

During trail closures, crew members should be posted to monitor the worksite warn visitors of the hazards ahead; inform them to wait in a safe area until the hazard has passed; or communicate with the crew to cease hazardous operations until visitors are escorted through the worksite.

Trail Open During Maintenance

When the project presents a low safety risk to the public, it may be simpler to leave the trail open. This type of project should be scheduled during a period of low visitation to minimize potential conflicts with visitors. When working on a low risk project, consider the following precautions and procedures.

Signage

Post a public notice of the construction activity at the same locations as would be done for a closure order. The notice should include the location and nature of the work, as well as trail conditions that may be encountered, such as muddy areas, extreme noise or dust, or heavy wheelbarrow traffic. At a minimum, a “Trail Work Ahead” sign is posted at the trailhead.

Work Habits

Crew members must constantly be alert to the development of hazardous conditions on the trail. Tools inadvertently left along the trail may create a hazard to trail users. Visitors entering the worksite must be announced to the crew members or escorted through the worksite. If visitors are allowed to proceed on their own, they must be advised of the appropriate safety precautions.

Equestrian Use

Equestrian use may require additional precautions for safe passage through a worksite. Crew members should turn off noisy equipment and avoid sudden movements as an equestrian passes through a worksite. The crew should stand on the downhill side of the trail, as visible to the horse as possible while it passes.

High Risk Situations

Some work, such as tree felling, wire rope rigging, or sand blasting, necessitate a high level of security, such as the placement of monitors at all approaches or temporary closure of the trail. Whether the trail is open or closed, high-risk areas must be flagged or barricaded to prevent users from accidentally entering the area. Of particular concern are bridges under construction. In the absence of a physical barricade, a user can walk onto a bridge that is not yet ready for use. In such situations, a barrier must be in place whenever the crew is not present.

Every project should be as safe as possible when the crew leaves, whether they are shutting down for the evening or going home for the weekend. Assume that visitors will come into contact with everything they can access and that any potential hazard left at or near the worksite represents a risk to unaware visitors. Potential hazards include railings or decking that are not yet nailed down and rocks or logs perched near the trail. If these items are not secured, they should be removed from the trail corridor until the crew returns. If a wire rope under tension crosses the trail, it should be released so it is lying on the ground and identified with flagging to make it more visible, or barricaded with caution tape.

User Compliance and Illegal Trail Use

Trail crews are not law enforcement. When encountering trail users that have ignored trail closure signs, they should politely inform the users of the hazards necessitating the closer and ask them to return back down the trail. If the users ignore the request and enter the closed area, the crew member should immediately notify the crew leader. The crew leader should halt all work activities until the users are out of the closed area. The crew leader should then immediately notify park law enforcement of the incident and provide a description of the users. More commonly, the crew encounters non-permitted user groups, such as cyclists or equestrians on hike-only trails. The crew should inform the user that the use is not permitted on the trail. If the crew has the knowledge, it can direct users to other areas where the use is permitted. The crew should not attempt to stop the user if they continue on the trail. The crew should get a good description of the individual and immediately inform law enforcement.

Crew Safety

Prior to undertaking a new project, ensure that the crew receives proper training on the safe use of basic tools.

Tool Safety

Crew leaders should thoroughly cover the safe use and handling of tools with the crew prior to starting work. Basic safety measures include the following.

Personal Protective Equipment

Personal Protective Equipment (PPE), such as hard hat, gloves, eye and hearing protection, and proper footwear, should be worn at all times, especially when using hand or power tools or when in close proximity to trail construction or maintenance activities.

Getting a Grip

Proper tool use begins with a good grip. Wet or muddy gloves may cause a worker to lose his or her grip on the tool, allowing it to slip and strike the worker or someone nearby.

Be Aware

Watch out for people nearby. When chopping or brushing, be aware of any people in the area including co-workers and trail users. Be aware of the combined length of arm and tool when maintaining a safe distance from co-workers. An unaware hiker may walk right into a crew member's backswing. If someone approaches the worksite, stop work, notify co-workers, and wait for the person to pass.

Maintaining Space
Make sure there is a wide, clear area in which to swing a tool. Watch out for hazards overhead or to the side or for anything that could interfere with the complete swing of a tool and cause it to fall or fly from the worker's hands. This spacing is often referred to as "maintaining your dime", a ten foot spacing between workers.

Maintaining Footing
Be alert for hazardous footing, such as loose rocks, branches, or other debris. Have a firm, balanced, and comfortable stance and clear any debris before starting work.

Tool Selection
Choose the right tool for the job. Don't waste energy trying to use the wrong tool for the job. Also, make sure the tool is sharp. A dull tool that bounces off what it was attempting to cut can be very dangerous. A sharp tool will cut faster and be less tiring to the worker. An axe or Pulaski used for chopping wood should be sharpened differently than one used for chopping roots. The shape and angle of the edge is critical.

Tool Transport
Transport tools properly. Always carry tools by hand and down at the side of the body and keep the cutting edge of the tool facing downward toward the ground. This position allows the tool to be thrown away from the crew member in case he/she trips and/or falls. Use blade guards whenever possible. Never carry hand tools over the shoulder; a stumble or fall could be disastrous. For long distances, strap tools to a backpack for safe and easy handling.

Safety Harnesses
Personnel working near a steep drop-off, such as on a bare bridge stringer over a deep canyon, must wear a safety harness at all times. A harness should be maintained in good condition and be properly fitted to the person wearing it. All safety harnesses should inspected prior to use and twice a year as per CalOSHA regulations. The harness should be clipped from the designated anchor to an approved climbing rope with only as much slack as necessary to allow the worker the mobility required to perform the job. The other end of the climbing rope should be fixed to a secure anchor point or to a skyline not being used to hoist loads. Personnel wearing a safety harness should be trained to tie knots and use carabineers.

Chainsaw Safety
The most common and serious type of chainsaw injury involves being cut by the chain. A cut can be caused by unsafe operation of the saw, leading to a kickback. Careless movements or poor footing can cause cuts to the legs or feet. Improperly carrying or handling a saw, regardless of whether it's running, can also cause injury to the hands, face, or neck. Besides the potential to cut, a saw produces poisonous exhaust gas that can impair or injure the sawyer. A running or recently run saw has hot, exposed parts that can burn skin or ignite clothing. Saws also run on a mixture of fuel and oil, which can ignite and explode. Most chainsaw-related injuries can be avoided by the sawyer

by using the proper safety equipment and features and following safe operating procedures.

Personal Protection Equipment

Anyone operating a chainsaw or working near a running saw should wear the following PPE.

Hard Hat

A hard hat will protect the sawyer's head from falling material and provide a degree of protection to the head and face in the event of a kickback. The suspension of the hat should be in good repair and fit the sawyer's head snugly. The helmet shell should be in good repair, free from breaks or cracks, and worn with the brim forward (over the eyes).

Chaps

Ballistic fabric leg coverings protect the front of the legs from cuts in the event of contact with the chain of the saw. Chaps should fit snugly to avoid catching in underbrush, but loose enough to allow free movement of the legs. Chaps should be in good repair, free of large cuts or loose strings. Leg straps should be kept buckled at all times.

Eye Protection

Securely-fitting, clear eye protection must be worn to protect the sawyer's eyes from smoke, dust, and flying wood chips. Wire mesh saw goggles offer good protection, unobstructed vision and do not fog up with condensation. Goggles with lenses should be shatterproof, not excessively scratched, and keep fogging to a minimum. Prescription glasses with shatterproof or polycarbonate lenses are acceptable. Hard hats designed for use while operating a chainsaw that have a protective face shield that flips over the face is also acceptable.

Gloves

Heavy duty, well-fitting work gloves are vital to protect the sawyer's hands. Gloves are especially important when carrying or sharpening the saw or anytime the bare chain is handled. Gloves also provide a measure of protection from cumulative nerve damage by providing an additional cushion between the hands and the vibrations of the engine.

Hearing Protection

Protection sufficient to prevent auditory damage must be worn when excessive noise is expected on the worksite. Whether the protection is ear plugs or muffs, it must fit well and not interfere with the use of safety glasses or helmet.

Boots

Well-fitting boots suitable to the worksite must be worn to prevent slipping and falling or injury from dropped tools or materials. Boot tops should be high and snug to provide ankle support. Soles should provide traction adequate for the given environment. In most forested settings, caulks or caulked sandals provide the best footing. In extremely wet or muddy sites, heavy rubber boots may be used. Steel toes are optional on leather boots but highly recommended on rubber boots.

Standard Safety Features

The following safety features should be installed on a saw to help protect the sawyer. All safety features must be in place and functional or the saw should not be used.

Hand Guard

This device is attached to in the front of the power head to keep the sawyer's left hand from contacting the chain if it slips off the front handlebar. It may be attached to a chain brake.

Chain Brake

When activated, this device stops the chain from turning. It usually works via a steel band that tightens around the clutch drum to stop the chain in a few thousandths of a second. It may be activated either through the centrifugal force of a kickback or by the sawyer’s left hand striking the hand guard. Chain brakes should not be used to prevent the chain from turning while starting the saw or to hold a chain stopped on a saw with a defective clutch or idle adjustment.

Chain Stop

This small plastic or aluminum device is mounted on the bottom of the saw, forward of the clutch. It catches the chain and reduces the length of loose chain that may swing back toward the sawyer in the event that the chain breaks or is knocked loose from the bar.

Rear Chain Protection Plate

This plate extends out the right side from the bottom of the rear handle to the edge of the clutch cover. It primarily protects the sawyer's right hand in the same fashion as the chain stop.

Optional Safety Features

Reduced Radius Tip Bar

This saw bar tip has a radius that is narrower than the height of the rest of the bar, which reduces the likelihood of a kickback by reducing the size of the zone at the tip of the bar that causes most kickbacks. It may be of symmetrical or asymmetrical ("banana nose") design.

Low Profile Chain

This chain has cutter teeth of reduced height, which are less likely to catch on an obstruction as they pass around the top of the bar tip, and, thus, are less likely to cause a kickback. It is often incorporated with a guard link.

Guard Link Chain
This chain features a modified depth gauge (tie strap) that provides a smooth surface that protrudes higher than the top of the cutter tooth as the chain rounds the tip of the bar, reducing the chance of a kickback. Guard links reduce the chain's cutting ability and efficiency. It can be a hindrance to bore-cutting.

Kick Guard Nose Protector
This curved attachment can be fixed to the tip of the bar to protect the chain as it passes around the tip. It limits the size of the material that can be cut to less than full bar length, and, therefore, is of limited utility. However, it can be useful for cutting brush or small limbs.

Safe Operations
Never attempt to operate a power saw or brusher unless you have completed an approved training program. PPE and safety features are no substitute for training and experience when operating a chainsaw. All personnel should receive verbal and written instructions on safe operations, and should operate a saw in a variety of situations under the guidance of a qualified sawyer before being authorized to use a saw independently.

To reduce the potential of fire when refueling gas powered equipment, allow the motor and muffler to cool before adding fuel.

Store fuel at a designated location where containment measures have been taken and have spill protection materials available to reduce the risk of environmental contamination.

General Safety
When operating a chain saw, follow these procedures for safety.

- Always inspect a saw for proper assembly and functioning before use.
- Wear all appropriate PPE and ensure it is in good condition.
- Use safe handling practices at all times including when starting, carrying, or refueling.
- Carefully position hands, feet, and body while operating a saw.

Kickbacks
Kickbacks occur when the chain encounters something it cannot cut. If the tooth is traveling along the top half of the bar when it is caught, it forces the saw back in a straight line toward the sawyer. If the tooth is traveling around the upper half of the bar tip when it is caught, it throws the tip up and back toward the sawyer. In either case, the sawyer must be prepared for the kickback or suffer a possibly serious or fatal injury.

Most importantly in dealing with kickbacks is maintaining the proper stance and grip. A proper grip is with the left hand on the front handlebar with the thumb wrapped underneath and the left elbow locked straight. If the saw kicks back, the sawyer can maintain a grip on the saw and control the kickback. The head and body of the sawyer should be kept to the left of the saw bar, so if an uncontrolled kickback occurs, these vital areas won't be hit. In addition, before making any cut, determine how far the tip of the bar will reach into the tree and ensure that the tip will not contact any objects (e.g., knots or wedges) on the far side of the cut.

Under most circumstances, regardless of its position on the bar, a cutter tooth is most likely to cut the material it contacts. For this reason, keeping the engine running at a high RPM when cutting and keeping the teeth sharp are important to reducing the potential for a kickback.

Rigging and Griphoists

Rigging has a wide variety of applications in trail work, from removing large logs to constructing bridges. Griphoist brand wire rope pullers allow a trail crew to pack in enormous pulling capacity in a lightweight, compact, highly portable unit. A built-in “overload protection” device makes them very safe. There are a few simple points to bear in mind to keep a Griphoist functioning smoothly

<u>Mainlines</u>

Only the four-strand Griphoist brand mainlines available through the manufacturer are constructed to the tolerance needed for smooth operation. Be certain the wire rope is free of kinks, "bird cages," and frays. Keep it clean, or at least clean the wire rope before it passes into machine.

<u>Handles</u>

Use only the handles supplied by griphoist. These handles are designed to lock onto the forward and reverse levers of the hoist. Metal pipe should not be used as a handle as it will not lock onto the levers and may damage the casing.

<u>Clean and Lubricate</u>

A Griphoist is full of small parts that must slide past each other for it to function. Even small quantities of dust, rust, or grit can impair function. Strive to keep the machine out of the dirt and mud as much as possible. Periodically dip the hoist into a cleaning solvent that will not damage nylon or rubber. Soak the hoist overnight and drain it in the upside down position and allow it to dry. After drying, put the rope release lever in the open position and lubricate the hoist with SAE 90 to 120 weight motor oil. Grease or oil containing additives such as molybdenum disulphide or graphite should not be used as they will reduce the gripping efficiency of the jaws. It is impossible to over lubricate a Griphoist.

<u>Shear Pins</u>

Use only the overload shear pins supplied by the manufacturer for the hoist. Substituting with nails, drift pins, or drill bits can result in overloading the hoist’s safe operating capacity.

<u>Safe Working Loads</u>
Before setting up a rigging operation, identify the safe working loads for all the components used in the system including the hoist, wire ropes, nylon straps, clevises, blocks, and wire rope grippers. The safe working load of any component used with the rigging system must not be exceeded by the force applied by the hoist or any mechanical advantages used in the system. The failure point in any rigging system must always be the shear pins in the hoist.

<u>Fly Zones</u>
Wire ropes under tension sometimes move quickly. There are zones in any rigging operation in which it is unsafe to stand or work.

<u>Straightening and Line Shock</u>
Any time tension is applied to both ends of a load, as in a high lead with a brake system, the wire rope and the load will shift as tension is applied until they are extended in a perfectly straight line between the anchors. This shift can occur suddenly as the hoist applies more and more force to the load. If the wire rope is caught on an obstruction, such as limb or root, it can suddenly release from that obstruction causing the wire rope to snap upward, sending a sudden shock to the system. This release can also cause the hoist to suddenly jump upward, possibly injuring the operator.

<u>Rolling Load</u>
Whenever a load is pulled across a hillside or down a hill, the possibility exists that the load may roll or slide down the hill suddenly. Such movement may even be the desired effect. When the load takes off downhill, it will take the wire rope with it. The wire rope will swing downhill with the load, possibly injuring anyone in its path until the load stops on its own, reaches the end of the wire rope, or the wire rope wraps around an obstruction. The hoist may also suddenly jump upward or sideways, possibly injuring the operator. Personnel operating the Griphoist must be aware of these hazards and be sure to stand in a safe area relative to the hoist and the wire rope.

<u>Rigging Operation under Tension</u>
Whenever a rigging operation is under tension (force being applied to the load, lines, and points of attachment), there is a risk of a failure within the system. To prevent injuries to workers, no one should be allowed to enter areas where any component of the system will travel if there is a failure, including under overhead lines (wire rope), under the load, or where a wire rope changes direction at a block and forms a "V" shape. If the block or anchor should fail, the wire rope and possibly the block will suddenly fly down into this V-shaped area. If someone needs to enter these areas while the system is under tension, slack the tension on the lines of the system before entering the zone.

<u>Tree Climbing</u>
Tree climbing is a necessary part of setting a high lead or skyline. There are three basic ways to climb a tree.

Free Climbing
Free climbing is the least commonly used method because few trees that are appropriate for rigging have limbs close to the ground. Also, limbs can interfere with rigging operation when the wire rope is tensioned or slacked. When free climbing, the "Three Point System" is used. The climber has a total of four "points" - two hands and two feet - that can be used to anchor oneself in a tree. The "Three Point System" of free climbing is to ensure that a minimum of three points (hands or feet) have a secure grip at all times.

Ladders
An ordinary extension or step ladder is not recommended for most tree work. Segmented tree climbing ladder systems that can be stacked to a variety of heights are useful for climbing trees up to about 4 feet in diameter. When used properly and set up by trained personnel using safety chains, pass ropes, and safety belts, this climbing system can be extremely quick and safe.

Spur Climbing
For large diameter (greater than 4 feet) trees with thick bark plates, specially trained personnel may use climbing spurs, belts, and pass ropes to climb a tree. This technique is very strenuous and can cause greater resource damage than ladder systems, but it requires less gear and, therefore, is more portable.

Section 4. Trail Maintenance

Chapter 23. Trail Maintenance Principles

The intent of trail maintenance is to keep a trail in a sustainable and safe condition that:
- ensures visitor safety;
- protects natural and cultural resources;
- preserves the public investment in the trail; and
- provides for public use and visitor convenience.

Types of Trail Maintenance
Maintenance activities can be broken into two types: ongoing and deferred.

Ongoing Maintenance
In the California state park system, ongoing maintenance is identified as activities that need to occur on a cycle of less than every five years to maintain the designed function of a trail. For the purposes of budgeting and scheduling, ongoing maintenance tasks are divided into two categories: those that occur on a daily to annual basis and those that occur every two to five years. In addition, ongoing maintenance includes repair work caused by an incident ("incident related") that can be anticipated based on previously recorded inventory information, such as the quantity of downed trees and landslide occurrences, as well as prorated repairs required to replace trail structures that have reached their usable lifespan.

Daily, Annual, Two-Year, and Five-Year Cyclical Maintenance
It is important to note that the maintenance interval for different activities varies between locations. For example, trail brushing may be required once or twice a year in one location but only once every five years in another due to differences in vegetation types and growth rates.

Incident Related Repairs
Incident related repairs (one-time repairs) may be difficult to predict, but the need can be anticipated by considering inventory and maintenance records from previous years. Incident related repairs are addressed when they occur. A good maintenance program is prepared to take on these one-time activities and respond in a timely manner.

Prorated Maintenance
Within the ongoing maintenance program is the replacement of trail structures that have reached their safe and usable lifespan, known as “proration.” Funding for the replacement of trail structures is allocated based on the total quantity of structures, their expected lifespans, and their replacement costs. By dividing the total replacement costs by the life expectancies, an annual replacement cost for those structures is identified.

Deferred Maintenance
“Deferred maintenance” refers to trail reconstruction and rehabilitation projects that are required when a trail system’s maintenance needs exceed the trail program’s capabilities. These projects are generally large and involve the replacement of multiple trail structures or the reconstruction of the trail. These projects may also involve the replacement of trail structures if the original design or function of the structure is altered, such as replacing a multiple milled stringer bridge with an all weather steel bridge. Significant trail reroutes, trail removal and rehabilitation, and road-to-trail conversions may also be necessary. It is vital to track deferred maintenance needs and to have a mechanism to identify and prioritize them when funding becomes available.

Incremental Improvements
Although ongoing maintenance is performed to maintain the design and function of a trail, improvements in the design and construction of trail features and structures (“incremental improvements”) should be performed whenever possible. Changing the design of a trail feature or structure to one that is more appropriate, accessible, and sustainable will better meet the user’s needs, protect park resources, and reduce future maintenance costs.

Care must be taken when performing these incremental improvements to ensure that the nature of the improvement does not create an unfunded, increased maintenance workload. Additionally, while these activities may fall within the definition of maintenance, the potential for a high level of disturbance may trigger the need for environmental compliance review.

Identification and Prioritization
With limited funding, the selection of maintenance projects must be determined using an objective evaluation process. Setting maintenance priorities facilitates allocation of limited resources and provides a focus for fund raising efforts. Through the use of a project selection matrix, the most critical ongoing maintenance projects can be selected.

A good maintenance program incorporates every aspect of trail management. A sound decision-making process will direct limited funding and labor to the areas of greatest need. Only by efficiently using maintenance funds can a balance between protecting resources and providing public access be achieved. Even with a well-funded program, any improvement to trail facilities requires sound management decisions and efficient use of available resources.

Environmental Considerations
Maintenance activities may or may not be identified as a project as defined by environmental compliance requirements, but should be reviewed by resource and environmental compliance staff for a determination and assurance of resource protection. The Department's Project Evaluation Form (PEF) should be used for this purpose. It is recommended that initial project compliance documents (i.e., documents required for compliance with CEQA or NEPA, or for regulatory permitting) and planning documents (e.g. General Plan, Road and Trail Management Plan) identify ongoing maintenance as a requirement for the continued existence and use of the facility. Maintenance requirements are thereby built in to the initial project development and subsequently covered under the associated environmental review process. Compliance documents should be kept in the program record for reference during future maintenance activities.

Chapter 24. Clearing and Brushing

Clearing
Maintenance "clearing" includes the removal of downed trees, limbs, rocks, chunks of wood, and other miscellaneous debris blocking the trail, creating drainage problems, or otherwise impeding trail users. This work is performed on an annual or cyclical basis and often in combination with brushing and structure maintenance.

Due to variations in weather, geology, vegetation, and visitor use, managers should determine the frequency for clearing on a park by park basis. In most locations, clearing is necessary annually to open and prepare trails for the peak season. On trails with heavy use and in areas with severe environmental conditions, dense forest, or weathered and highly sheared rock formations, more frequent maintenance is necessary to protect resources, reduce visitor safety issues, and maintain public access. The schedule for clearing is also affected by operational protocols to protect rare and endangered wildlife.

Clearing requirements are determined by trail classification and design standards. In addition, resource management protocols can establish clearing limits for certain species of trees. When the trail is located on a side hill, it is cleared from 2 feet beyond the top of the cut bank to 2 feet below the outboard hinge. When the trail is on flat ground, it is cleared 2 feet beyond the prescribed trail bench width.

When bucking a downed tree out of the trailway, every effort should be made to remove the cut out section of tree in one piece and place it perpendicular to the trail and parallel to the tree from which it was removed to avoid unsightly log rounds and chunks of wood next to the trail.

When clearing a trail, evaluate its condition and note any maintenance work beyond brushing and clearing that needs to be performed. This work may be accomplished in concert with the brushing and clearing or included in the trail's annual condition assessment so it can be corrected before it becomes a visitor safety or resource protection issue.

Brushing

The frequency of brushing is dependent on a number of variables. In dense redwood forest, trails are brushed at least once a year because vegetative growth will readily obscure the trail. Whereas on the San Diego coast, it may be necessary to brush a trail only every two to three years, as vegetation grows more slowly there. Brushing frequency is even less in arid, desert climates.

Like clearing, brushing limits are based on trail classification and design standards. Brushing limits are narrower than clearing limits because only the vegetative growth blocking user passage is removed. Brushing limits extend 1.5 feet beyond the inboard and outboard hinges or 1.5 feet beyond the trail edges on flat ground. The trail should maintain a natural appearance and not be brushed beyond these limits. The exception to these brushing limits is brushing that occurs during trio maintenance in which the trail is brushed back to its original construction standards.

Bucking Downed Trees

<u>Evaluating Downed Trees</u>

Before removing a downed tree, determine which direction the cut out section will roll once it is bucked. Based on where the cut out section will roll, finish the cut so that the sawyer and crew are out of harm's way. The sawyer determines if the tree is under stress ("bind") based on its position on the slope or contact with other trees or natural features. Bind occurs when the wood on one side of the tree is compressed. When one side is compressed, the wood on the opposite side of the tree is stretched or pulled apart by tension. These conditions are caused by the weight of the tree on those sections suspended above the ground or by lateral compression created when a tree is wedged between other trees or objects. Large limbs that contact the ground can support the tree in a manner that can neutralize this effect and even reverse the bind. Study all tree limbs before making any saw cuts to determine if they are affecting the bind.

Due to the complexities that exist when a tree is under tension, sawyers must watch the behavior of the tree as they cut. They must be prepared to adjust bucking cuts as the tree reveals its hidden stresses. If the binds and tensions are not identified and the proper techniques used, the sawyer could potentially encounter hazards while bucking the tree, including getting their saw stuck when the compressed wood closes around the bar, or being struck by a portion of the tree when the tension is released.

Prior to bucking a downed tree identify the downhill side of the tree where the bucked section will roll easiest. Next, remove any rocks, impact berm, or vegetation that might inhibit the tree from rolling in the desired direction once it is bucked. On steep slopes it may be necessary to secure the tree with rigging prior to bucking to keep it from rolling downhill uncontrollably when it is released. A temporary trail closure or use of a "spotter" who can watch for trail users may be required to ensure public safety. Also, be sure there are a couple of inches of clear space under the tree where the cuts are performed. Avoid dulling the chain through contact with the ground by watching the color of the wood chips as you near the bottom of the tree. Darker bark chips indicate the edge of the tree.

Bucking Procedures

Remove any soil or rocks embedded in the tree bark where the saw cuts will be made. Soil and rocks are often splashed on the tree when it hits the ground. If they are not removed and the saw makes contact with them, it will become dull in an instant. For downed trees with thick bark, the bark should be cut away with an ax where the saw cuts will be made. Removing the bark will eliminate the possibility of cutting soil and rocks embedded in it and reduce the diameter of the tree, providing a better surface for the "dogs" (a plate with toothed spikes mounted on the power head) to penetrate and plastic wedges to be inserted.

To ensure that the section of tree being removed will roll freely out of the downed tree once the bucking cuts are completed the saw cuts should be performed at compound angles. When finished, the compound angle cut leaves the bucked ends of the tree wider in the off side (front) and at the top. The backside and the bottom of the bucked tree are narrower, and when the bucked tree is rolled out of the cuts toward the off side, the opening between the two cut ends is wider to allow the bucked tree to be removed without binding on the cut ends.

If the section of tree to be removed can be rolled out of the cut with the use of a peeler or rock bar, begin the bucking cuts. If additional force will be required to help roll the bucked section out of the downed tree, (which is common with large diameter trees) rigging should be used to roll it out of the cuts. If rigging is required, a wire rope choker should be inserted under the tree before it is bucked. A choker roll set should be applied to provide additional mechanical advantage.

Resource and Trail Protection

Regularly scheduled brushing maintains public access and prevents users from deviating from the trail bed and damaging sensitive resources adjacent to the trail.

When trails become overgrown, trail users hike or ride where there is the least amount of vegetative resistance. Trail use off the designated trail can also create soil erosion. They also develop volunteer trails outside the established travelway, which can damage sensitive natural and cultural resources.

When brushing a trail, extra care is given to important plants, such as oaks and redwoods or any other large tree or shrub identified as special or unique, including shrubs such as rhododendrons, azaleas, and Western redbuds. These plants are pruned rather than brushed to preserve their overall shape and beauty when flowering. If the vegetation is part of an historic landscape, such as a historic farm or homestead, care should be taken to prune and maintain these plants according to their historic style or design intent. Resource staff can provide guidance on the appropriate methods for treatment of historic vegetation

Areas with an abundance of seasonal wildflowers should be brushed when flowers are not in bloom. Native wild flowers are allowed to grow, flower, and produce seeds to perpetuate their numbers. If the trail was developed prior to current environmental review and plant survey protocols, there may be rare or endangered plants nearby. In this case, contact appropriate resource staff to determine if rare or endangered plants are present and to develop strategies for their protection.

Brushing and Clearing on Accessible Trails
When performing clearing and brushing on an accessible trail, the brushing limits may need to be modified. One technique in accessible design is to use native vegetation as trail edge protection. Woody plants such as manzanita and chemise can be used to replace safety railings because they are almost impenetrable and prevent trail users in mobility assistive devices from leaving the trail. When used for this purpose, the plants are left growing along the outside edge of the trail. In addition, trail users with a visual impairment like to touch and smell the vegetation the trail traverses through. If the trail is brushed beyond their reach, they miss out on this experience.

Brushing of Scenic Overlooks
A scenic overlook is often designed into a trail alignment as a trail destination with views of the surrounding landscape, as well as unique or outstanding points of interest. Every effort is made to maintain the view from such overlooks, as they are an integral part of the trail experience.

Brushing a scenic overlook requires a balance of maintenance of the viewshed with preservation of the vegetation. Remove only the vegetation blocking the view and only to the extent necessary to maintain the view. Aggressive vegetation removal creates a visual impact that detracts from the user’s experience. Excessive brushing also tempts trail users to venture beyond the perimeter of the overlook, which can lead to the development of volunteer user created trails, resource damage, and visual scars on the landscape.

Brushing Procedures
Regulations or operational protocols in some parks prohibit the use of power tools during certain months of the year. In this situation, use only hand tools, such as brush axes, brush hooks, loppers, handsaws,McLeods, machetes, weed whips, and pitchforks.

Crews should gather the piles of brush and stash them off the trail and out of sight. Sometimes it is more efficient to form a human chain and pass the brush from worker to worker to where it will be stashed. This method also reduces resource damage caused by trail workers climbing the cut bank and hillslope.

Chapter 25. Trail Tread Maintenance

Tread maintenance is conducted on a cyclical schedule that depends on the types and amounts of use, soil and weather conditions, and the extent of canopy cover. For example, a trail that has soft dry soil and is used by equestrians and mountain bikers requires more frequent maintenance than a trail with rocky soil.
The maintenance schedule must take into account soil moisture content. Maintenance should be completed when moisture is adequate. When the soil is too dry, it becomes difficult to shape and compact and unravels quickly. When the soil is too wet, it becomes plastic and deforms when loads are applied. A good test to ensure soil moisture is optimal for maintenance work is to take a handful of soil and squeeze it. When released, the material should be in a clump, not fall apart, and no water should squeeze out. The clump of soil should be firm enough that it can be broken in half without crumbling apart.

Tread Maintenance

Accessibility
Whenever maintenance is performed on a trail, there is an opportunity to improve the trail's level of accessibility by widening the tread surface to meet the minimum 36 inch width requirement. There is also an opportunity to improve the smoothness, uniformity, firmness, and stability, as well as to reduce the number of obstacles in the trail tread by removing or capping tree roots and rocks. These improvements may not make the trail fully compliant with accessibility standards, but they allow some trail users with mobility impairment to use a trail that would not otherwise be available to them.

Light Tread Maintenance
Once the trail tread begins to show minor cupping, riling, flattening out of the cross slope, or loss of its ability to effectively drain water, it should be scheduled for "light tread maintenance", which involves removal of the vegetation and organics accumulated on the inboard and outboard edges of the trail, and reshaping the tread surface by lightly cutting, filling, and compacting.

<u>Trio Maintenance</u>
When the tread surface develops a build-up of soil and organics along the inboard hinge of the trail (slough) or along the outside edge of the trail (berm), and the center of the trail becomes entrenched, “trio maintenance” is required. Trio maintenance is a three step process that (1) brushes the trail back to its original construction limits; (2) removes slough and berm; and (3) reshapes the trail tread to its designed standard and construction specifications. Trio maintenance is usually performed on a two to seven year cycle, depending on the rate of trail degradation.

Trail Reconstruction
When the work required to repair the tread exceeds what can be accomplished under trio maintenance, the trail needs to be reconstructed. Trail reconstruction occurs only when the trail alignment is suitable to achieve a sustainable trail or when political, cultural, or environmental issues require retaining a substandard alignment. Reconstruction involves brushing the trail back to its original design standards and construction specifications and performing minor reroutes that are within the original trail corridor. Using curvilinear techniques, these adjustments can reduce the linear grade and improve drainage by lengthening the trail and decoupling it from natural watercourses. Linear grades can also be reduced by installing steps where appropriate. Trail reconstruction involves reshaping the back slope, removing the berm, scarifying the tread, and restoring designed tread elevations and drainage. Typically, work of this scope also involves repair or reconstruction of other trail structures, such as switchbacks, climbing turns, retaining walls, steps, bridges, and puncheons.
Every reconstruction project presents an opportunity to improve access by widening the trail tread, removing or covering rocks and roots in the trail bed, eliminating steps and water bars, and reducing linear trail grades.

Entrenched Trails
An entrenched trail does not allow the natural sheet flow of water across the landform, but instead captures it and acts as a watercourse. To repair this problem, the entrenched portion of trail needs to be elevated by importing surplus gravel or soil from other sections of the trail where slough and berm removal or back slope repair have occurred. Prior to importing fill material, the tread surface needs to be scarified (de-compacted). Fill material is imported, shaped, and compacted in maximum 3 inch lifts. The trail tread is elevated until it is well above the surrounding soil horizon. In flat terrain, the trail tread is crowned so that water flows off the tread into a parallel ditch or onto the surrounding terrain. On a hillslope, the trail tread is outsloped per design standards.

Aggregate Surfacing
When crushed aggregate has been installed as surface material, it is because of special needs such as accessibility, equestrian use, mountain bike use, or to harden soil with very low capabilities. Maintenance of this surface includes re-establishing original tread elevations, shape, and drainage. The surface must be uniform and free of dips, voids, or any place that allows water to settle or collect.

Sections of tread needing repair must be scarified or de-compacted to allow for new crushed aggregate to bond to the old surface. Without scarification, the new layer slips across the surface of the existing material and unravels, resulting in an unstable and poorly performing surface. Once the tread is scarified, new crushed aggregate is installed, shaped, graded, and compacted with a vibraplate.

In very moist areas, geotextile fabric may have been used to support the crushed aggregate. In this case, cover any exposed fabric with a minimum of 4 inches of crushed aggregate on pedestrian trails and 6 inches of crushed aggregate for equestrian or mountain bike trails.

Exposed Roots

When performing maintenance, loose or dead roots at the surface are excavated and removed to well below the tread surface. Roots connected to live plants are identified as either support roots for trees and large shrubs or small, feeder roots bringing nutrients to the plant. Feeder roots can be removed without damaging the plant and will quickly re-grow. Large roots are the support roots for the plant and are slow to re-grow. When removing roots, caution must be taken not to jeopardize the health and stability of the plant. When in doubt, consult a resource specialist or leave the root intact. As a general rule, no root over 3 inches in diameter should be removed without consulting a resource specialist. However, each park is responsible for the protocols for removing tree roots.

The best practice is to import fill material left over from excavations elsewhere on the trail and cover the roots. The fill should cover the roots by a minimum of 4 inches and provide drainage off the entire tread surface. The surface should be free of voids and should not allow any water to collect. When the fill area is greater than a few inches, a turnpike may be necessary.

Uprooted Trees

When the tree falls downhill on the lower side of the trail, it can leave a hole in the tread. The hole created by the void of the root wad can be filled with material collected from other excavations on the trail or with soil from the root wad. When re-establishing the tread, fill material is installed and compacted in maximum 3 inch lifts with a tamper or vibraplate until the proper elevation is achieved. The final grade, width, and drainage must be consistent with the standards for that trail. If necessary, a retaining wall can be constructed to hold the fill material.

When a tree from the cut bank above the trail falls downhill, it can pull up a large root wad that blocks the trail. Logging out a tree in this situation is difficult and time-consuming. Sometimes the tree can be bucked off near its base and the stump pulled back into its hole with rigging. Often, it is more efficient to perform a small reroute above the root wad by excavating into the hillslope. The bank is laid back to the maximum angle at which it will retain its position without sliding down the slope and the excavated material used to fill the hole left by the root wad. Excess soil is transported to another site or sidecast off the trail away from watercourses. The tread is constructed to match the standards of the existing trail.

Slides
After a landslide occurs, determine if the trail can remain in the same alignment or must be rerouted. If the landslide is shallow and not part of a larger slope instability problem, the trail may be re-established in the same alignment.

Usually when a cut bank has failed, it is because the back slope has been cut too steep. The bank finally gives way and falls onto the tread. Re-cut the tread to the original standard, with the proper outslope and width. Cut the back slope back to the maximum angle at which it will retain its position without sliding down the slope and transport excess soil to another worksite or sidecast away from watercourses.

Repair failures on the outer portion of the trail by moving the trail into the hillslope (similar to repairs on root wad holes described above), or by installing a retaining wall that spans the entire slip out and is anchored into stable, undisturbed ground.

Turnpikes, Causeways, and Approaches
Over time, turnpikes, causeways, and approaches to bridges and puncheons will become worn and entrenched from mechanical wear, which can lead to excessive moisture content and soil erosion. To correct these problems, the tread is reconstructed and returned to its designed elevation, shape, and firmness by importing fill from other worksites along the trail or aggregate from the nearest trailhead for a firmer and more durable tread.

The surface of the tread approaching a bridge or puncheon should be level with the top of the structure's deck. Tread below the elevation of the decking can be a tripping hazard and barrier to users with mobility assistive devices. To return the tread to its original standard, areas receiving fill material must be scarified to promote the bonding of existing and imported fill material. The combined depth of the existing, scarified tread material and the new fill should be a minimum of 3 inches to ensure a consolidated and durable trail tread. The fill must have adequate moisture content to be shaped and compacted. Fill is installed in maximum 3 inch lifts. The surface of the tread should be installed to the original specifications and crowned to provide drainage.

The tread of turnpikes and causeways is maintained similarly to the approach to a bridge or puncheon, except that the entire length of the structure is crowned above the logs and rocks containing the fill for proper drainage.

Switchbacks and Climbing Turns
Maintenance of switchbacks and climbing turns involves re-shaping the upper leg, turn, and lower leg. The upper leg should have a transition where the outsloped trail switches to an insloped trail creating a subtle berm that crosses the trail at an angle of approximately 45 degrees. This berm may need to be re-shaped to facilitate drainage from outslope to inslope. The inboard hinge of the trail may need clearing, due to

sloughing from the cut bank and soil migration from the tread. The drain at the end of the turn is cleared and dug out as necessary. If there is a channel beyond the drain from the upper leg, it should be unobstructed, and the drainage ditch armored with a rock energy dissipater to protect the slope below the drain point. Scarify any entrenched or deformed tread, and use the excess soil from the inboard hinge and drain to fill and restore the tread to its designed specifications. If there are insufficient materials, surplus materials from maintenance activities elsewhere on the trail can be used.

Chapter 26. Drainage and Structure Maintenance

Understanding Water Flow
Water can cause significant damage to a trail and its features and is a major factor to anticipate during trail layout and design. The potential for water-related damage is greatest when it is overlooked. Because rain and snow are normally seasonal and event related, their destructive power is unnoticed during dry periods when most trail work takes place. Maintaining proper drainage must be considered throughout the year and during all trail maintenance and construction activities.

Drainage Problems
Find drainage-related problems by performing a trail condition assessment during wet weather, preferably when the soil is wet, ephemeral watercourses are flowing, and sheet flow is occurring. These conditions enable staff to determine the source of water flowing on the trail, which is essential to correcting any problems. Failure to accurately identify the source of water on the trail can lead to unnecessary or unsuccessful (and costly) repairs, poor trail conditions, and increased trail maintenance workload.

Drainage Solutions
Maintenance of trail drainage depends on the condition and location of the trail. A properly laid out and constructed trail allows water to pass across, through, or under it where it bisects a flow. The objective is to ensure that the trail does not disrupt the natural drainage pattern of the landform, and that overland sheet flow and water courses are not disrupted or coupled (trail and drainage merge together) by the trail alignment.

The best time of year to perform maintenance is during these peak flows when the flowing water can be used to flush sediment and debris through structures. If maintenance cannot occur during peak flows, every effort should be made to prepare for these hydrologic events in advance. Inspections and Work Log prescriptions can be developed during peak flows and then incorporated into scheduled trail projects at a future date.

Basic drainage maintenance includes:
- Maintain tread outslope and remove impediments to cross-drainage flow such as heavy organic litter build up, woody debris, and soil deposition, to allow sheet flow to

follow its natural course across the trail and down the slope. A good outsloped trail design is the most immediate form of drainage control.

- Clear open watercourse channels of large, woody debris, rocks, and soil dislodged from bank failures. Debris can dam a channel, causing overflow or widening of the channel and allow water to flow down the trail. Where a puncheon or bridge has been constructed, clean the channels leading up to, under, and away from the structure to sustain unobstructed flow and protect abutments from erosion.
- Inspect the drainage system of retaining walls to make sure they work properly. A retaining wall subject to additional pore pressure associated with captured water has an increased risk for failure.

These simple activities are performed annually or more frequently as the local conditions dictate. Other maintenance activities considered critical to trail longevity include:

- Parallel and inboard drainage ditches: remove soil and organic matter build-up; in vegetated ditches, remove excessive growth that might be an impediment to drainage.
- Culverts and other closed or underground drainage structures: remove woody debris and sediment at the inflow and outflow and inspect and repair headwalls and energy dissipaters.
- Drain Lenses: inspect and ensure the permeability of the rock lens is sufficient to accommodate the incoming flow and replace drain rock as required.
- Drain dips and rolling grade dips: These drainage features that are constructed as part of the trail bed. Maintaining these features requires simply reshaping and compacting the trail bed back to its original design.
- Water Bars: De-compact the soil on the downhill side of the water bar. The sediment from the uphill side of the water bar is excavated, placed on the downhill side, and compacted, preferably with a vibraplate. If there is a shortage of fill material for below the water bar, it can be imported from sections of the trail receiving slough and berm or back slope maintenance.

Structure Maintenance

Preventative maintenance keeps trail structures at or near their design and construction standards. The goals of maintaining a structure are ensuring visitor safety and protecting resources, as well as maintaining public access and avoiding expensive reconstruction and/or replacement.

Maintenance needs are identified during the annual trail condition assessment. Usually the maintenance needs of a single trail structure are minimal, and dedicating a trail crew to the task is an inefficient use of resources. To maximize crew efficiency, structure maintenance is performed in conjunction with brushing and clearing, tread maintenance, and other annual or cyclical maintenance activities. However, repairs to correct issues that affect visitor safety must be performed immediately; they cannot wait to be scheduled with other projects and are often assigned to small work groups that can work quickly and efficiently.

Bridges
Annual maintenance is focused on the surrounding soil and vegetation, as these items can affect the bridge. The tread adjacent to the soil dams on the ends of the bridge must not project beyond the dam elevation, nor should it make contact with other bridge components. Any soil that is above the top of the dam may come into contact with the decking, posts, and stringers, and accelerate their failure. Check the condition of the soil dam, which separates the stringers from the soil and will naturally deteriorate over time. Properly sized and installed soil dams should present no problems over the lifetime of the structure, but should be monitored annually

Inspect the mudsills to ensure the top, including the space between the stringers, is clean and clear of any soil or vegetative matter. Both ends and the face of each mudsill should be above the surrounding ground to allow water to drain off the top of the sill, instead of standing next to and under the stringers.

Walk across the bridge, inspecting it for wear or broken parts. Check railing and posts to ensure they are tight. Keep in mind that rails are leaned on by users and if the rail fails the user may fall off the bridge. Make note of and repair any loose or damaged rails and posts. Check the decking for pieces that are worn or damaged, and remove and replace as needed. Clear the top of post sills of any soil or vegetative matter that may have accumulated.

Check under the bridge to ensure a good air gap remains around all the stringers. Clear away any vegetation that has encroached on the stringers. Stringers are usually the first part of a bridge to fail, and anything done to increase their longevity is time well spent. While under the bridge, inspect the diaphragms or bridging as applicable. Check the condition of the sway braces and make certain they are tight. You should be able to pull the braces apart by about an inch where they cross. Braces that are loose and rattling need to be tightened. If the braces cannot be pulled apart where they cross, they need to be loosened. Inspect adjacent streambanks for lateral scour and undercutting. Also, check for trees being undermined or failing within close proximity of the bridge.

Bridge approaches require cyclical maintenance. Make certain they are at the original design standards. Level approaches are best for accessibility. Other cyclical maintenance items include replacement of wear boards on equestrian bridges and replacement of any other item likely to require maintenance on a shorter cycle than the lifespan of the bridge.

Seasonal pipe bridges are installed and removed annually. The components are inspected and repaired during annual installation and removal. Inspect the ends of the stringers where they attach to the brackets for cracks or breakage; the decking for wear or broken pieces; brackets and especially the welds for cracks or signs of breakage; and plastic-coated wire rope railings to ensure they are sound and free of cuts and frays that might cause injury. Have a supply of replacement brackets, nuts, and bolts available during installation.

Because a pipe bridge is installed below the high water level, maintenance of the tread approaches must be performed annually during installation of the bridge.

In addition to the wooden components and metal brackets that comprise the bulk of the bridge parts, the pipes (stanchions) driven into the creek or riverbed get flared at the top from pounding and must be trimmed back annually prior to assembling the bridge. Therefore, these pipes get shorter every year and must be replaced when they no longer have the required length.

Puncheons and Boardwalks
Annual inspection and maintenance of puncheons and boardwalks are essentially the same as for bridges, with emphasis on maintaining air gaps. It is common to find vegetation and soil encroaching on the joists of these low lying structures, which must be cleared to maintain the same air gap as for bridge stringers. Soil dams are inspected and mudsills cleaned to provide an air gap and ensure proper drainage. The importance of cleaning mudsills cannot be over-emphasized. Vegetation and soil on top of a mudsill are the leading cause of early puncheon and boardwalk failure. Inspect the tread pieces for wear, breakage, or loose fasteners. Repair or replace as needed.

Cyclical maintenance includes maintenance of the approaches to the puncheon or boardwalk. Make certain that soil is not overflowing the top of the soil dams and that the trail tread has not eroded and created a step at the edge of the puncheon or boardwalk.

Puncheon and Boardwalk Drainage Maintenance
Puncheons and boardwalks are used to cross small ephemeral streams, swales, or bogs. With an elevated tread surface, they permit dry passage for trail users while allowing ephemeral or poorly defined watercourses to function. Puncheons and boardwalks require cyclical maintenance to ensure that any associated drainage structures (parallel ditches, cross drains) remain functional and do not accumulate vegetation or soil. One-time or incident-related maintenance may also be required due to fallen trees or debris blocking parallel or cross drains.

Steps
Wooden, interlocking, and crib steps are inspected annually to ensure stability. Any steps that have come loose need to be reset and secured. If some steps are rotten or damaged they need to be replaced. If more than a couple of steps require replacement, the step section is probably at or near the end of its life and needs to be replaced entirely.

Cyclical maintenance includes refilling the backfill of wooden steps to the top as necessary. Clear or fill the back part of the step to re-establish the designed height between the backfill and the top of the step. Make certain all steps have cross slope drainage into a drainage structure and clear the structure as necessary. Sediment removed from ditches can be used to backfill eroded steps. If the drainage ditch has eroded, it may be necessary to install an energy dissipater.

Cable steps are removed and installed annually, depending on the location. For cable steps in a stable location and not subject to annual removal, the maintenance is the same as for other types of steps. Otherwise, cable steps can be evaluated during annual installation and removal. If the steps are not removed but are subject to flooding or wave wash, expect to have to re-install them. Inspect the step pieces, wire ropes, and wire rope clips. During re-installation, it may be necessary to repeat the step calculation to account for variations that may have occurred to the slope. If an individual step needs replacement, cut the wire rope above or below the step, install a new step, and splice the wire rope back together.

Railings
Safety railings generally require only minimal maintenance. Inspect railings and posts, and make certain they are secure. Any deficiencies must be corrected immediately. Check for loose, rotten, or damaged posts, mid-rails, and top rails. Lightly damaged or vandalized rails may still be serviceable. Drawknife or sand any rough surfaces that could result in splinters.

Cyclical maintenance includes sanding any roughness from weathering of the top rail and re-setting nails or screws that have worked loose.

Incident-related or one-time repairs commonly involve removing carved graffiti or the railing being struck by falling trees and limbs. The need to remove the graffiti is balanced against structural damage that removal may cause. If a drawknife is used every time someone puts initials on a railing, the railing may need to be replaced earlier than if the graffiti was left in place.

Retaining Walls
Retaining walls require minimal annual maintenance beyond inspections. Check that gaps between wall sections are not clogged with debris that prevents drainage from the backfill material, and clear as needed.

Cyclical maintenance includes maintaining the trail tread material behind and approaching the retaining walls at an elevation above the top of the retaining wall to allow drainage off the trail. Maintenance of the trail tread behind a retaining wall should also prevent water from ponding behind the wall.

Prorated maintenance may include scheduled replacement of the wall. Isolated repairs may involve the replacement of individual wooden components (facers, wings, or anchor post) or resetting stones that have come loose and are making poor contact with adjacent stones.

When performing maintenance on trail structures, look for opportunities to improve the level of accessibility. Bridge, puncheon, and boardwalk decking can be widened to 36 inches or more; abrupt elevation changes on the approaches and decking can be eliminated or smoothed out; and bull rails to provide edge protection can be installed. Hand railings can be added to step sections to aid users in ascending and descending stairs. Remember to keep the individual rise and run of each step and landing consistent. Elevated edge protection can be provided along retaining walls, where there is a precipitous drop off, steeper linear grade, cross slope, or a bend or turn in the trail.

Chapter 27. Erosion/Sediment Control and Trail Removal

Erosion and Sediment Control

Weather Conditions
While performing trail construction and maintenance work, it is important to minimize soil erosion and prevent sediment from entering nearby watercourses. One of the most basic measures to minimize soil erosion and provide sediment control is to refrain from performing soil excavation during inclement weather or when soil is very wet. Under these conditions, soil cannot be shaped or compacted. As a result, it can be washed into nearby waterways.

Organic Wattles
A basic sediment retention measure is to rake the organic layer removed from the brushed and cleared trail alignment to below the intended trail tread where it serves as a wattle that catches sediment coming from the trail alignment. This organic material can later be spread over the finished trail tread and backslope.

Soil Export
Another sediment control method is exporting all soil excavated within the influence of a watercourse. Excavated soil is transported to locations where it can be used as fill material or spread onto the hillslope outside the influence of the watercourse. Soil stored on the trail alignment should also be encapsulated and contained in a sediment retention structure.

Silt Fences and Straw Wattles
In addition, sediment retention structures such as silt fences, straw wattles, or bales of sterile straw should be installed below the trail or trail structure if adjacent to a watercourse.

Silt fences can be installed with or without the wire fence backing. When installed where there is minimal soil catchment anticipated the geotextile fabric can be attached with 9 gauge wires directly to the steel T posts. Where substantial soil catchment is anticipated the fence wire is installed to provide additional structural support to the silt fence.

Straw wattles are designed for low surface flows and can be installed on flat ground or slopes of varying degrees. They should always be installed perpendicular to the surface runoff (sheet flow). To keep water from running under the wattle, a shallow trench with a minimum depth of 3-5 inches, depending on the size of the wattle, is dug for the wattle to lie in. When installed on a slope, the spacing of wattles is as follows:

% Hillslope	Maximum Spacing between Wattles
<25%	40 feet
25-33.5%	30 feet
33.5-50%	20 feet
50-100%	10 feet

Wattles are secured to the ground with wooden stakes that are 18 inches long for 9-inch diameter wattles and 24 inches long for 12-inch diameter wattles. The stake is driven through the center of the wattle and perpendicular to the ground. Stakes are driven in at the end of each wattle as well as at 3- to 4-foot intervals for the rest of the length of the wattle. When installing wattles in a riparian area, willow cuttings can be substituted for wooden stakes to provide extra slope stabilization because their roots will help retain soil and their canopy will help protect the soil from rainfall impact.

Once the silt fences and straw wattles are no longer required, the soil behind them is carefully removed and taken to a location where it can be used as fill material or dispersed below the trail alignment. Bare areas should be replanted with native vegetation and covered with organics as required to prevent erosion.

Trail Removal and Restoration
When a trail is removed, take time to obliterate the trail and restore the area to as natural condition as possible to eliminate its continued impact on resources, as well as the visual scar created by the trail. Rehabilitation of the former trail alignment also prevents it from continuing to be used.

Restoration work includes the following:
1. All woody debris, organics, and loose rocks are removed from the travelway (2 feet beyond the top of cut bank to 2 feet below the outboard hinge). This material is placed above the trail for use later.
2. Natural watercourse features of the landform are fully restored. All watercourse crossings (including small swales and crenulations) are decoupled from the trail alignment and restored to their original drainage pattern. Ruts and rills are eliminated to prevent further water accumulation and soil loss. They can be eliminated by de-compacting the bottom of the rills and filling them with local soil and gravel to return the surface to its original shape and contour. Again, soil and rock from the new alignment can be used for this purpose when necessary. Do not use organic-rich materials such as sod for fill because the organics will eventually deteriorate and compact, allowing the depressions to return.
3. Cut bank and bench are de-compacted and the soil aerated to promote re-vegetation of the trail bench and improve bonding of imported soil. Soil below the outboard hinge (from the original trail excavation) is excavated and placed against the cut bank and trail bench to restore the natural slope and contour of the hillslope and recover the topsoil and seed bank, which greatly enhances the process of re-vegetation. If the trail is on flat ground, soil can be recovered from both sides of the trail. If there is a soil deficit, import soil from the new trail or trail reroute. The need

for imported soil should be identified before construction of the new trail, so that soil can be saved and stockpiled.

4. In some situations, ruts can be so severe and deep that they become gullies. Filling in these gullies with native soil will ultimately fail because the soil will be mobilized by water flowing down these erosional features. Furthermore, local fill material may be unavailable and projects too remote to import materials. In these situations, check dams are installed to halt further erosion and to allow backfilling to occur through sediment trapping. Fill the gullies between check dams with brush cuttings to slow down water runoff and trap soil.
5. Simple check dams are installed by placing rocks, logs, or boards within the channel, perpendicular to the flow. They are keyed into the bottom of the gully and adjacent banks to prevent water from flowing under or around the dams. The spacing of these dams is as follows:

% Hillslope	Maximum Spacing between Check Dams
<20%	25 feet
20-30%	15 feet
>30%	10 feet

Once installed, check dams are monitored to ensure they are functioning. Additional dams are installed as needed. Once filled, leave check dams in place and allow them to become part of the slope's natural contour. Re-vegetation of the filled channel may be necessary if plant growth does not occur naturally. Further stabilization is accomplished by the use of erosion cloth, nets, wattles, or other biodegradable coverings to slow the velocity of water runoff and inhibit gullying and rilling.

6. Once the trail bench is recontoured and gullies are stabilized, vegetation is re-established. Vegetation for planting must be native to the area and hardy enough to survive transplanting. Maintaining genetic integrity is critical in every re-vegetation project. Typically, the vegetation and seeds come from the same sub-watershed where the project is located. The best place to obtain vegetation is from the new trail route. Suitable plants are harvested during brushing and clearing and stored in wet burlap sacks until transplanted. Plants can also be collected from the surrounding area in a dispersed fashion, if it does not adversely affect local plant populations. Collecting seeds and cuttings from the watershed and growing them at a local nursery will produce a viable plant source. Protocols for plant collection and nursery operations with the goal of maintaining genetic integrity must be developed and followed. Within every plant community there are species that are more resilient to transplanting than others. Trail supervisors must be familiar with the local species and consult with a resource specialist to use them in appropriate numbers and locations.
7. Transplanting must occur at the appropriate time of year to improve plant survival. Usually this time coincides with the wet season. Transplanting when plants are dormant and soil conditions are moist reduces the shock of transplanting and ensures that the plant has enough moisture to re-develop its root system before encountering more stressful summer conditions.

8. Proper transplanting procedures are followed to reduce mortality and improve plant vigor. When plants are harvested from the new trail alignment or from the surrounding area, they are removed from the ground so that the entire root ball is intact and encased in soil. The hole excavated to receive the plant is twice as wide as the diameter of the root ball and at a depth of one and a half to twice the size of the root ball. When the plant is placed within the hole, loose topsoil is formed around the root ball to fill voids and elevate the plant stem to a level similar to its pre-harvest level. The soil is then firmly packed around the plant by hand until it matches ground elevation. If the soil is dry, the plants are watered until rain can maintain the soil moisture. Nursery plants are planted in the same fashion, except the roots are trimmed when removed from their containers so they grow into the surrounding native soil and do not become root bound.
9. Vegetation is planted randomly in the old trail alignment to mimic natural conditions. Vegetation planted in a row or in a linear arrangement will look unnatural. Use the plant dispersal patterns of the surrounding area to guide the placement of plants. Once the old trail is re-vegetated, large woody debris and rocks are placed randomly along the former trail alignment, consistent with the dispersal of these objects in the surrounding area. Finally, the duff collected earlier and placed above the alignment is scattered over the old trail. Upon the completion of a properly recontoured and revegetated trail removal project, the landform should appear as though the trail never existed. With practice, this level of restoration can be achieved in most environmental conditions.
10. When all of the above measures have been completed, the old trail alignment will be obscured from view. Large rocks and downed trees are winched across the entrance to the old alignment, so that the old trail cannot be easily used by the public.
11. In some cases there may not be enough vegetation, logs, or rocks to obscure the old trail. In this case, you can install symbolic or barrier fencing and interpretive signage to keep the public from using the trail. Once the old trail has fully recovered and is no longer visible, the fencing and signs are removed. Occasional monitoring is required to ensure the public does not resume using the old trail alignment.

Removing Volunteer Trails

Shortcuts and volunteer trails must be eliminated as soon as they are discovered. If left uncorrected, these trails encourage use and can lead to damaged vegetation, soil erosion, and drainage problems. Additionally, the longer volunteer trails are in place, the more difficult it is to change the resulting patterns of use.

Once discovered, volunteer trails are blocked with native materials, such as limbs, logs, rocks, and brush. If suitable native material is not available or effective, railing or fencing can be installed to block access to the unwanted trail.

When removing a volunteer trail, the trail bed must also be rehabilitated. Entrenched trails are de-compacted, filled, reshaped to the natural contour, and re-vegetated following the procedures identified above. Once rehabilitation is complete, the volunteer trail should be obscured and or present a difficult and unappealing route to potential users. In the case of a volunteer trail between switchbacks rehabilitation should block the view of the trail down slope, if possible.

Rehabilitation of a fall line oriented volunteer trail on an open slope in grassland environment may require the use of straw wattles and grass seed to stabilize the rehabilitated trail. If native grass seeds can be obtained, they should be used. Otherwise, a non-invasive annual grass such as red fescue may be used to help protect the bare soil until native grasses adjacent to the trail can populate the bare soil. Check with a resource specialist first to ensure that the grass seeds being used are appropriate for re-vegetation purposes.

Trail Narrowing

A trail that exceeds the standard for width can be narrowed in one of two ways.

1. For trails cut on a side slope, part of the sidecast (material deposited on the hillslope below the trail during construction) is pulled in and placed against the cut bank. If plants are present in ether the sidecast material or cut bank, they are removed with their root ball intact and replanted into the remaining side slope.
2. For trails on flat ground, de-compact the ground to loosen the soil. Block off the trail the section of trail to be removed with natural debris, such as downed logs, limbs, brush, rocks, or fill. Scatter material in an irregular pattern so it looks natural. Rocks and logs are partially buried with the weathered side up (side previously exposed to air). Re-plant restored areas with native vegetation and scatter duff over the entire area. In grassland areas, sod can be transplanted along the edge of the trail after it has been de-compacted.