CHAPTER 2

ROAD PLANNING AND RECONNAISSANCE

2.1 Route Planning

Planning with respect to road construction takes into account present and future uses of the transportation system to assure maximum service with a minimum of financial and environmental cost. The main objective of this initial phase of road development is to establish specific goals and prescriptions for road network development along with the more general location needs. These goals must result from a coordinated effort between the road engineer and the land manager, forester, geologist, soil scientist, hydrologist, biologist and others who would have knowledge or recommendations regarding alternatives or solutions to specific problems.

The pattern of the road network will govern the total area disturbed by road construction. The road pattern that will give the least density of roads per unit area while maintaining minimum hauling distance is the ideal to be sought. Keeping the density of roads to an economical minimum has initial cost advantages and future advantages in road maintenance costs and the acreage of land taken out of production.

Sediment control design criteria may be the same as, or parallel to, other design criteria, which will result in an efficient, economical road system. Examples of overlap or parallel criteria are:

1. Relating road location and design to total forest resource, including short and long term harvest patterns, reforestation, fire prevention, fish and wildlife propagation, rural homestead development, and rangeland management.

2. Relating road location and design to current and future timber harvesting methods.

3. Preparing road plans and specifications to the level of detail appropriate and necessary to convey to the road builder, whether timber purchaser or independent contractor, the scope of the project, and thus allow for proper preparation of construction plans and procedures, time schedules, and cost estimates.

4. Writing instructions and completing companion design decisions so as to minimize the opportunity for "changed conditions" during construction with consequent costs in money and time.

5. Analyzing specific road elements for "up-front" cost versus annual maintenance cost (for instance culvert and embankment repair versus bridge installation, ditch pavement or lining versus ditches in natural soil, paved or lined culverts versus unlined culverts, sediment trapping devices ("trash racks", catch basins, or sumps) versus culvert cleaning costs, retaining walls or endhauling sidecast versus placing and maintaining large embankments and fill slopes, roadway ballast or surfacing versus maintenance of dirt surfaces, and balanced earthwork quantities versus waste and borrow).

The route planning phase is the time to evaluate environmental and economic tradeoffs and should set the stage for the remainder of the road development process. Although inclusion of design criteria for sediment control may increase initial capital outlay, it does not necessarily increase total annual cost over the life of the road which might come from reductions in annual maintenance, reconstruction, and repair costs (see Section 2.2). If an objective analysis by qualified individuals indicates serious erosional problems, then reduction of erosional impacts should be a primary concern. In some areas, this may dictate the location of control points or may in fact eliminate certain areas from consideration for road construction as a result of unfavorable social or environmental costs associated with developing the area for economic purposes.

2.1.1 Design Criteria

Design criteria consist of a detailed list of considerations to be used in negotiating a set of road standards. These include resource management objectives, environmental constraints, safety, physical environmental factors (such as topography, climate, and soils), traffic requirements, and traffic service levels. Objectives should be established for each road and may be expressed in terms of the area and resources to be served, environmental concerns to be addressed, amount and types of traffic to be expected, life of the facility and functional classification. Additional objectives may also be defined concerning specific needs or problems identified in the planning stage.

1. Resource management objectives: Why is the road being built; what is the purpose of the road (i.e., timber harvesting, access to grazing lands, access to communities, etc.)?

2. Physical and environmental factors: What are the topographic, climatic, soil and vegetation characteristics of the area?

3. Environmental constraints: Are there environmental constraints; are there social-political constraints? Examples of the former include erosiveness of soils, difficult geologic conditions, high rainfall intensities. Examples of the latter include land ownership boundaries, state of the local economy, and public opinion about a given project.

4. Traffic requirements: Average daily traffic (ADT) should be estimated for different user groups. For example, a road can have mixed traffic--log or cattle trucks and community traffic. An estimate of traffic requirements in relation to use as well as changes over time should be evaluated.

5. Traffic service level: This defines the type of traffic that will make use of the road network and its characteristics. Table 3 lists descriptions of four different levels of traffic service for forest roads. Each level describes the traffic characteristics which are significant in the selection of design criteria and describe the operating conditions for the road. Each level also reflects a number of factors, such as speed, travel time, traffic interruptions, freedom to maneuver, safety, driver comfort, convenience, and operating cost. Traffic density is a factor only if heavy non-logging traffic is expected. These factors, in turn, affect: (1) number of lanes, (2) turnout spacing, (3) lane widths, (4) type of driving surface, (5) sight distances, (6) design speed, (7) clearance, (8) horizontal and vertical alignment, (9) curve widening, (10) turn-arounds.

6. Vehicle characteristics: The resource management objectives, together with traffic requirements and traffic service level criteria selected above, will define the types of vehicles that are to use the proposed road. Specific vehicle characteristics need to be defined since they will determine the "design standards" to be adopted when proceeding to the road design phase. The land manager has to distinguish between the "design vehicle" and the "critical vehicle". The design vehicle is a vehicle that ordinarily uses the road, such as dual axle flatbed trucks in the case of ranching or farming operations, or dump trucks in the case of a mining operation. The critical vehicle represents a vehicle which is necessary for the contemplated operation (for instance, a livestock truck in the case of transporting range livestock) but uses the road infrequently. Here, the design should allow for the critical vehicle to pass the road with assist vehicles, if necessary, but without major delays or road reconstruction.

7. Safety: Traffic safety is an important requirement especially where multiple user types will be utilizing the same road. Safety requirements such as stopping distance, sight distance, and allowable design speed can determine the selected road standards in combination with the other design criteria.

8. Road uses: The users of the contemplated road should be defined by categories. For example, timber harvest activities will include all users related to the planned timber harvest, such as silviculturists, foresters, engineers, surveyors, blasting crews, and construction and maintenance crews, as well as the logging crews. Administrative users may include watershed management specialists, wildlife or fisheries biologists, or ecologists, as well as foresters. Agricultural users would include stock herders and

rangeland management specialists and will have a different set of objectives than timber objectives. An estimate of road use for each category is then made (e.g., numbers of vehicles per day). For each category, the resource management objective over several planning horizons should be indicated. For instance, a road is to be built first for (1) the harvest of timber from a tract of land, then (2) access for the local population for firewood cutting or grazing, and finally (3) access for administration of watershed rehabilitation activities. The planner should determine if the road user characteristics would change over the life of the road.

9. Economics: The various road alternatives would undergo rigorous economic evaluation.

As part of this process a "roads objectives documentation" plan should be carried out. This process consists of putting the road management objectives and design criteria in an organized form. An example of such a form is given in Table 4.

	A	B	C	D
FLOW	Free flowing with adequate passing facilities.	Congested during heavy traffic such as during peak logging or recreation activities.	Interrupted by limited passing facilities, or slowed by the road condition.	Flow is slow or may be blocked by an activity. Two way traffic is difficult and may require backing to pass.
VOLUMES	Uncontrolled; will accommodate the expected traffic volumes.	Occasionally controlled during heavy use periods.	Erratic; frequently controlled as the capacity is reached.	Intermittent and usually controlled. Volume is limited to that associated with the single purpose.
VEHICLE TYPES	Mixed; includes the critical vehicle and all vehicles normally found on public roads.	Mixed; includes the critical vehicle and all vehicles normally found on public roads.	Controlled mix; accommodates all vehicle types including the critical vehicle. Some use may be controlled to minimize conflicts between vehicle types.	Single use; not designed for mixed traffic. Some vehicles may not be able to negotiate. Concurrent use between commercial and other traffic is restricted.
CRITICAL VEHICLE	Clearances are adequate to allow free travel. Overload permits are required.	Traffic controls needed where clearances are marginal. Overload permits are required.	Special provisions may be needed. Some vehicles will have difficulty negotiating some segments.	Some vehicles may not be able to negotiate. Loads may have to be off-loaded and walked in.
SAFETY	Safety features are a part of the design.	High priority in design. Some protection is accomplished by traffic management.	Most protection is provided by traffic management	The need for protection is minimized by low speeds and strict traffic controls.
TRAFFIC MANAGEMENT	Normally limited to regulatory, warning, and guide signs and permits.	Employed to reduce traffic volume and conflicts.	Traffic controls are frequently needed during periods of high use by the dominant resource activity.	Used to discourage or prohibit traffic other than associated with the single purpose.
USER COSTS	Minimize; transportation efficiency is important.	Generally higher than "A" because of slower speeds and increased delays.	Not important; efficiency of travel may be traded for lower construction costs.	Not considered.
ALIGNMENT	Design speeds is the predominant factor within feasible topographic limitations.	Influenced more strongly by topography than by speed and efficiency.	Generally dictated by topographic features and environmental factors. Design speeds are generally low.	Dictated by topography, environmental factors, and the design and critical vehicle limitations. Speed is not important.
ROAD SURFACE	Stable and smooth with little or no dust, considering the normal season of use.	Stable for the predominant traffic for the normal use season. Periodic dust control for heavy use or environmental reasons. Smoothness is commensurate with the design speed.	May not be stable under all traffic or weather conditions during the normal use season. Surface rutting, roughness, and dust may be present, but controlled for environmental or investment protection.	Rough and irregular. Travel with low clearance vehicles is difficult. Stable during dry conditions. Rutting and dusting controlled only for soil and water protection.

table 7 Traffic service levels definitions used to identify design parameters (from U.S. Forest Service, Transportation Eng. Handbook).

2.1.2 Design Elements

A road design standard consists of such elements as the definitive lengths, widths, and depths of individual segments (e.g., 4.3 meter travelled way, 0.6 meter shoulders, 3/4:1 cutslopes, 1 meter curve widening, 15 cm of crushed aggregate surfacing). Figure 6 illustrates the road structural terms that will be used throughout the rest of this handbook. Selection of the appropriate road design standard is critical to the overall efficiency of the road network to be installed, and certain elements will have a more rigid standard than others depending on the location of the road or road segment. The entire range of values for each standard must be evaluated and selected according to their appropriateness for a given segment. Then, the various design elements must undergo testing to ensure that the final design meets the previously agreed upon management objectives. For instance, on steeper grades vertical alignment has a greater effect on travel speed than horizontal alignment. Therefore, surfacing and horizontal alignment should not be improved to increase speed where the road gradient is the controlling element.

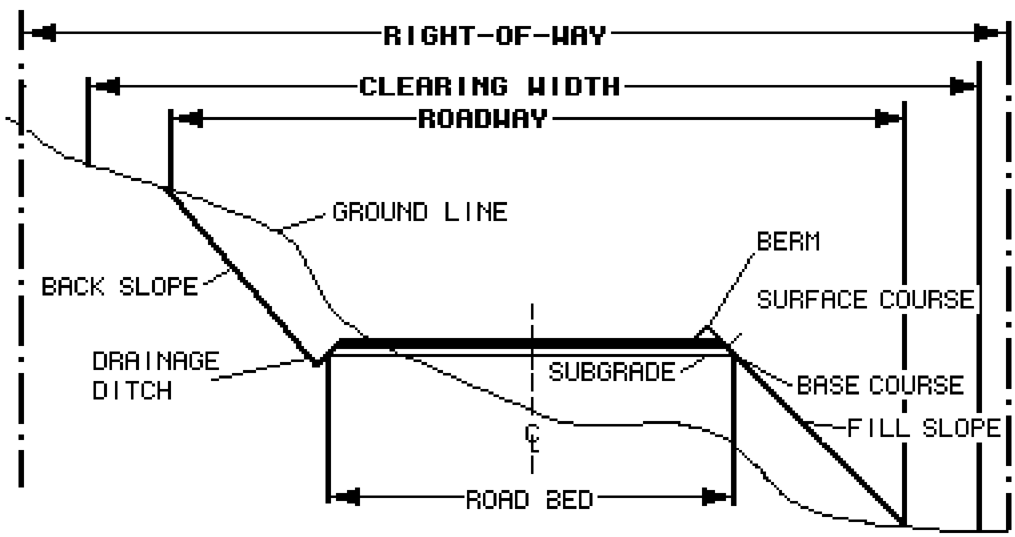

Figure 6. Road structural terms.

table 8 Example of a roads objective documentation form (from U.S. Forest Service, Transportation Eng. Handbook).

ROAD MANAGEMENT — DOCUMENTATION

ROAD NUMBER 8000,8010,8020 DATE 12/3/85 ROAD NAME ______

TOWNSHIP 15N RANGE 5E SECTION 5

DESIGN CRITERIA						ELEMENT SELECTED A. DESIGN B. TRAFFIC MGT C. MAINTENANCE
USER	TIME	1. REC MGT OBJ	2. ENVIR. CONST.	OTHER CRITERIA *	ROAD CLASS	
Timber	1988	2669.16 MBF Timber Sale	Wildlife Mgt	3. Inadequate for mixed traffic, narrow road 4. ridge edge-gentle side slope 5. 8-12 ADT (log truck) 6. Low-boy critical vehicle 7. Lowest cost to purchaser for Class C road and DNR specs.	C	A. 8000 Rd - Single lane 12' T.O. Road Class C. Curve widening for road class C. Surfaced with pit rock. Design speed 15 MPH. Culverts every 400' and where needed. 8010 Rd - Single lane 10' T.O Road Class C. Curve widening for class C. Surfaced with pit rock. Design speed 15 MPH. Culverts every 400' and where needed. B. Discourage Pass. Cars, RV, & Trail - restrict use during haul C. Close 8000-8010 system, after silvicultural procedures, for 10 yrs. Maintain ditch clearance.
Rec	1988	Firewood				
Timber	1998	1430.2 MBF Timber Sale	Same As Above (S.A.A.)	3-6. S.A.A. 7. Reconstruction costs for 8000-8010 road system.	C	A. S.A.A. B. S.A.A. C. Close 8010 Rd - no further timber sales are planned to use this road except for silvicultural mgt. Maintain ditch clearance. Maintain 8000 Rd.
Rec	1998	Firewood				

*OTHER CRITERIA: 3. SAFETY 4. PHYSICAL 5. TRAFFIC 6. VEHICLE 7. ECONOMY

2.1.2.1 Number of Lanes and Lane Width

The majority of forest development road systems in the world are single-lane roads with turnouts. It is anticipated that most roads to be constructed or reconstructed will also be single-lane with turnouts because of the continuing need for low volume, low speed roads and their desirability from economic and environmental impact standpoints. In choosing whether to build a single- or double-lane road, use the best available data on expected traffic volumes, accident records, vehicle sizes, and season and time-of-day of use. Historically, the United States Forest Service has used traffic volumes of approximately 100 vehicles per day to trigger an evaluation for increasing road width from one to two lanes. Considering a day to consist of 10 daylight hours, traffic volumes greater than 250 vehicles per day ordinarily require a double-lane road for safe and efficient operation. Intermediate traffic volumes (between 100 and 250 vehicles per day) generally require decisions based on additional criteria to those listed above: (1) social/political concerns, (2) relationships to public road systems, (3) season of use, (4) availability of funding, and (5) traffic management.

Many of the elements used in such an evaluation, although subjective, can be estimated using traffic information or data generated from existing roads in the area. For instance, if heavy public use of the road is anticipated, a traffic count on a comparably situated existing road will serve as a guide to the number of vehicles per hour of non-logging traffic. Some elements can be evaluated in terms of relative probabilities and consequences and can be identified as having a low, moderate, or high probability of occurrence and having minor, moderate, or severe consequences. The more criteria showing higher probabilities and more severe consequences, the stronger the need for a double-lane road.

2.1.2.2 Road width

The primary consideration for determining the basic width of the roadbed is the types of vehicles expected to be utilizing the road. Secondary considerations are the general condition of the traveled way, design speed, and the presence or absence of shoulders and ditches. Tables 5 and 6 list recommended widths for single- and double-lane roads, respectively.

table 9 Traveled way widths for single-lane roads.

Type and Size of Vehicle	Design Speed (Km/Hr)		
	30	40	50
	Minimum Traveled Way Width (m)		
Recreational, administrative and service vehicle, 2.0 to 2.4 m wide	3.0	3.0	3.6
Commercial hauling and commercial passenger vehicles, including buses 2.4 m wide or greater			
1. Road with ditch, or without ditch where cross slope is 25% or less	3.6	3.6	4.2
2. Roads without ditch where ground cross slope is greater than 25%. The steepness of roadway backslope should be considered to provide adequate clearance.	3.6	3.6	4.2

The presence of a ditch permits a narrower traveled way width since the ditch provides the necessary clearance on one side. Except for additional widths required for curve widening, limit traveled way widths in excess of 4.4 m (14 ft) to roads needed to accommodate off-highway haul and other unusual design vehicles. Double-lane roads designed for off-highway haul (all surface types) should conform to the following standards:

table 10 Lane widths for double-lane roads

Size and Type of Vehicle	Type of Road	Type of Surface	Design Speed (Km/Hr) 15	30	45	60	80
			Minimum Lane Width (m)				
Recreational, adm. and service:							
1. up to 2.0 m wide	Recreation or	All surface	2.7	2.7	3.0	3.3	3.0
2. 2.0 to 2.4 m wide	administrative	types	3.0	3.0	3.3	3.3	3.3
Commercial hauling and comm. passenger vehicles incl. buses	Roads open to truck traffic or mixed	Gravel or native	-	3.3	3.6	3.6	-
2.4 m wide or greater	traffic	Bituminous	-	3.3	3.3	3.3	3.6

Gravel or native surface roads should not have design speeds greater than 60 km/hr
Additional width is required for lower quality surfaces, because of the off-tracking corrections needed compared to a higher quality surface.

Vehicles wider than the design vehicle (a "critical vehicle") may make occasional use of the road. Check traveled way and shoulder widths to ensure that these vehicles can safely traverse the road. Critical vehicles should never attempt to traverse the road at or even approaching the speeds of the design vehicle.

Shoulders may be necessary to provide parking areas, space for installations such as drainage structures, guardrails, signs, and roadside utilities, increase in total roadway width to match the clear width of an opening for a structure such as a bridge or tunnel, a recovery zone for vehicles straying from the traveled way, additional width to accommodate a "critical vehicle", lateral support for outside edge of asphalt or concrete pavements (0.3 m is sufficient for this purpose). The space required for these features will depend on the design criteria of the road and/or the design of specific structures to be incorporated as part of the roadway.

Minimum Width of Traveled Way
for Design Speed

Bunk Width	30 km/hr(20 mph)	50 km/hr (30 mph)	60 km/hr (40 mph)
3 .0m (10 ft)	6.7 m (22 ft)	7.3 m (24 ft)	7.9 m (26 ft)
3.7 m (12 ft)	7.9 m (26 ft)	8.5 m (28 ft)	8.5 m (28 ft)

2.1.2.3. Turnouts

Turnout spacing, location, and dimensions provide user convenience and safety and allow vehicles to maintain a reasonable speed. Spacing can be computed using the following formula and the curves from Figure 7 and Table 7 :

$$T = 1.609*(DS)/36$$

Where: T = Increase in travel time for the interrupted vehicle (percent)
D = Delay time per kilometer for the interrupted vehicle (seconds)
S = Design speed (kilometers per hour).

Solve the equation for T and then use the graph in Figure 7 to determine the turnout spacing required to accommodate the number of vehicles passing over the road per hour (VPH).

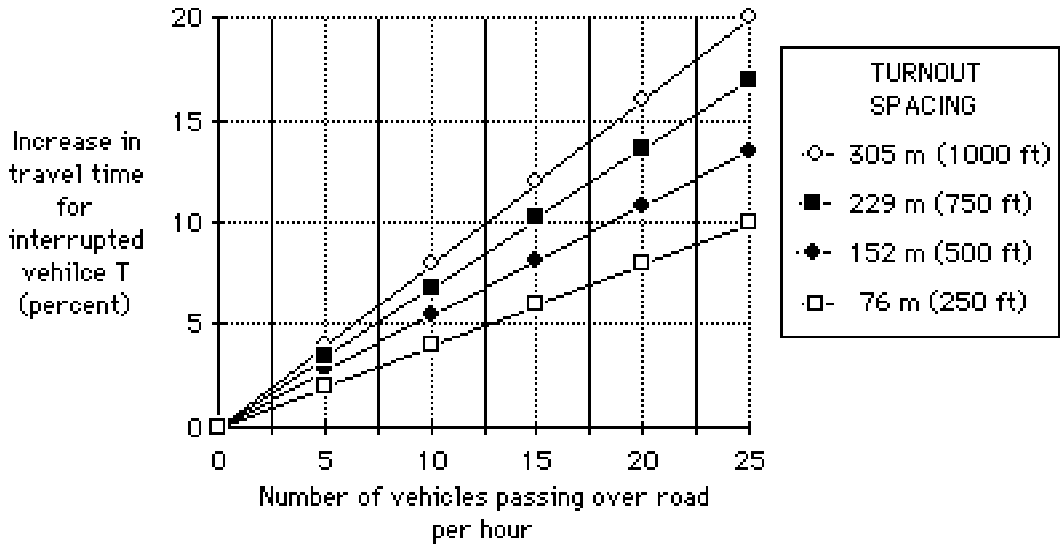

Figure 7. Turnout spacing in relation to traffic volume and travel delay time.

Figure 8 illustrates a typical turnout in detail. Turnouts should be located on the outside of cuts, the low side of fills, or at the runout point between through cuts and fills, and preferably on the side of the unloaded vehicle. Table 8 gives recommended turnout widths and lengths for various traffic service levels. The maximum transition length should be limited to 22.5 m for all service levels.

table 11 Recommended turnout spacing--all traffic service levels

Traffic Service	Turnout Spacing	Operational Constraints
A	Make turnouts intervisible unless excessive costs or environmental constraints preclude construction Closer spacing may contribute to efficiency and convenience. Maximum spacing is 300 m.	Traffic: Mixed Capacity: Up to 25 vehicles per hour Design Speed: Up to 60 km/hr Delays: 12 sec./km or less
B	Intervisible turnouts are highly desirable but may be precluded by excessive costs or environmental constraints. Maximum spacings 300 m.	Traffic: Mixed Capacity: Up to 25 vehicles per hour Design Speed: Up to 40 km/hr Delays: 20 km/hr or less Use signs to warn non-commercial users of traffic to be expected. Road segments without intervisible turn-outs should be signaled.
C	Maximum spacing is 300 m. When the environmental impact is low and the investment is economi-cally justifiable, additional turn-outs may be constructed.	Traffic: Small amount of mixed Capacity: Up to 20 vehicles per hour Design Speed: Up to 30 km/hr Delays: Up to 40 sec./km Roads should be managed to minimize conflicts between commercial and non-commercial users.
D	Generally, only naturally occurring turnouts, such as on ridges or other available areas on flat terrain, are used.	Traffic: Not intended for mixed Capacity: Generally 10 VPH or less Design Speed: 25 km/hr or less Delays: At least 45 sec./km expected. Road should be managed to restrict concurrent use by commercial and non-commercial users.

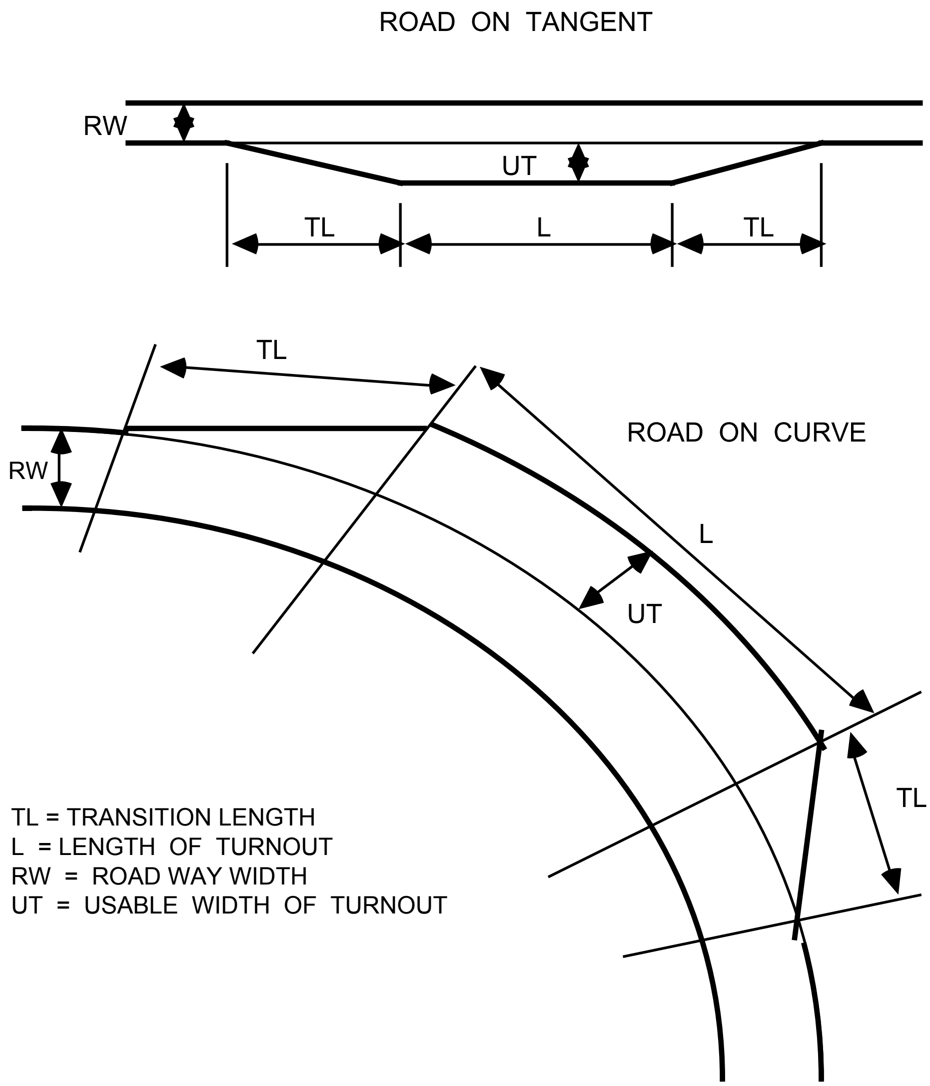

Figure 8. Typical turnout dimensions

table 12 Turnout widths and lengths

Traffic Service Levels	Turnout Width	Turnout Length & Transition Length
A	3.0 m	Design vehicle length or 22.5 m minimum, whichever is largest. Minimum 15 m transition at each end.
B	3.0 m	Design vehicle length. Minimum 15 m transition at each end.
D	Make the minimum total width of the traveled way and turnout the width of two design vehicles plus 1.2 m	Empty truck length (trailer loaded on truck) Minimum 7.5 m transitions at each end.

2.1.2.4. Turn-arounds

Turn-around design should consider both critical and design vehicles and should be provided at or near the end of single-lane roads, and at management closure points, such as gates or barricades. If intermediate turn-arounds are necessary, signing should be considered if they create a hazard to other users. The turn-around should be designed to allow the design vehicle to turn with reasonably safe maneuvering.

2.1.2.5. Curve Widening

Widening may be required on some curves to allow for off-tracking of tractor-trailer vehicles and for some light vehicle-trailer combinations. Widening of the traveled way on curves to accommodate the design vehicle is considered a part of the traveled way. Generally, the need for curve widening increases as curve radius decreases with shorter curves requiring less curve widening than longer curves. Criteria for establishing the need for curve widening given traffic service levels are given in Table 9.

table 13 Curve widening criteria

Traffic Service Level	Curve Widening
A	Design curve widening to accommodate the design vehicle (normally low-boy) at the design speed for each curve. Curve widening for critical vehicles to be provided by the use of other road elements, if planned, such as turnouts and shoulders. Provide widening if needed width is not available. Critical vehicle should be accommodated in its normal traveling configuration. Curve widening to be provided in each lane of double-lane roads.
B	Same as A.
C	Same as A, except the critical vehicle configuration may need alteration.

D Curve widening to be provided only for the design vehicle. Loads carried by the critical vehicle should be off-loaded and walked to the project or transferred to vehicles capable of traversing the road. Temporary widening to permit the passage of larger vehicles may be accomplished by methods such as temporarily filling of the ditch at narrow sections.

2.1.2.6 Clearance

The desired minimum horizontal clearance is 1.2 m (4 ft) the minimum vertical clearance is 4.3 m (14 ft). At higher speeds consideration should be given to increasing the clearances.

2.1.2.7. Speed and Sight Distance

Design speed is the maximum safe speed that the design vehicle can maintain over a specified segment of road when conditions are so favorable that the design features of the road govern rather than the vehicle operational limitations. The selected design speed establishes the minimum sight distance for stopping, passing, minimum radius of curvature, gradient, and type of running surface. Alternative combinations of horizontal and vertical alignment should be evaluated to obtain the greatest sight distance within the economic and environmental constraints. Suggested horizontal curve radius for a packed gravel or dirt road with no sight obstruction is 33 and 62 m (108 and 203 ft) for design speeds of 24 and 32 km/hr (15 and 20 mph), respectively. For curves with a sight obstruction 3 m (10 ft) from the travel way, horizontal curve radii are 91 and 182 m (300 and 600 ft), respectively. Suggested vertical curve length is 61 m (200 ft). Recommended stopping distances for single-lane roads with a maximum pitch of 2 percent (horizontal and vertical control) and traffic service level C or D are:

km/hr (MPH)	Stopping Distance, meters (feet)
16 (10)	21.3 (70)
24 (15)	36.5 (120)
32 (20)	54.9 (180)
48 (30)	94.5 (310)

For a more comprehensive discussion on stopping sight distance and passing sight distance, the reader is referred to the following sources: Route Location and Design, by Thomas F. Hickerson; USDA, Forest Service Handbook #7709.11, "Transportation Engineering Handbook"; Bureau of Land Management, Oregon State Office, "Forest Engineering Handbook"; or "Geometric Design Standards for Low Volume Roads", Transportation Research Board.

2.1.2.8. Horizontal and Vertical Alignment

For low volume roads with design speeds of 24 kph (15 mph) or less, a horizontal alignment that approximates the geometric requirements of circular curves and tangents may be used. Alignment should be checked so that other design elements, such as curve widening and stopping sight distance can be considered. A minimum centerline radius of curvature for roads should be 15 meters (50 ft) except for some recreation and administrative roads. Superelevation should not be used for design speeds less than 32 kph (20 mph). If snow and ice are factors, the superelevation rate should not exceed 6 percent and should be further reduced on grades to accommodate slow truck traffic. Transition segments into and out of superelevated sections should be provided to avoid abrupt changes in the roadway template.

Vertical alignment, or grade, is of critical concern because of its potential for environmental damage and becomes increasingly important for grades exceeding 10 percent. Erosion potential increases as a function of the square of the slope and the cube of water velocity. The most desirable combination of grade and other design elements should be determined early in the road location phase with additional caution exercised when grades exceed 8 percent. Vertical alignment normally governs the speed of light vehicles for grades exceeding 15 percent favorable and 11 percent adverse and of loaded trucks for grades exceeding 8 percent favorable and 3 percent adverse. The ability of a vehicle to traverse a particular grade is dependent on vehicle weight and horsepower and on the traction coefficient of the driving surface.

Travel time and cost are affected by horizontal alignment, such as curve radius and road width. Figure 9 shows the relationship between average truck speed and curve radius for several road widths. For example, there is a 15 percent difference in average truck speed on a 30.5 m (100 ft) radius curve for a 3.7 m wide road when compared to a 4.3 m wide road.

Horizontal alignment has been classified on the basis of curve radius and number of curves. The U. S. Forest Service, for example, uses the following classification system:

[Average radius (m)] / [# of curves / km]

Poor	=	< 4	Good	=	10 - 20
Fair	=	4 - 10	Excellent	=	> 20

The effect of grade on truck speed (loaded and unloaded) is shown in Figure 10. The speed of a loaded truck is most sensitive to grade changes from 0 to 7 percent in the direction of haul. For grades steeper than 7 percent other considerations are more important than impact on speed.

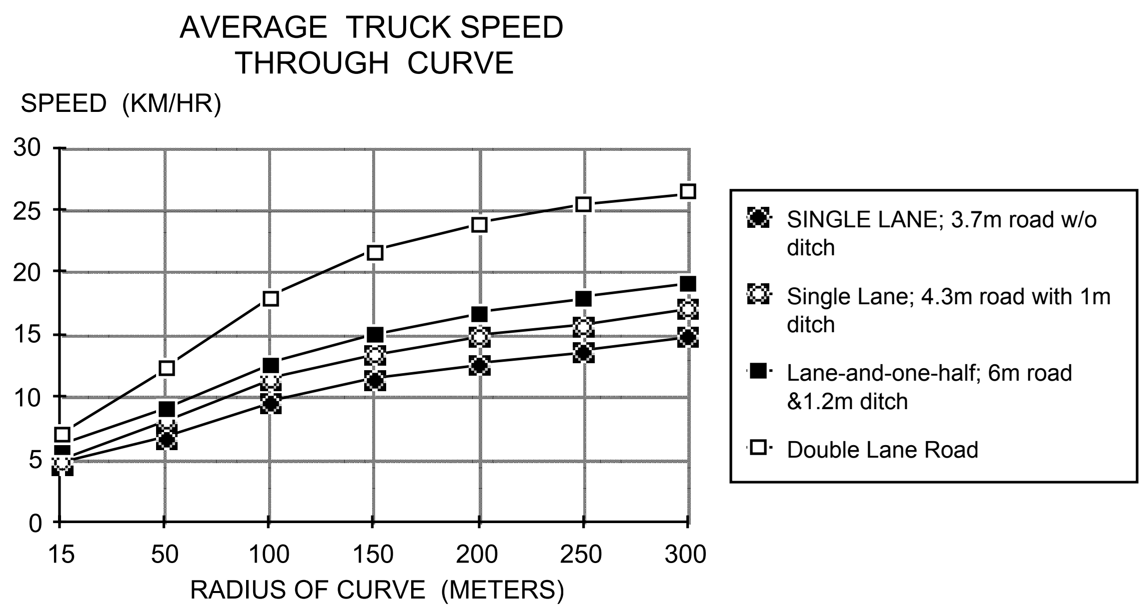

Figure 9. Relationship between curve radius and truck speed when speed is not controlled by grade.

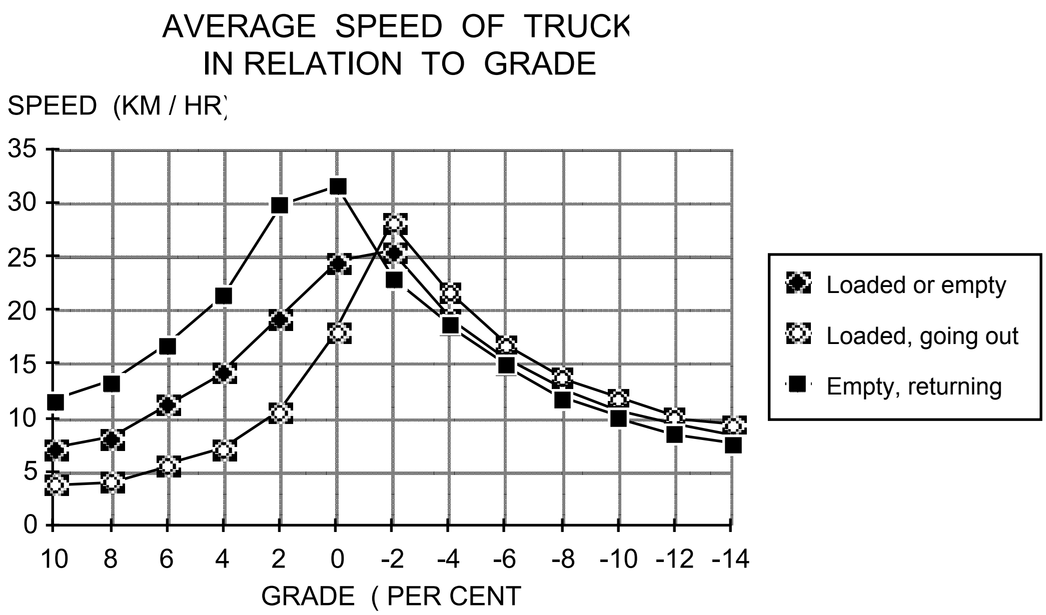

Figure 10. Relationship between grade and truck speed on gravel roads.

2.1.2.9. Travel Time

It is important to emphasize that travel time is influenced by grade, nature of road surface, alignment, roadway width, sight distance, climate, rated vehicle performance, and psychological factors (such as fatigue, degree of caution exercised by driver, etc.). Table 10 shows travel time for loaded and empty trucks over paved, graveled, and dirt surfaces as influenced by vertical and horizontal alignment. The information from Table 10 is helpful in the planning stage to assess the effects of vertical and/or horizontal alignment, road surface and width on travel time and costs. The planned road should be divided up into segments of similar vertical and/or horizontal alignment sections. Average times can be calculated for each segment and/or road class and summed.

table 14 Relationship between round trip travel time per kilometer and surface type as influenced by vertical and horizontal alignment; **adverse grade** in direction of haul (U.S. Forest service, 1965).

Class of Road[1]	Percent Grade in Direction of Load (Adverse)									
	+10	+9	+8	+7	+6	+5	+4		+2	0
	--	--	--	--	min/km	--	--	--	--	--
1. Lane and one-half with turnouts (car lane and truck lane with 4-ft. ditch)[2]:										
A. Alignment excellent:										
1. Paved	7.93	7.28	6.59	5.93	5.28	4.59	3.95	-	2.95	2.42
2. Gravel	8.21	7.56	6.87	6.21	5.53	4.84	4.23	-	3.20	2.42
B. Alignment good:										
1. Paved	7.93	7.28	6.59	5.93	5.32	4.78	4.25	-	3.25	3.01
2. Gravel	8.21	7.56	6.87	6.21	5.57	5.03	4.53	-	3.50	3.01
C. Alignment fair:										
1. Paved	7.93	7.28	6.62	6.12	5.62	5.09	4.56	-	3.61	3.61
2. Gravel	8.21	7.56	6.90	6.40	5.87	5.34	4.84	-	3.81	3.61
2. Single lane with turnouts (truck lane with 3-ft. ditch)[2]:										
A. Alignment excellent:										
1. Paved	7.93	7.28	6.59	5.93	5.28	4.59	4.02	-	3.02	2.58
2. Gravel	8.21	7.56	6.87	6.21	5.53	4.84	4.30	-	3.27	2.58
B. Alignment good:										
1. Paved	7.93	7.28	6.59	5.93	5.38	4.85	4.32	-	3.32	3.20
2. Gravel	8.21	7.56	6.87	6.21	5.63	5.10	4.60	-	3.57	3.20
3. Dirt	8.49	7.81	7.12	6.43	5.85	5.35	4.82	-	4.18	3.20
C. Alignment fair:										
1. Paved	7.93	7.28	6.75	6.25	5.75	5.22	4.68	-	3.89	3.89
2. Gravel	8.21	7.56	7.03	6.53	6.00	5.47	4.97	-	3.94	3.89
3. Dirt	8.49	7.81	7.28	6.75	6.21	5.72	5.18	-	4.15	3.89
D. Alignment poor:										
1. Gravel	8.45	7.95	7.42	6.92	6.39	5.86	5.36	-	4.68	4.68
2. Dirt	8.73	8.20	7.67	7.14	6.61	6.11	5.58	-	4.68	4.68
3. Single lane with turnouts (truck lane without ditch)[2]:										
B. Alignment good:										
3. Dirt	8.49	7.81	7.12	6.45	5.92	5.42	4.88	-	3.85	3.28
C. Alignment fair:										
3. Dirt	8.49	7.93	7.40	6.86	6.33	5.83	5.30	-	4.27	4.08
D. Alignment poor:										
3. Dirt	9.03	8.49	7.96	7.43	6.90	6.40	5.87	-	5.28	5.28

[1] Alignment classification basis:

Poor .... = Average radius (meter) / No. of curves per km = less than 4

Fair .... = do. = 4 to 10

Good .... = do. = 10 to 20

Excellent... = do. = over 20

[2] On single-lane or land-and-one-half roads, increase the time for passing vehicles on turnouts by the percent shown in following tabulation. Consider all vehicles for single-lane roads and only trucks for land-and-one-half roads.

Turnout spacing (meter)	Increased time when number of vehicles passing over road per hour is			
	5	10	15	20
	Percent	Percent	Percent	Percent
75	2.0	4.0	6.0	8.0
150	2.6	5.4	8.0	10.7
225	3.4	6.8	10.2	13.6

table 15 Relationship between round trip travel time per kilometer and surface type as influenced by vertical and horizontal alignment; **favorable grade** in direction of haul (U.S. Forest service, 1965).

Class of Road[1]	Percent Grade in Direction of Load (Favorable)									
	0	-2	-4	-6	-7	-8	-9	-11	-12	-14
	--	--	--	--	min/km	--	--	--	--	--
1. Lane and onehalf with turnouts (car lane and truck lane with 4-ft. ditch)[2]..										
A. Alignment excellent:										
1. Paved	2.42	2.42	2.47	2.89	3.22	3.53	3.87	4.53	4.87	5.59
2. Gravel	2.42	2.42	2.53	2.97	3.31	3.65	3.97	4.62	4.97	5.68
B. Alignment good:										
1. Paved	3.01	3.01	3.01	3.05	3.22	3.53	3.87	4.53	4.87	5.59
2. Gravel	3.01	3.01	3.01	3.13	3.32	3.65	3.97	4.62	4.97	5.68
C. Alignment fair:										
1. Paved	3.61	3.61	3.61	3.61	3.61	3.67	3.87	4.53	4.87	5.59
2. Gravel	3.61	3.61	3.61	3.61	3.61	3.80	3.97	4.62	4.97	5.68
2. Single lane with turnouts (truck lane with 3-ft. ditch)[2]...............										
A. Alignment excellent:										
1. Paved	2.58	2.58	2.58	2.89	3.22	3.53	3.87	4.53	4.87	5.59
2. Gravel	2.58	2.58	2.62	2.97	3.31	3.65	3.97	4.62	4.97	5.68
B. Alignment good:										
1. Paved	3.20	3.20	3.20	3.20	3.34	3.53	3.87	4.53	4.87	5.59
2. Gravel	3.20	3.20	3.20	3.25	3.44	3.65	3.97	4.62	4.97	5.68
3. Dirt	3.20	3.20	3.20	3.31	3.50	3.72	4.06	4.72	5.06	5.75
C. Alignment fair:										
1. Paved	3.89	3.89	3.89	3.89	3.89	3.89	4.02	4.53	4.87	5.59
2. Gravel	3.89	3.89	3.89	3.89	3.89	3.95	4.11	4.62	4.97	5.68
3. Dirt	3.89	3.89	3.89	3.89	3.89	4.02	4.20	4.72	5.06	5.75
D. Alignment poor:										
2. Gravel	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.88	5.07	5.68
3. Dirt	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.98	5.17	5.75
3. Single lane with turnouts (truck lane without ditch)[2]...............										
B. Alignment good:										
3. Dirt	3.28	3.28	3.28	3.33	3.52	3.72	4.06	4.72	5.06	5.75
C. Alignment fair:										
3. Dirt	4.08	4.08	4.08	4.08	4.08	4.09	4.28	4.72	5.06	5.75
D. Alignment poor:										
3. Dirt	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.47	5.82

[1] Alignment classification basis:

Poor .... = $\frac{\text{Average radius (meter)}}{\text{No. of curves per km}}$ = less than 4

Fair .... = do. = 4 to 10

Good .... = do. = 10 to 20

Excellent .. = do. = over 20

[2] On single lane or lane-and-one-half roads, increase the time for passing vehicles on turnouts by the percent shown in following tabulation. Consider all vehicles for single-lane roads and only trucks for land-and-one-half roads.

Turnout spacing (meter)	Increased time when number of vehicles passing over road per hour is			
	5	10	15	20
	Percent	Percent	Percent	Percent
75	2.0	4.0	6.0	8.0
150	2.6	5.4	8.0	10.7
225	3.4	6.8	10.2	13.6

2.2 Economic Evaluation and Justification

2.2.1 Economic Analysis Methods

A long-range plan, including road planning, is the basis for an economically, as well as environmentally, sound road system. A well planned road system will result in the least amount of roads to economically serve an area or watershed. It will also result in the least amount of sediment delivery to streams as shown in Figure 1.

The first step in road access planning is to determine the optimum road spacing for a given commercial use. A break-even analysis can often be applied. Plotted graphically, the optimum spacing would lie at the minimum total cost, or the intersection of the cost lines. Additional information can be found in Pearce (1960), Dietz et al (1984), von Segebaden (1964), and others.

An economic evaluation of a particular road standard will require a rough estimate of road construction costs be determined from road design data and from locally available cost information for the various cost components. Likewise, annual maintenance cost per kilometer of road is best estimated based on local experience for comparable roads. Trucking cost data will consist of the average cost per round-trip kilometer of haul over the road and would take into consideration travel time (see Section 2.1), fixed costs (depreciation, interest, insurance, etc.), operating costs per minute driving time (fuel, lubrication, repairs), dependent costs per minute driving time plus delay time (driver's wage, social security tax, unemployment compensation, administration), and tire cost per mile by surface type.

The combined annual costs of road construction, maintenance, and trucking make up the annual cost:

$$A = R + I + M + T$$

where A is total annual cost per kilometer, R is annual cost per kilometer of road construction for the amortization period, I is average annual interest cost, M is annual maintenance cost per kilometer, and T is average trucking cost per kilometer for the annual commodity volume to be hauled over the road.

EXAMPLE:
Assume the following costs (in US dollars) have been estimated for three classes of road. (Annual volume of commodity, 10 million cubic meters.)

ROAD CLASS	I	II	III
Construction cost per kilometer	$40,000.00	$22,000.00	$15,000.00
Maintenance cost per kilometer	300.00	400.00	500.00
Trucking cost per 1,000 m^3 per kilometer	0.25	0.30	0.35
Trucking cost per annum per kilometer	2,500.00	3,000.00	3,500.00
<u>Annual cost per km over 25 years</u>			
R road construction cost	1,600.00	880.00	600.00
I interest costs	700.00	383.00	262.00
M maintenance cost	300.00	400.00	500.00
T trucking cost	2,500.00	3,000.00	3,500.00
A Total Annual Costs	$5,100.00	$4,663.00	$4,862.00

(If amortization period is 25 years, the annual rate is 4 percent of the construction cost. If the interest rate is 3.5 percent, the average annual interest rate is 1.75 percent.)

Note that in the above calculation the Class II road is the most economical by a margin of $199.00 over the Class III road. Over the period of amortization of 25 years, the margin for the Class II road will be $4,975.00 per kilometer.

Another method in choosing the most economical of two road standards is to calculate the annual amount or volume of commodity at which the costs of the two roads will be equal. If annual volume exceeds the calculated amount the higher road standard will be justified; likewise, if annual volume is less than the calculated amount, the lower standard is justified. The formula for calculating V is:

$$V = \frac{(R + I + M)_H - (R + I + M)_L}{T_L - T_H}$$

The subscripts H and L indicate high and low standard, respectively, and T is expressed as cost per 1000 m^3 per kilometer. All other values are expressed in units stated above.

EXAMPLE

Using the same costs as in the previous example for the Class II and Class III road, the annual volume is calculated as:

$$V = \frac{(880 + 383 + 400) - (600 + 262 + 500)}{(0.35 - 0.30)} = 6{,}020 \times 10^3\ m^3$$

Hence, for volumes exceeding $6.02 \times 10^6\ m^3$ the Class II road is the more economical choice; for volumes less than $6.02 \times 10^6\ m^3$ the Class III road would be chosen. If the two roads differ in length, multiply the costs per kilometer by the number of kilometers of each road for use in this formula.

2.2.2 Analysis of Alternative Routes

The above formulas can also be used to evaluate two or more alternatives to a proposed route. One common situation is to choose between a longer route on a gentle favorable grade and a shorter route involving an adverse grade and a steeper favorable grade.

EXAMPLE.

1. Longer route segment: 3.67 km of 3% favorable grade. Trucking cost = $.562 per 1000 m^3; construction cost $55,050 at 6% amortization plus interest = $3,303; annual maintenance at $300/km = $1,101. Total annual cost = $4,404.

2. Shorter route segment: 2.0 km of 8% favorable grade, 1 km of 5% adverse grade. Trucking cost = $.81 per 1000 m^3; construction cost $41,000 at 6% amortization plus interest = $2,460; annual maintenance at $400/km (steeper grade, sharper curves) = $1,200. Total annual cost = $3,660.

$$V = (4{,}404 - 3{,}660)/(0.81 - 0.562) = 3 \times 10^6\ m^3$$

(According to the formula, the longer route will be the more economical if the annual volume hauled exceeds 3 million cubic meters.)

In justifying the added capital investment to achieve greater road stability the risk of potential cost of a road failure must also be weighed in the balance. This type of risk analysis is commonly done when determining culvert size for a particular stream crossing. The probability of occurrence of a peak flow event which would exceed the design capacity of the proposed culvert installation must be determined and incorporated into the design procedure. The 1964-65 winter season floods occurring throughout the Pacific Northwest Region of the United States have been classified as 50- to 100-year return interval events. ("Return interval" is defined as the length of time that a storm event of specified magnitude would be expected to reoccur. A 50-year event, therefore, would be expected to occur, on the average, once every 50 years.) Damages to transportation structures (roads, bridges, trails) in Oregon was estimated at $12.5 million, or, 4 percent of the total investment of $355 million not including destruction of stream habitat, water quality, private property, and "down time" and other inconveniences associated with these losses.

As mentioned earlier in this handbook, constructing roads specifically to control erosion may not cost any more than constructing roads using conventional methods. The money invested to achieve satisfactory levels of stability while still meeting design criteria will generally be recouped over the life of the road in reduced maintenance costs, serviceability, longer life, and reduced impacts on stream habitat and water quality. The goal of fitting roads to the terrain and adopting appropriate road standards to achieve that goal will often result in reduced earthwork per station.

Incremental costs for roads built to high standards of construction (compacted fills, surface treatments, terraced fills, etc.) associated with the amount of reduction of sediment yield is difficult to generate since such wide variability exists in equipment and labor costs, environmental factors (such as soil erodibility), and operator skill. Gardner (1971) has developed some rudimentary data for comparing annual road costs for single and double lane roads with differing surface treatments depreciated over 20 years and using 6 percent capital recovery. The author suggests that user cost for environmental protection is represented as the difference in annual cost between two-lane paved and one-lane gravel roads in Table 11. More detailed comparisons of annual cost per km at different user levels is presented in Tables 12 and 13.

table 16 Comparison of single-lane versus double-lane costs at three different use levels.

Number of Vehicles per year	Total annual cost per kilometer 1 lane gravel	 2 lane paved	 Difference
	--------------------US Dollars --------------------		
10,000	3,440	4,200	-760
20,000	5,800	5,690	+112
40,000	10,530	8,680	+1,790

table 17 Comparison of annual road costs per kilometer -- 10,000 vehicles per year.

Cost distribution	2 lane paved	2 lane chip-seal	2 lane gravel	1 lane gravel	1 lane spot stabilization	1 lane primitive
	Road Standard					
	----------------Dollars per kilometer-------------------					
Initial Construction	$31,070	$24,860	$18,640	$12,430	$9,320	$6,210
	--------Dollars per kilometer per year (20-year period)-------					
Depreciation[1]	2,710	2,170	1,620	1,080	810	540
Maintenance	120	250	370	500	680	310
Vehicle use	1,370	1,430	1,680	1,860	2,730	5,280
Total annual	4,200	3,850	3,670	3,440[2]	4,230	6,130

1 20 years at 6% using capital recovery.

2 Lowest annual cost.

table 18 Comparison of annual road costs per kilometer for 20,000 and 40,000 vehicles per year

Cost distribution	2 lane paved	2 lane chip-seal	2 lane gravel	1 lane gravel	1 lane spot stabilization	1 lane primitive
	Road Standard					
	----------------Dollars per kilometer-------------------					
Initial construction	31,070	24,860	18,640	12,430	9,320	6,210
	--------Dollars per kilometer per year (20-year period)------- 20,000 vehicles per year					
Depreciation[1]	2,710	2,170	1,620	1,080	810	540
Maintenance	250	500	750	1,000	1,370	620
Vehicle use	2,730	2,860	3,360	3,730	5,470	10,560
Total annual	5,690	5,530[2]	5,730	5,810	7,650	11,720
	--------Dollars per kilometer per year (20-year period)------- 40,000 vehicles per year					
Depreciation	2,710	2,170	1,620	1,080	810	540
Maintenance	500	1,000	1,490	1,990	2,730	1,240
Vehicle use	5,470	5,720	6,710	7,460	10,940	21,130
Total annual	8,680[2]	8,890	9,820	10,530	14,480	22,910

1 20 years at 6% using capital recovery.

2 Lowest annual cost.

Gardner (1978) analyzed alternative design standards and costs in addition to observing the initial performance of the experimental road and its esthetic acceptability. Alternate design features included reducing road width to a level that would accommodate the tracks of the proposed yarding equipment (3.81 m (12.5 ft)), treating slash by chipping and scattering below the toe of the fill, using turnouts only when the terrain was favorable thus keeping road widths to a minimum, creating stepped backslopes (Figure 11) where bedrock competence was good and planting shrubs and grasses with and without straw mulches, and, finally, incorporating neoprene down- spouts below culverts to dissipate energy and protect the road prism. Sections I and II of the experimental road had the following characteristics:

	Average grade (percent)	Average curve radius (meters)	# curves / km (mi)
Section I	7.26	25.00	12.1 (19.4)
Section II	5.90	19.30	10.8 (17.4)

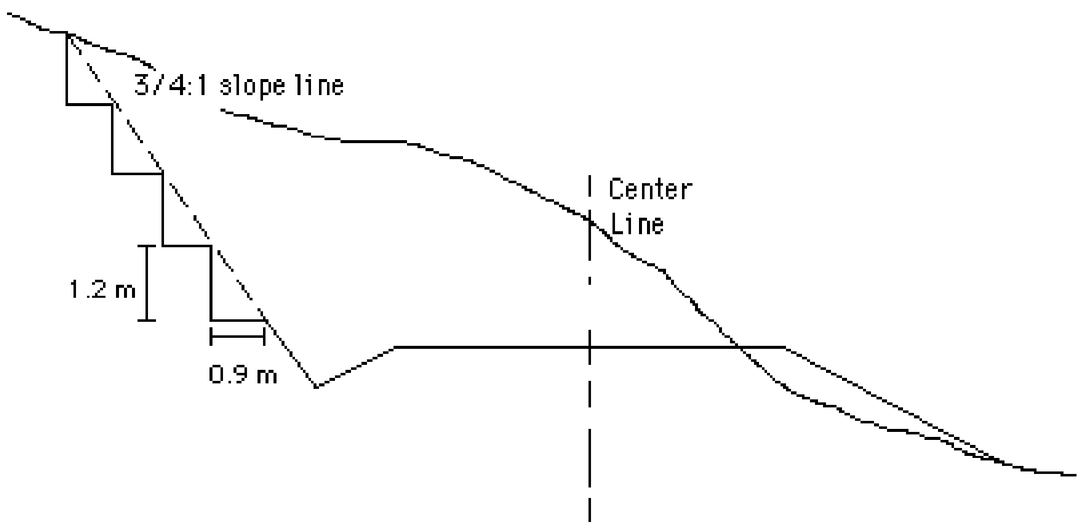

Figure 11 Stepped backslope (no scale).

Gardner found that using 1/10:1 backslopes and reducing clearing widths in the experimental road saved approximately $4,333 in construction cost and had no adverse effect on logging or hauling cost (Table 14). The effects on harvesting costs were not analyzed in this study.

table 19 Cost summary comparison (5 vehicles per hour--1/2 logging trucks, 1/2 other traffic); assumes 8-hour hauling day, 140 days/year use, 20 year road life, 23.8 m^3 (6.0 M bd. ft.) loads for logging trucks, cost of operating logging trucks including driver's wage--$0.25/min, cost of operating other vehicles--$0.04/minute, 5,535 m^3 (1 1/2 MM bd. ft.) timber harvested. (Gardner, 1978)

Road standard*	Annual amortized difference in cost	Annual difference hauling cost	Annual difference other traffic	Net difference
		-------------------Dollars----------------------		
Experimental	0			
III	+1,842.99	-3,187.65	-431.20	-1,775.86
IV	+11,790.22	-15,287.59	-2,371.60	-5,868.97

* Experimental road: single lane, 4.27 m (14 ft) width, 24.1 kph (15 mph) design speed, 0.91 m (3 ') ditch.
III road: single lane, 4.88 m (16 ft) width, 27.4 km/hr (17 mph) design speed, 0.91 m (3 ft) ditch.
IV road: double lane, 7.32 m (24 ft) width, 38.6 km/hr (24 mph) design speed, 1.22 m (4 ft) ditch.

Table 14 indicates that any environmental values gained by the construction of the experimental road would cause little economic sacrifice at vehicle use levels of 5 per hour. At higher use levels, however, the trade-offs become more significant and decisions regarding standards become more difficult.

2.3 Route Reconnaissance and Location

Keep in mind that a bad road in a good location is preferable to a good road in a bad location. A bad road can nearly always be fixed. However, no amount of quality survey or design work can correct any significant location error. For instance, a road constructed across a steep headwall area is more likely to intercept surface and subsurface water flow and has a far greater potential for failure than a road constructed along the ridgeline above the headwall. Since excess moisture is nearly always associated with landslides, it is always best to avoid drainage areas where water is expected to collect. Some important factors to remember when locating roads include:

1. Avoid high erosion hazard sites, particularly where mass failure is a possibility.

2. Utilize natural terrain features such as stable benches, ridgetops, and low gradient slopes to minimize the area of road disturbance.

3. f necessary, include short road segments with steeper gradients to avoid problem areas or to utilize natural terrain features.

4. Avoid midslope locations on long, steep, or unstable slopes.

5. Locate roads on well-drained soils and rock formations which dip into slopes rather than areas characterized by seeps, highly plastic clays, concave slopes hummocky topography, cracked soil and rock strata dipping parallel to the slope.

6. For logging road, utilize natural log landing areas (flatter, benched, well-drained land) to reduce soil disturbance associated with log landings and skid roads.

7. Avoid undercutting unstable, moist toe slopes when locating roads in or near a valley bottom.

8. Roll or vary road grades where possible to dissipate flow in road drainage ditches and culverts and to reduce surface erosion.

9. Select drainage crossings to minimize channel disturbance during construction and to minimize approach cuts and fills.

10. Locate roads far enough above streams to provide an adequate buffer, or provide structure or objects to intercept sediment moving downslope below the road.

11. If an unstable area such as a headwall must be crossed, consider end hauling excavated material rather than using sidecast methods. Avoid deep fills and compact all fills to accepted engineering standards. Design for close culvert and cross drain spacing to effectively remove water from ditches and provide for adequate energy dissipators below culvert outlets. Horizontal drains or interceptor drains may be necessary to drain excess groundwater.

2.3.1 Road Reconnaissance

Erosion and sedimentation rates are directly linked to total road surface area and excavation. The closer the road centerline follows the natural topographic contour, the smaller the erosional impact will be. On low-volume roads it is permissible and even advisable to use non-geometric alignment standards, or the "free alignment method". The beauty of this system is its ability to permit design decisions to be made in the field while allowing for tighter control in areas with critical grades and alignments such as draws, switchbacks, steep topography, or ridges, and less control in areas where resource risks are minimal. Clearing and excavation quantities are substantially reduced compared to conventional geometric alignment methods. More time is spent "on the ground" in the road location step and preliminary survey so that major alignment changes are not necessary during the design phase.

The road locator runs two types of tag or grade line. On more gentle ground the tag or grade line follows closely, or is identical to the proposed road centerline (Figure 12).

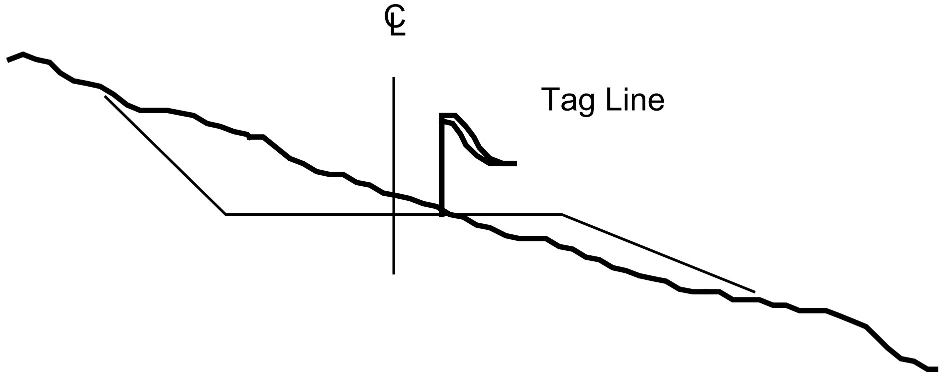

Figure 12. Tag line location and centerline location of proposed road. Sideslopes are typically less than 40 to 50 percent.

On steeper ground where heavy cuts on centerline are required (sideslopes greater than 50 to 60 percent), the tag line is marked on the "grade-out" or "daylight" point (Figure 13).

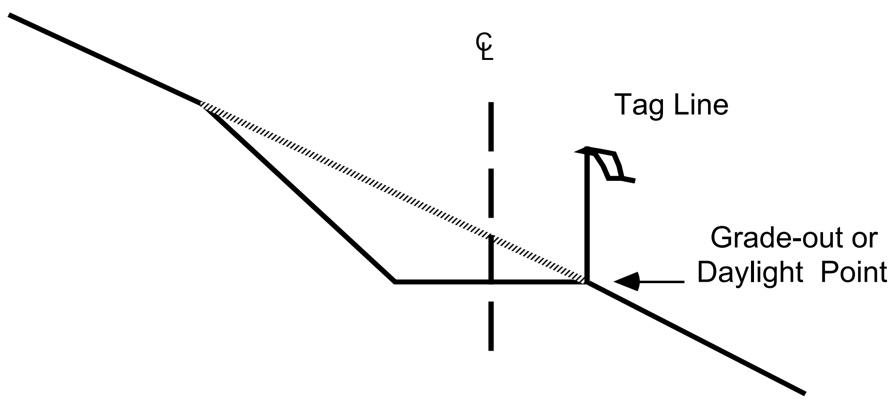

Figure 13. Tag line location and centerline location of proposed road. Sideslopes are typically 50% or steeper.

The following procedure has been proven to be successful for direct location of the centerline. First, the tag line is run with abney or clinometer. Tags, flagging, or ribbons are hung at eye level (approximately 150 to 170 cm) above ground. The ribbon should be intervisible and hung every 15 to 25 m depending on topography and vegetation density. Once a satisfactory tag line has been established, a second pass is made marking tangents and points of intersection (PI) of tangent (Figure 14).

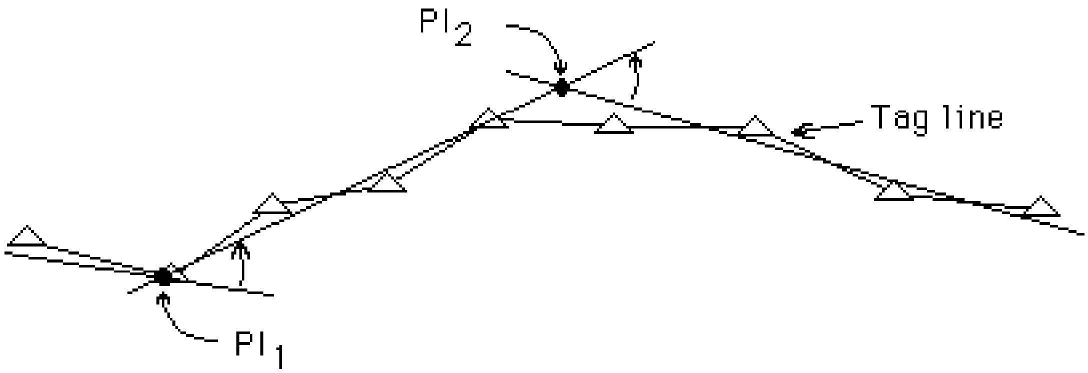

Figure 14. Selection of the road alignment in the field by "stretching the tag line"; This "stretched", or "adjusted"tag line is surveyed and represents the final horizontal location of the road.

It is good practice to cut a pole of sufficient height with brightly colored flagging to be placed at the proposed PI. This allows the road locator to clearly see the proposed tangent in relation to the marked tag line. By moving the tag ribbon horizontally "on-line" with the tangent, the road locator can evaluate the required cut/fill at centerline (Figure 15). Likewise, he can measure the deflection angle at the PI, and, based on the selected curve radius, determine the suitability of centerline location along the curve. As a rule, the selected tangent should be uphill for the majority of the ribbons marking the tag line. The longer the tangents are, the larger the offset will be and the greater the impact from cuts and fills. Therefore, on low volume, low design speed roads, short tangents should be favored in order to minimize earthwork. For example in Figure 14 an additional tangent could be inserted near the PI 2. As shown in Figure 15, still closer proximity of the tag line to the selected road centerline would result.

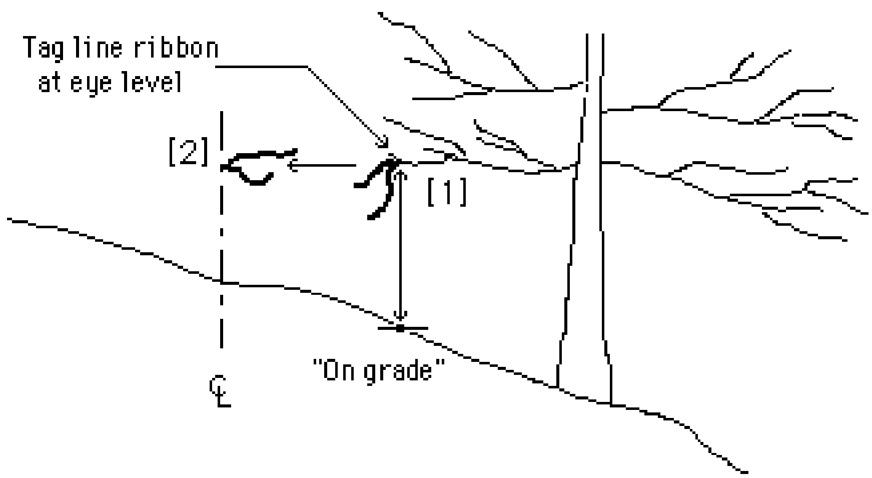

Figure 15. Position [1] shows tag line ribbon at approximately eye-level. The feet of the road locator are "on grade". Position [2] shows the ribbon on-location over the centerline or tangent as selected in the field after stretching. The ribbon has been moved horizontally, thereby allowing an estimate of required cut or fill at centerline.

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Tag lines in the field should always be run 1 or 2 percent less than the allowable maximum grade. For example, if a projected road on the map shows 10 percent grade, the road locator should use 8 or 9 percent in the field. The final design grade of the proposed road will likely be 1 or 2 percent steeper than the tag line grade in the field.

Tag line grades around sharp-nosed ridges or steep draws should be reduced, or preferably located along the proposed curve. Otherwise, the designed centerline will be significantly shorter than the marked tag line, resulting in an unacceptably steep design grade (Figure 16).

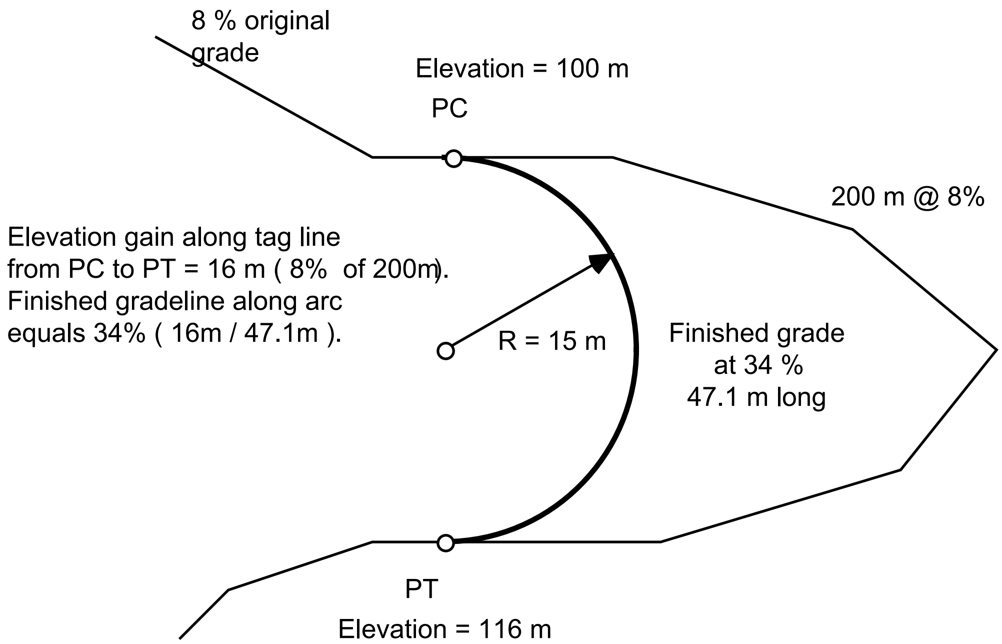
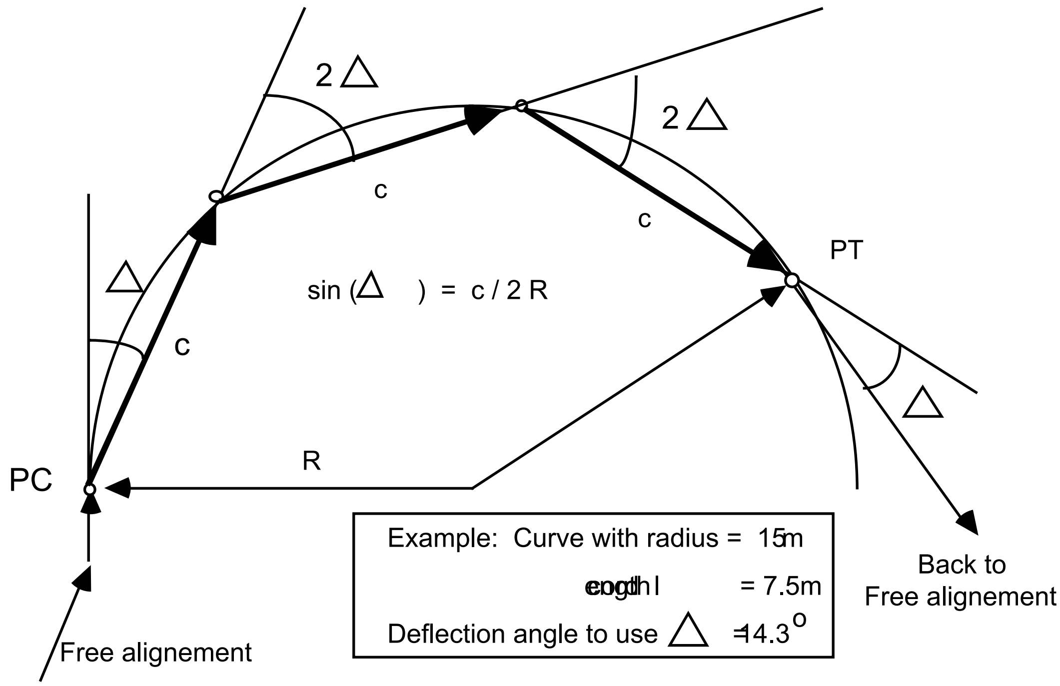


Figure 16. Example of the effect of shortened centerline through a draw or around a sharp ridge. This situation develops when running the tag line into the draw or around a sharp ridge without allowing for proper curve layout and design location.

In such cases, the tag line should be set "on location"by setting curve points using the deflection method (Figure 17). The points are selected with hand compass by turning the appropriate deflection angle and measuring the corresponding chord length.



Note: Following deflection angles are double the first deflection angle

Figure 17. Curve layout by deflection method, a useful approach during the original road location phase.

By setting the ribbon to the corresponding grade percent, the road locator can immediately evaluate the effect of his decision. Table 15 lists some convenient deflection angles and cord lengths for various curve radii.

table 20 Deflection angles for various chord lengths and curve radii.

Radius of curve (meters)	Deflection per meter	Chord Lengths c (meters)		
		5	7.5	10
degrees / meter	Deflection Angles (degrees)*			
15	1.9	9.6	14.3	19.1
20	1.4	7.2	10.7	14.3
25	1.15	5.7	8.6	11.5
30	0.96	4.8	7.2	9.6
35	0.82	4.1	6.2	8.2

* First deflection angle; subsequent deflection angles in layouts are double the indicated value

The following techniques during tag line installation should be followed to avoid increased final design grades:

1. In the case of steep draws, run the desired grade into the draw until the opposite hillside is at a distance equal to twice the minimum radius. Now, sight across the draw at zero grade, find that point on the other hillside and continue from that point with the original grade (Figure 18).

2. In the case of sharp ridges, the procedure is similar. Find the starting point for the curve. At that point, lay the tag line at zero percent around the ridge until you are opposite your beginning point and at the desired ending point for the curve. At this point resume your original grade.

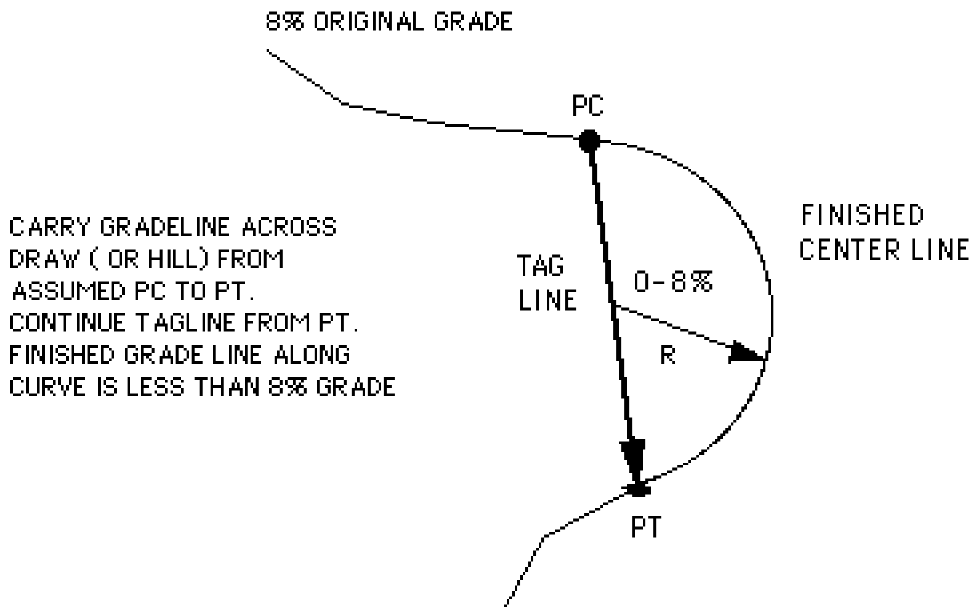


Figure 18. By sighting across draw at 0 percent grade, the desired curve is laid out without increasing the grade.

For more information on reconnaissance and road location procedure, the reader is referred to Forest Engineering Handbook (1960), by J. K. Pearce.

Location of switchbacks requires careful location in the field in order to minimize impacts on travel (excessive grades) as well as on road construction (excessive cuts and fills). As a rule, grades through a switchback at centerline should not exceed 6 to 8 percent. Because of the shortened distance along the inside road edge, the grade there will typically be 2 to 3 percent steeper. The result is that inside truck wheels will start to slip causing a "wash-board" effect. Likewise, increased erosion and sedimentation rates will result because of the continued spinout of the traction wheels. The grade along the inside edge of the road can be calculated by the following formula:

$$Grade_{R_i} = Grade_{CL} * \frac{R_{CL}}{R_{CL} - \frac{W}{2}} \quad \frac{\Delta}{180}$$

where

$Grade_{R_i}$ = grade along the inside road edge

$Grade_{CL}$ = grade along the center line of the road

R_{CL} = radius of curve to center line

Δ = deflection angle at PI

W = road width

Example: A switchback has a grade at centerline of 8 %. The deflection angle measures 160 degrees and road width (travelled width) is 3.6 meters. Additional curve widening of 1.5 meters is required on the inside of the switchback.

What is the grade along the inside edge of the road?

$Grade_{CL}$ = 8 %

Δ = 160°

R_{CL} = 10 m

W = 3.6 m

$$R_{CL} - \frac{W}{2} - \text{additional widening} = 6.7 \text{ m}$$

$$Grade_{R_i} = 8 * (10/6.7) * (160/180) = 10.6 \%$$

The grade along the inside would be 10.6%, considerably higher than what is desirable.

Several steps can be taken to minimize the impact of excessive grade. If the grade cannot be reduced through a larger radius, for example, adequate surface material should be used that can withstand the added tire action and provide enough traction to prevent spinout. Switchbacks should not be located on slopes in excess of 35 percent because of the excessive amount of earthwork required. Natural topographic features, such as benches, saddles, or ridge tops should be used for locating switchbacks. The following example illustrates the effect of slope on cuts and fills (Figure 19):

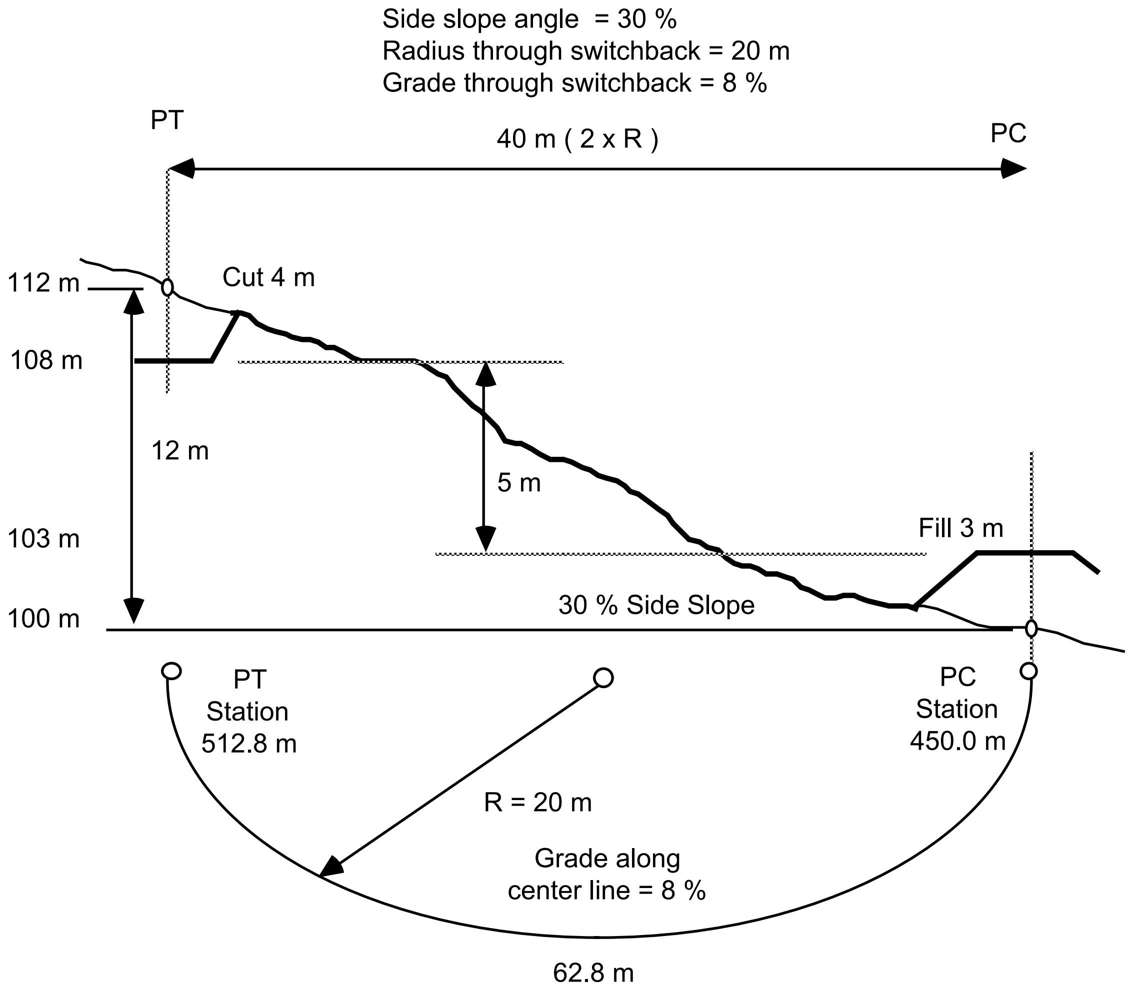


Figure 19. Cut and fill apportioning through a switchback to maintain a given grade.

From this it follows that an elevation difference (DE) of 12 m has to be overcome between the PC (beginning point) and PT (ending point) of the switchback. However, road length along centerline is 20 * π = 62.8 m. The required grade of 8 % along 62.8 m overcomes only 5.0 m of the total DE of 12 m. Therefore, 7 m (12 m - 5 m) have to be made up through either cuts or fills. Local conditions would dictate how the 7m would be apportioned between cuts and fills. (For example, 4 m of cut at the PT and 3 m of fill at the PC would be required to overcome the elevation difference on a 30 percent sideslope.). As a general rule "cutting" or excavation should be favored over filling or embankments. Proper fills are more difficult to construct than excavations.

2.3.2 Faults

Alternative routes should be carefully reviewed in the office and at the site, utilizing all available background information and technical expertise. Among the most useful tools available to the road engineer is a recent set of aerial photos. These must be of a scale small enough to reasonably identify surface features such as natural drainage characteristics, topographic characteristics (ridgelines, slope gradients, floodplains, wet areas, landslides), existing cultural features (roads, buildings, etc.), vegetation or stand type and density, bare soil areas, and geologic features such as faults.

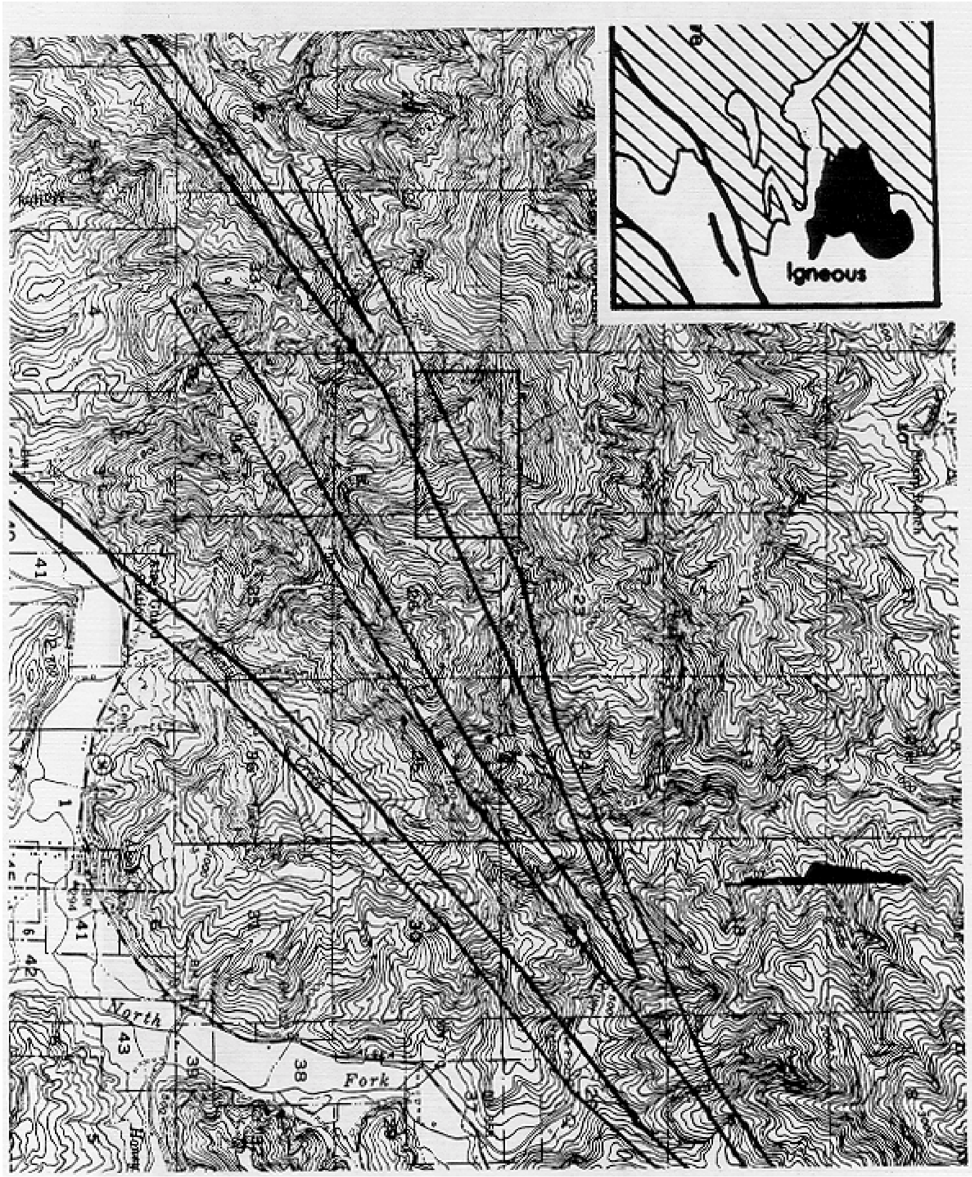


Figure 20. Suspected fault zones are indicated by the alignment of saddles in ridges and by the direction of stream channels. Geologic map is found in upper left corner. Major faults are shown as heavy dark lines on geologic maps (Burroughs,et al.,1976)

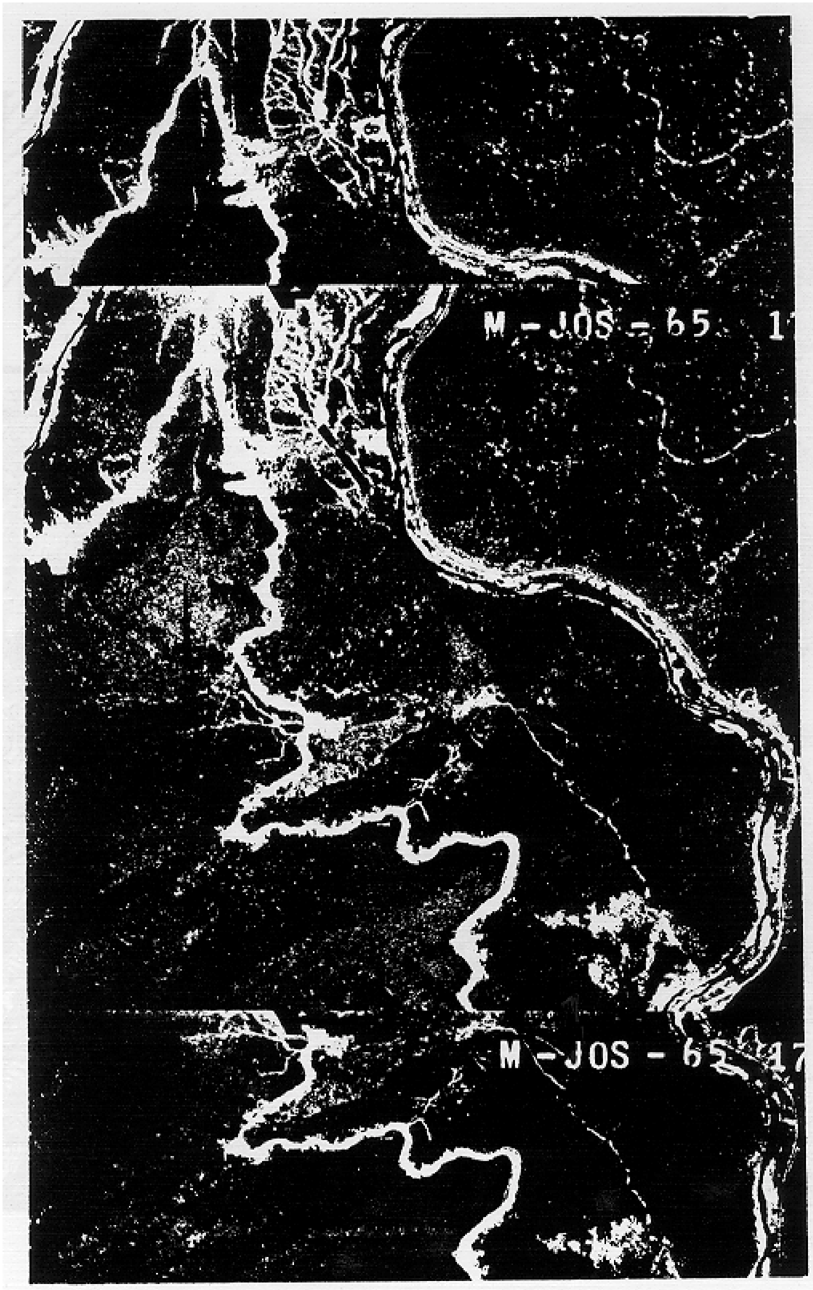


Figure 21. Stereogram of a possible fault zone. The location of the fault is indicated by the dashed line through the low saddle between the large, older slump at A and the newer slope failure at B (Burroughs, et al.,1976).

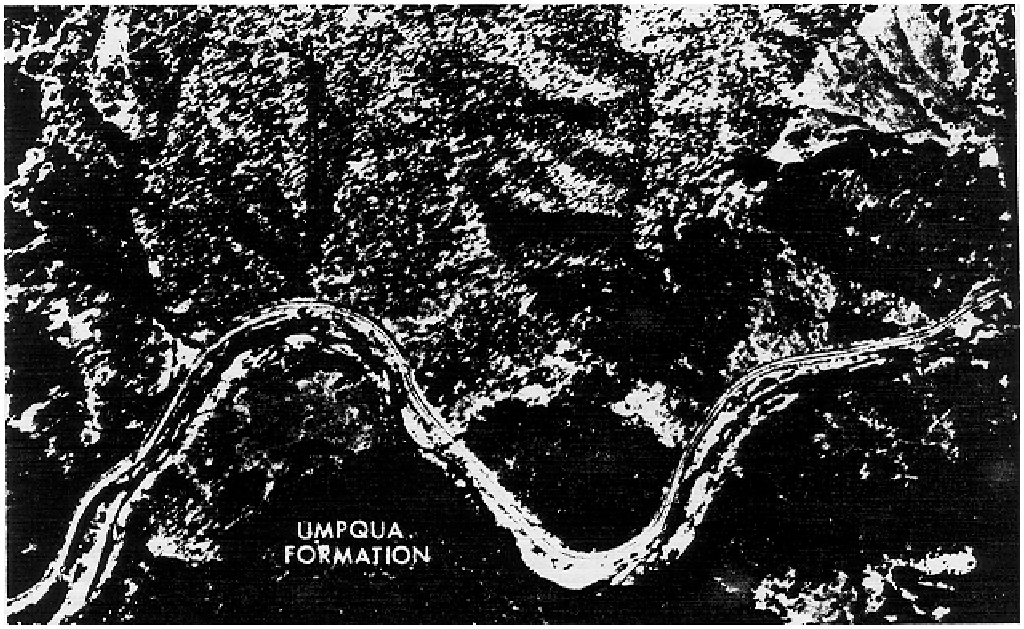


Figure 22. Approximate boundary between serpentine (metamorphic rock) material and the Umpqua formation is shown by the dashed line. The determination is based primarily on the basis of vegetation density. Timber on portions of the Umpqua formation have been harvested which accounts for a reduction in vegetation density, particularly in the northwest corner of the photo. (Burroughs, et al., 1976)

Many of the geologic features that affect slope stability can be detected in the field and on topographic maps and photos. Mountain ranges will often indicate a pronounced directional trend in which faulting can be identified. Since faults are focal points for stress relief and for intrusions of igneous and metamorphic rocks, these zones usually contain rock that is fractured, crushed, partially metamorphosed, or highly weathered and are critical to road location. (Burroughs, et al., 1976) Overlaying geologic maps with topographic maps often reveals the location of major fault zones (Figure 20). Indicators of fault zones include saddles, or low sections in ridges, which are aligned in the same general direction from one drainage to another and streams that appear to deviate from the general direction of nearby streams. Aerial photographs can be examined for clues to possible fault zones when neither geologic nor topographic maps can provide assistance or are unavailable. Figure 21 is a stereogram of an area in southwest Oregon and indicates a possible fault zone that passes through several saddles and begins and ends in the river channel. A large old slide is indicated at A and a newer slide at B. Maps and photos will also provide clues as to the relative engineering properties, or competence, of rocks in the area.

Geologic maps and topographic maps can help locate boundaries between geologic materials with different values of competence and resistance to weathering. Changes in vegetation patterns on aerial photos can also help in identifying such boundaries (Figure 22). Field personnel should be alert for on-the-ground indicators of faulting --fractured and uptilted rock and individual rocks with "slickensides", or shiny surfaces resulting from the intense heat developed by friction on sliding surfaces within the fault zone.

2.3.3 Indicators of Slope Stability

Certain features can serve as indicators of potential slide-prone areas. With some practice, these can be easily identified in the field.

Hummocky topography. This type of landscape generally contains depressions and uneven ground that has resulted from continued earthflow or slumping. Some areas that are underlain by particularly incompetent parent material, deeply weathered and subject to heavy rainfall, show a characteristically hummocky appearance (Figure 23). "Sag ponds (areas of standing water),seeps,and springs are often found within these areas. Certain plant species, called hydrophytes, frequently indicate the presence of groundwater near the surface and potential instability.

Pistol-butted, tipped and "jackstrawed" trees. Pistol-butted trees were tipped downslope while small as a result of sliding soil or debris, or as a result of active soil creep. As the tree grew, the top regained a vertical posture. These are good indicators of slope instability in areas with climates dominated by rain; deep heavy snowpacks at high elevations may also cause pistol-butting. Tipping and jackstrawed or "crazy" trees that lean at many different angles within the stand indicate unstable soils and actively moving slopes.

Tension cracks or "cat steps". Soil movement builds up stresses in the soil mantle which are sometimes relieved by tension cracks. These features may be hidden by vegetation but are a definite indicator of active movement.

Soil mottling. When groundwater is present intermittently within the soil mantle, the iron compounds present in the soil will oxidize to form distinctive orange or red spots. If groundwater levels are more persistent throughout the rainy season, iron reduction occurs giving the soil profile a gray or bluish-gray color. The occurrence of these "gleyed" soils indicates a soil that is saturated for much of the year. The presence of mottles alone is not an indication of instability, but together with other indicators such as those described can point to the need for special consideration in the location and design of a road. They often point to the need for drainage and/or extra attention to the suitability of a subsoil for foundation material.

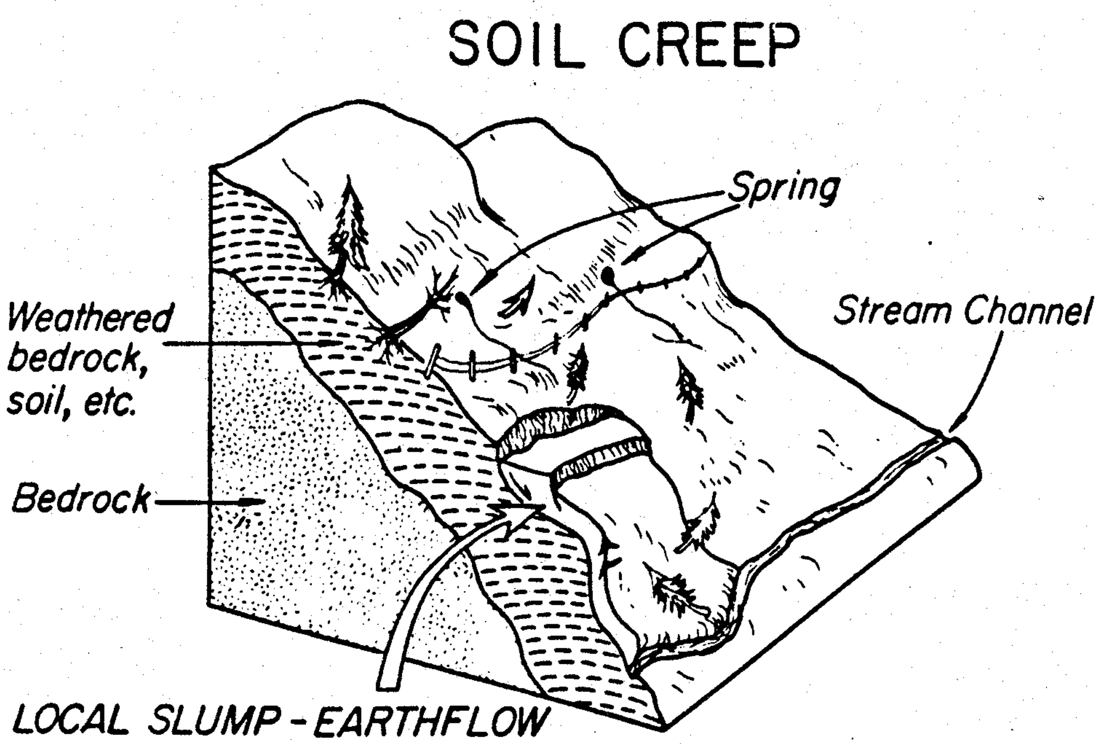
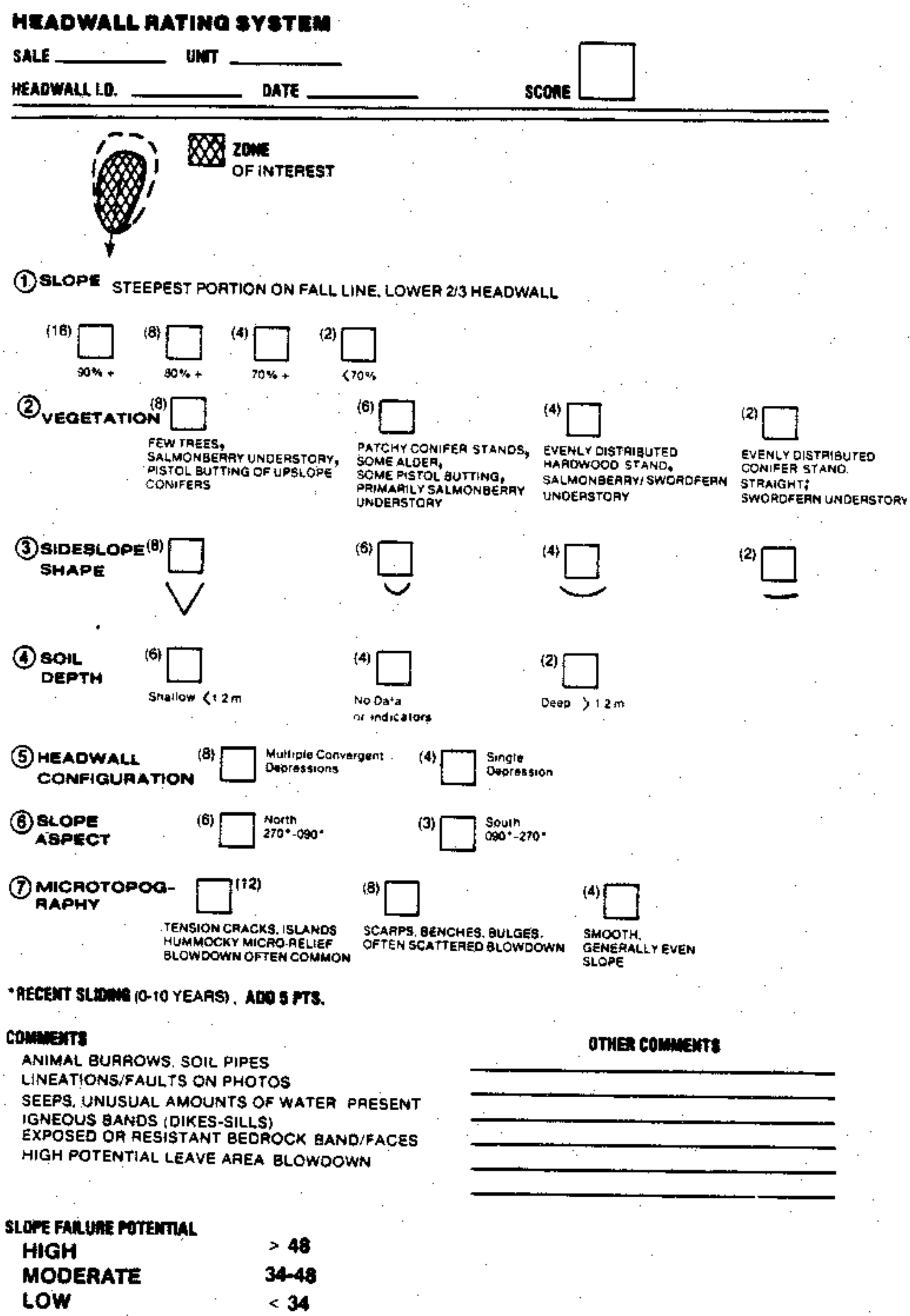


Figure 23. "Hummocky" topography with springs, curved or tilted trees, and localized slumps characterize land undergoing active soil creep.

Less quantitative methods involve subjective evaluations of relative stability using soils, geologic, topographic, climatic, and vegetative indicators obtained from aerial photos, maps, and field observations A headwall rating system such as the one presented in Figure 24 can be used to broadly evaluate relative stability of a particular site. The rating obtained in the field is entered into an empirical slope stability model to evaluate various timber harvesting options. As with most subjective rating systems, consistency among field personnel is a major problem. However, they accurately represent the relative importance of individual factors and their effects on likelihood of failure by mass movement type. The weighted values for hazard indices are presented as guides only, and can be adjusted to reflect local conditions.



HEADWALL RATING SYSTEM

SALE ________ UNIT ________

HEADWALL I.D. ________ DATE ________ SCORE [ ]

ZONE OF INTEREST

① SLOPE STEEPEST PORTION ON FALL LINE, LOWER 2/3 HEADWALL

(16) [ ] 90% + (8) [ ] 80% + (4) [ ] 70% + (2) [ ] < 70%

② VEGETATION

(8) [ ] FEW TREES, SALMONBERRY UNDERSTORY, PISTOL BUTTING OF UPSLOPE CONIFERS

(6) [ ] PATCHY CONIFER STANDS, SOME ALDER, SOME PISTOL BUTTING, PRIMARILY SALMONBERRY UNDERSTORY

(4) [ ] EVENLY DISTRIBUTED HARDWOOD STAND, SALMONBERRY/ SWORDFERN UNDERSTORY

(2) [ ] EVENLY DISTRIBUTED CONIFER STAND, STRAIGHT; SWORDFERN UNDERSTORY

③ SIDESLOPE SHAPE (8) [ ] (6) [ ] (4) [ ] (2) [ ]

④ SOIL DEPTH

(6) [ ] Shallow < 1.2 m (4) [ ] No Data or indicators (2) [ ] Deep > 1.2 m

⑤ HEADWALL CONFIGURATION (8) [ ] Multiple Convergent Depressions (4) [ ] Single Depression

⑥ SLOPE ASPECT (6) [ ] North 270°-090° (3) [ ] South 090°-270°

⑦ MICROTOPOGRAPHY

(12) [ ] TENSION CRACKS, ISLANDS HUMMOCKY MICRO-RELIEF BLOWDOWN OFTEN COMMON

(8) [ ] SCARPS, BENCHES, BULGES, OFTEN SCATTERED BLOWDOWN

(4) [ ] SMOOTH, GENERALLY EVEN SLOPE

*RECENT SLIDING (0-10 YEARS), ADD 5 PTS.

COMMENTS

ANIMAL BURROWS, SOIL PIPES
LINEATIONS/FAULTS ON PHOTOS
SEEPS, UNUSUAL AMOUNTS OF WATER PRESENT
IGNEOUS BANDS (DIKES-SILLS)
EXPOSED OR RESISTANT BEDROCK BAND/FACES
HIGH POTENTIAL LEAVE AREA BLOWDOWN

OTHER COMMENTS

SLOPE FAILURE POTENTIAL

HIGH	> 48
MODERATE	34-48
LOW	< 34

Figure 24. Empirical headwall rating system.used for shallow, rapid landslides on the Mapleton Ranger District, U.S. Forest Service, Region 6, Oregon.

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