Steps and Considerations in Initial Watershed and Reach Review

Review the road context
- Access needs
- Road location
- Road management objectives
- Landownership and partnership potential

Review watershed and site resource values
- Aquatic species, habitats, and conditions
- Terrestrial animal passage needs
- Flood-plain values
- Water uses

Evaluate watershed-scale risk factors
- Geomorphic hazards
- Event history
- Past and projected land management
- Crossing maintenance history
- Channel stability

Evaluate site risk factors
- Channel stability
- Potential for blockage by debris, ice, and/or sediment
- Flood-plain constriction
- Large elevation change across existing structure
- Channel sensitivity to change

Evaluate site suitability

Establish project objectives
- Traffic access requirements
- Degree of stream continuity
- Degree of flood-plain continuity
- Aquatic and terrestrial animal passage requirements
- Channel restoration

RESULTS

Site suitability evaluation
- Type of crossing

Broad project objectives
- Full aquatic organism passage
- Terrestrial wildlife passage
- Full flood-plain continuity
- Channel restoration, etc.

Figure 4.1—Steps and considerations in initial watershed and reach review.

Chapter 4—Initial Watershed and Reach Review

The first phase of the crossing-design project is the watershed-scale review and site reconnaissance (figure 4.1). It can be completed quickly at low-risk sites where stream and watershed conditions are well known. The process applies to replacements, removals, and new installations, and much of it applies to any crossing, whether or not it is a stream simulation.

The questions to answer in this phase are:

- Is the site suitable as a crossing location? Determining site suitability is mostly a matter of weighing risks and consequences. The team can learn a great deal about risks and environmental consequences in this phase by synthesizing historical, management, and watershed condition information. That information, along with a site walk-through, is usually sufficient for identifying sites that are unsuitable for any rigid structure and unsuitable for stream simulation.
- What are we trying to achieve with this project? Setting realistic project objectives requires knowledge of watershed and road network conditions that only a broad-scale review can provide. Setting realistic objectives also requires some understanding of the stream **reach**, which you can get from a quick reconnaissance of the site. Project objectives may later be validated, stated in more detail, or changed in light of new information.
- Do site characteristics and project objectives lend themselves to stream simulation? The feasibility of using stream simulation depends on both project objectives and site conditions. In this rapid initial review, you can identify some important site conditions that might make stream simulation infeasible or complicated, and decide whether to pursue stream simulation as an option. The broad overview also will indicate how complex the project is likely to be.

4.1 REVIEW THE ROAD CONTEXT

Note: Because most Forest Service crossing projects today are on already existing roads, this guide usually assumes the crossing-design project is for a replacement. For new crossings and crossing removals, the steps and considerations are essentially the same.

Before planning a crossing replacement, always ask the questions: ***Is the road necessary? Is there a better location for the road and/ or crossing?***

Consult existing planning documents, such as the area roads analysis and pertinent watershed analyses. Those analytical efforts should show:

- Location and type of the resources the road accesses.
- Long-term access needs in the area.
- Expected future development and its effects on road use and stability.
- Road standard needed.
- Stability and appropriateness of the current road location.

This information allows a reasonable evaluation of the long-term need for the road and whether it justifies expected maintenance requirements.

If a road analysis has been done (section 2.1), it will indicate whether the road should remain at its current location or could be relocated. If not, make those determinations before continuing.

Review **road management objectives** to identify traffic access requirements—an important component of the crossing project objective. What transportation needs are to be served, at what standard, for how long, at what cost? For some seasonally closed roads on **intermittent streams**, a **ford** or other low-water crossing may suffice. If a road is being closed or put into long-term storage, removing crossing structures might be an option until the road reopens. Roads that must stay open during all but the largest floods will require a structure that reliably passes not only large floods but also the sediment and **debris** they carry. Safety is a primary consideration.

After reviewing land ownership in the area, identify potential partners for passage and habitat restoration among downstream or upstream property owners. Other interested parties—such as watershed councils, county road departments, and wildlife interest groups—might be possible partners.

4.2 REVIEW RESOURCE VALUES

To build an understanding of the degree of passage required at a site, compile existing information on watershed- and site-resource values. Background information might come from stream surveys, watershed inventories, special uses databases, and the personal knowledge of forest specialists, among other sources. Where the crossing is a passage barrier, habitat value for upstream reaches is an especially critical piece of information. It helps establish the context and priority of a possible passage-restoration project. If existing information is not adequate, do the necessary field investigations.

Examples of potential resources values might include:

- Threatened or endangered aquatic species.
- Excellent or rare aquatic habitats (both up- and downstream of the crossing) that need protection from excessive sediment and other pollutants at all costs.
- Terrestrial animal travel routes (for example, the valley is an important migration corridor for large mammals).
- Specialized **flood-plain** habitats (for example, ground-water-fed channels provide crucial cool-water refuges for fish).
- Flood-plain water storage for flood attenuation, maintenance of base flows, and maintenance of riparian habitats.
- Domestic, municipal, or irrigation water supplies.
- Cultural or archeological resources.
- Recreation.
- Aesthetics.

Where high-value or unique resources could be affected, the consequences of partially blocking movement of animals, water, sediment, and/or debris may be unacceptable. Where severe consequences combine with a high risk of crossing failure, such as in areas subject to **debris torrents**, consider relocating the crossing to a more suitable location. The value and sensitivity of the resources at risk are also two of the factors that dictate the level of effort that should go into the design and the degree of **stream continuity** the crossing should provide (see also section 4.6).

4.3 EVALUATE WATERSHED RISK FACTORS

Take a "big-picture" look at large-scale watershed conditions and processes that have or can influence the crossing reach. Some of them are:

- Geologic or geomorphic hazards.
- History of flooding and geologic/geomorphic events.
- Past, current, and anticipated land management in the contributing watershed.
- Regional channel instability (for example, downstream **channel incision**; see appendix A.7.2)

Note: Appendix A describes geomorphic concepts used in stream simulation.

Together with a field visit to the site, the watershed background information provides a basis for understanding how the channel has responded to watershed events in the past. This knowledge, in turn, helps predict the direction and degree of future channel change. Predicting future changes is critical because stream-simulation structures must accommodate future streambed changes. Key questions include:

- What events and processes led to the current channel form? Is the channel stable, or is it still adjusting to past events?
- What watershed changes are likely during the life of the structure? How might they affect runoff and **sediment loads**?
- What channel changes are likely during the life of the structure? How will the stream respond to large floods?

To answer these questions, it helps to know what the watershed has delivered in terms of floods, debris flows, droughts, etc., and how future land use changes might change flows and sediment and debris loads. On the site scale, it is important to know what current reach conditions are and how responsive (sensitive) the reach is to changes in water, sediment, and debris loads (see section 5.3). Depending on the complexity of the site and the watershed, these interpretations can be hard to make. Someone knowledgeable in watershed and channel processes should guide the team in interpreting watershed and channel risk factors.

4.3.1 Geomorphic Hazards

Research the geology, soil, vegetation, and hydrology of the general area. Interpret these characteristics in terms of their likely effect on watershed processes and site stability. If a watershed analysis has already been completed, this information will be available. If not, tailor the detail of the investigation to the apparent risks at the site. For example, a 3-foot-wide stream on a closed road may not require the same level of effort as a 20-foot-wide river on a highway.

Evaluate each site for its proximity to potentially unstable landforms that could dramatically change sediment and debris loading to the crossing reach (see sidebar info sources). Look for features such as:

- Slope stability problems such as landslides and **earthflows**.
- Snow-avalanche chutes.
- Debris torrent-prone channels.

In addition, the site itself may be located on an inherently unstable landform susceptible to sediment deposition or erosion (for example, alluvial fans, deltas, coastal bluffs). Geologic materials may be highly prone to erosion, such as unconsolidated glacial sands. These features raise red flags about site stability.

Information Sources. Information sources commonly available on national forests are watershed analyses, access- and travel-management plans, aquatic-habitat inventories, geographic information systems layers, Infra (Forest Service database housing information about constructed features on national forests) and the Natural Resources Information Systems (NRIS) database. U.S. Geological Survey professional papers, water-supply papers, technical reports, and surface-geology maps are valuable resources for helping identify geologic hazards. In more populated areas, State and local agency maps and reports are often available. Land-type maps with descriptions of dominant geomorphic processes and hazards are available on some forests. Do not rely solely on published information. Field and aerial photo interpretations are essential in identifying geomorphic hazards.

4.3.2 History and Location of Land Cover Changes and Watershed Events

Information needed includes:

- Location of the reach in the watershed and in relation to landforms or activities that could influence water, sediment, and wood input to the channel such as: geomorphic hazards, in-channel gravel extraction operations, large-scale riparian forest harvest, road and crossing failures, dams, etc.
- History of watershed land use and road system.
- Maintenance history at crossing site.
- History of major hydrologic events such as fires, floods, **mass wasting**, and droughts.
- Recent flood events.
- Type and intensity of channel responses to those events.
- Projected land use and road system changes in the watershed.

This historical information is the background needed to develop an understanding of current reach condition as it relates to past events and current watershed conditions (see figure 4.2 for an example). Is the reach changing? How have past changes affected the existing crossing? What is the direction of change? For excellent formal examples of this type of historical watershed analysis, see Wissmar et al. (1994); McIntosh et al. (1994); and Stillwater Sciences (2005).

Collect information on crossing maintenance and failure history to get an idea of how well the existing structure has performed at the site. This information will give an idea of channel processes that affect the crossing, and help identify chronic problems that the new structure should solve.

In addition, analyze how runoff timing and amount and **sediment loads** may change in the future as a result of expected watershed events such as fires, landslides, or development. Project how the reach may respond to those changes.

Figure 4.2—Flood-damage surveys can provide historical context for stream condition. (a) On Gap Creek in northeastern Washington, extensive erosion occurred on a riparian road in unconsolidated glacial sands during a 1993 flood. (b) Sediment filled the channel for several years but this transport channel remained stable and the sediment progressively cleared out during subsequent high flows.

4.3.3 Offsite Channel Stability

Instability elsewhere in the watershed can affect a crossing structure over time. For example, a **headcut** could migrate upstream and undermine a structure. (Refer to appendix A, section A.7.2 for a discussion of headcuts and channel incision.) Alternatively, if an upstream reach is unstable, it could dramatically increase sediment and debris loading to the site. Since the crossing structure will have to accommodate any large, enduring changes in the channel, it is important to predict the magnitude, direction, and timing of likely channel changes.

Detecting significant channel instability in the watershed is not always possible without field work. Where forest cover is not too dense, a time series of aerial photographs can show changes in channel reach **planform** and instability. Photos might show noticeable change in channel width, rapid growth and movement of depositional bars, and growth of alluvial fans at tributary mouths (Grant 1988). These changes frequently are associated with observable land uses such as mining, agriculture, subdivision and road development, or forest harvest. Channel incision is a common type of regional instability caused by channel straightening, gravel mining, or loss of an important **grade control** feature. Historical accounts of stream and watershed conditions sometimes are available in local libraries or from community elders.

4.4 CONDUCT THE INITIAL SITE RECONNAISSANCE

With this background knowledge about the watershed and the road, the project team should traverse the channel up- and downstream of the crossing to (a) get a general overview of channel conditions in the **project reach** and (b) identify key geomorphic features and potential channel stability concerns. The actual length of the reconnaissance depends in part on how much information already exists about the stream. If good stream surveys are not available, the reconnaissance may need to extend well upstream from the crossing to evaluate the extent, accessibility, and quality of habitat. If the team has confidence in the accuracy of the existing survey information, walk the channel for at least 30- to 50-channel widths up- and downstream of the crossing. The reconnaissance should be longer for more responsive channels, such as where the streambed is more mobile, or banks are sensitive to disturbance. Be sure to go far enough to confidently assess channel conditions outside the existing structure's area of influence.

"Read" the stream for clues about the magnitude of overbank floods and **channel-forming flows**, the frequency and type of sediment transport events, and other channel processes, such as debris transport, beaver influences, bank erosion, streambed aggradation and degradation, and general channel stability.

(*The sidebar provides a checklist of questions that might be a useful starting point.*) Identify unstable features that could affect the crossing, such as a sediment wave progressing downstream, an unstable debris jam that could fail, a potential landslide, or an active headcut. Consider how the crossing is aligned relative to the stream and whether the alignment could be improved. Be aware of recent large floods or other unique occurrences that might affect interpretations of channel conditions. Observing how the stream has responded to the existing crossing structure can help you predict stream responses when the structure is replaced.

Initial Site Reconnaissance Tickler Checklist

Note: This checklist is not exhaustive. There are likely many other questions that should be answered in different environments. Modify it as needed.

- ✔ What effects has the existing crossing had on the stream? How high is the perch, if any?
- ✔ How prevalent is woody debris? What role does it play in channel structure and stability? How stable is it? Does the riparian area provide a future supply of wood?
- ✔ Is there a high-conveyance flood plain? Is there evidence of scour, sediment, and wood deposition on the flood plain? Locate **side channels** and swales. Are there culverts or dips at these locations?
- ✔ What processes modify the channel (for example, debris flows, meander shift, ice or debris jamming, beaver, etc.)?
- ✔ Are the banks stable?
- ✔ What are the dominant streambed materials and how mobile are they?
- ✔ Is culvert alignment creating stability problems (for example, with plugging, bank erosion)? Should alternative alignments be considered?
- ✔ Is the channel a **response** or a **transport reach**? What channel type is it?
- ✔ Are there natural or other barriers to aquatic species passage in the reach?
- ✔ Are there solid grade controls (e.g., boulder weirs, bedrock outcrops, high-stability log weirs) in the reach? These locations can function as end points for the longitudinal profile surveyed in the site assessment (chapter 5).
- ✔ Is the downstream reach incised? If so, should the crossing be retained as a grade control?
- ✔ Is there a reach similar to the project site nearby that might be a potential **reference reach**?
- ✔ What features might constrain construction activities at the site?
- ✔ Are there specialized habitats that require protection during construction?

During the site reconnaissance, think through the elements of stream-simulation design (described in chapter 6) to verify that stream simulation is actually feasible at the site. Sketch a plan-view map of the channel and adjacent flood plain or valley side slopes. Annotate the map with observations, such as location of high flow marks, severe bank erosion, and bedrock outcrops. (See section 5.1.1 for more discussion on sketch maps.) Now is a good time to establish photo points. If multiple site visits become necessary, there may be opportunity to photograph the site at different flows. Locate the photo points on the sketch map, and mark them in the field.

Most importantly, focus on the stability of the existing channel and its responsiveness to water and sediment inputs from natural and anthropogenic disturbances. Since a stream-simulation design must accommodate the potential range of **channel adjustments** during the service life of the replacement structure, **channel stability** and responsiveness to disturbances strongly affect the design. In general, response reaches are more sensitive than transport reaches. As described in appendix A, section A.2, response reaches tend to have finer, more erodible materials, and are more prone to sediment deposition, channel widening, channel scouring, and **channel migration**. Knowledge of channel types (appendix A.6) can often help with interpreting channel responsiveness.

During the site assessment (chapter 5), channel characteristics affecting responsiveness and stability will be fully documented, but some channel characteristics and geomorphic settings that can complicate design are easily observable during the initial walk-through (see sidebar).

Reach Conditions Requiring Special Consideration

- Existing structures with large elevation drops (perched).
- High **flood plain-conveyance**.
- Active lateral channel migration.
- Depositional reaches: alluvial fans, braided streams, concave stream reaches.
- Channels with large amounts of woody debris, especially channels prone to debris flows or within a debris-flow runout zone.
- Channels prone to icing.
- Channels with unusual **flow regimes**, such as estuarine channels with tidal influences, glacial-meltwater channels, palustrine (wetland) channels where ground water and area flooding are important influences, tributary channels backwatered by the mainstem.
- Channels with intermittently exposed bedrock.
- Unstable channels (laterally or vertically unstable).

These channel characteristics and geomorphic settings are not universally or equally hazardous. In most situations, designs that mitigate risks to acceptable levels are feasible. Usually, mitigating designs will affect project costs to some degree, so be aware from the outset that these conditions may entail additional costs.

Descriptions of channel characteristics and geomorphic settings requiring special consideration along with some of their field indicators follow:

Existing structures with large elevation drops

Where substantial aggradation above and/or incision below the existing structure have occurred, the replacement structure design needs to address the large change in streambed elevation. Such situations can compromise the feasibility of stream simulation, and their implications are analyzed in full detail during the site assessment and design phases (chapters 5 and

6). Documenting the situation now alerts managers that the design may require more than the usual care and effort. If the existing structure is functioning as a grade control on an incising channel (see appendix A.7.2), the team will need to consider whether to preserve the grade control.

High flood plain-conveyance

Overbank flows may transport large quantities of sediment and debris on high-conveyance flood plains. These sites require special design elements to avoid putting the simulated streambed at risk by concentrating floodwaters through the crossing structure (see section 6.5.1.1). Geomorphic evidence of substantial flow on the flood plain includes: scoured channels or swales, slack-water sediment deposits, buried vegetation, trees scarred by floating debris, and small debris accumulations upstream of obstructions.

Active lateral channel migration

Rapid channel shifting across the valley floor may cause alignment problems for the crossing and structure design will need to account for the rate and extent of lateral migration (figure 6.4).

Estimate channel-migration rates from historical aerial photographs, anecdotal information, and/or field observations, although the first two techniques may be difficult to use in small channels obscured by vegetation or located in remote areas. In meandering channels, consider the following characteristics when evaluating the risk of channel migration in the field:

- Condition, type, and successional stage (age) of vegetation on channel banks and bars. (These can sometimes indicate the rates of shifting and heights of flooding; for example, age of vegetation on existing point bars can indicate rate of bar growth. The root strength of bank plants with dense and/or deep rooting habits can limit channel shifting.)
- Presence of a cutoff channel, **abandoned channel**, or swale along an inner channel bend (on the point bar).
- Composition and stratigraphy of bank materials. (Are bank sediments cohesive or **noncohesive**? Are certain layers more resistant or susceptible to erosion?)
- Evidence of active bank scour on the outside of bends, such as pieces of bank, exposed root masses, or fallen whole trees or shrubs lying at the bank toe or in the stream. (Be careful not to confuse channel migration with bank erosion resulting from sediment accumulation above an undersized culvert that has forced flow against one or both banks.)

- Recent sediment deposition on point bars that has partially buried vegetation.
- Large in-channel debris accumulations, with evidence of flow diversion onto the adjacent flood plain or **terrace** surface.
- Extreme angles of stream approach to a culvert inlet. (These may indicate (1) that the stream has migrated since the existing structure was built, (2) that sediment deposition upstream from an undersized culvert initiated local bank erosion, changing the stream's angle of approach, or (3) the crossing was poorly aligned with the stream when installed.)

Some channel shifting in the immediate vicinity of a crossing may have been caused by the original crossing alignment. For example, where a straight culvert replaced a meander bend, the stream may have responded by eroding banks and developing new meanders to restore the original channel length. The severity of this response depends on the amount of channel shortening and the composition of streambed and streambank material.

Channel migration is likely to be slower on moderately entrenched and **entrenched channels** because the shifting channel must erode higher banks. However, it can happen. For example, debris jams that **backwater** the main channel can force water to overtop the adjacent terrace and incise into the surface. If the process continues, it can lead to **channel avulsion**.

Depositional reaches

Braided streams, alluvial fans, and reaches where stream slope flattens tend to experience lateral channel shifting due to **aggradation** or sediment deposition on bars (figure 4.3). Review the aerial photos of the watershed above the reach, looking for active sediment sources, areas prone to mass wasting, etc. Consider how past land uses in the watershed affected erosion and sedimentation rates, and how expected land-use changes may affect them in future. Keep in mind that sediment deposition may be chronic (for example, land use may increase upstream bank erosion and long-term sediment supply) or episodic (for example, occasional landslides).

Figure 4.3—Depositional reach on Kiowa Creek, Colorado. The channel shifted location across the valley bottom during a flood several years before this photograph was taken, when aggradation put additional erosive pressure on banks.

In general, it is far better to avoid locating a road on an alluvial fan. The potential for sediment deposition and channel shift on fans makes for severe maintenance headaches. If an alluvial fan location is unavoidable, observe the upper, middle, and lower sections of the fan for recent sediment deposition activity or active channel incision. Coarse sediment from the watershed may be actively depositing during flood events near the upper portion of the fan. The channel may split into poorly defined distributaries as it flows down the fan, and their locations may change as deposited sediment and/or debris jams block them. On some fans, the stream may have incised through the fan deposits, so that deposition is occurring further downstream. These observations help determine the least active section of the fan—the best place to locate the road crossing in a difficult geomorphic setting. However, this least active section of the fan may still have the potential to become more active during the service life of the structure.

Channels with large amounts of woody debris

Observe the presence, stability, size, and accumulation potential of wood in the project reach, especially upstream of the road crossing. If large wood is abundant in or near the channel, wood may play an important role in maintaining channel stability and controlling grade. It may also pose a risk to the replacement structure.

The following questions help in evaluating woody debris risks and roles:

- Are there individual wood pieces or large woody debris structures in the channel? Is the woody debris well anchored, or is there evidence of recent transport? Are most of the wood pieces generally longer than channel **bankfull** width? (Pieces longer than bankfull width typically have limited mobility.)
- Is the wood mostly solid and likely to last, or is it decaying and subject to being washed away?
- If the watershed has a history of wood-dominated debris flows, is the crossing within the projected debris-flow runout zone?
- Are steps in the channel maintained by woody debris?
- Are there low-gradient channel segments with unusually fine bed material? (Check to see if these channel segments are controlled by embedded pieces of wood. Especially in fine-grained channels, even small pieces of wood can contribute to channel bed stability.)
- Do trees border the downstream channel assuring continued wood inputs to the channel? Do downstream channel conditions and stability depend on upstream woody debris inputs? (If so, wood transport through the crossing structure may be critical to the long-term stability of the whole reach.)
- Has woody debris been previously removed from this stream for fish habitat improvement, flood hazard mitigation, etc.?

Table 4.1 shows simple criteria for assessing the risk that woody debris may plug a crossing structure. Reaches may have any or all of the characteristics described for a particular class.

Table 4.1—Qualitative criteria for assessing the risk of plugging by woody debris at a road-stream crossing structure

Woody Debris Risk	Description
LOW	● Debris mostly absent or well anchored on banks and in channel.
	● Debris dispersed uniformly along the reach (i.e., it has not moved).
	● Available wood is much larger than the stream's ability to move it (i.e., large trees in small streams).
	● Little or no wood available for local recruitment.
	● Bed material not anchored by debris.
	● Woody debris likely to remain at or near source area.
MODERATE	● Most wood pieces anchored in the channel bed or channel banks.
	● Potential for local recruitment of wood.
	● History of occasional maintenance to remove wood at the crossing.
	● Small translational slides or undercut slopes adjacent to channel.
HIGH	● Unstable accumulations of woody debris present along banks, gravel bars, and channel constrictions.
	● Most wood pieces not anchored to bed or banks.
	● Considerable wood available for local recruitment.
	● History of frequent maintenance to remove wood at the crossing.
	● Upstream watershed susceptible to debris flows.

Figure 4.4—(a) A wood-controlled step exhibiting high stability. Note the large-diameter logs embedded in the bank. (b) A wood-controlled step exhibiting moderate stability, Mitkof Island, Alaska. (c) A wood-controlled step exhibiting low stability, New Hampshire. Note the small-diameter pieces and lack of embedment in the bank.

Channels prone to icing

In cold regions, ice can play havoc with crossing structures, especially on low-gradient streams. During spring breakup, moving ice can hit and damage a structure. Ice jams can also dam the channel, potentially causing floodwaters to overtop the road. These problems are most common on **perennial streams** and near lake outlets. In wetlands, ground water seeping from streambanks can build thick layers of ice that sometimes reduce the size of culvert openings.

Field evidence that ice jams and accumulations may pose a risk includes:

- Ice-impact scars on the upstream side of trees (on banks or overhanging the stream). These can be several feet up the tree because of ice dam break-out floods.
- Isolated piles of gravel or cobbles on the banks or flood plain before spring runoff. Sediments overlie snow, ice, or last year's old vegetation.
- Blocks of ice present on banks after spring thaw, especially near meander bends, on point bars, and above natural channel constrictions.
- Discontinuous scour holes or channels that begin on the flood plain away from the stream bank, then join the main channel downstream.
- Weeping cut banks or wetlands next to crossings.

To determine winter-ice thickness in the area, see USACE (1999).

Channels with unusual flow regimes

Designing a stream-simulation crossing (a stable channel with streambed characteristics similar to the natural channel) requires the flow regime be well understood, whatever that regime may be. Some unusual flow conditions make design more difficult because of their unpredictability (for example, glacial meltwater, backwatered tributary). The fine-grained bed materials common in palustrine and estuarine channels can limit the feasibility of constructing an embedded culvert.

Channels with intermittently exposed bedrock

Many times intermittent bedrock is a design advantage, because it limits the extent of vertical channel adjustment after placement of the new crossing. However, it also can be a problem. For example, if undetected until construction, bedrock can be a surprise obstruction to placing a culvert at the correct elevation. Likewise, if a crossing happens to be located just downstream of a natural bedrock **barrier** that is now buried under the backwater sediment wedge, the new installation will exhume the barrier.

The important thing is to notice the presence of shallow or intermittently exposed bedrock during the walk through. The team can then plan to determine its extent and design for it.

Unstable channels

Stable channels vary from nearly static and unchanging to highly dynamic and adjustable. Distinguishing highly dynamic but stable channels from unstable ones can be difficult (see appendix A, section A.4). Truly unstable channels are undesirable locations for stream crossings. They are particularly undesirable for stream-simulation crossings because of the need to project the changes that are likely to occur over the crossing lifetime, and design for them. There may be no stable reference reach for a design template.

Assess overall channel stability outside the influence of the existing crossing. A single indicator of instability is not necessarily conclusive by itself. Look for other geomorphic evidence along the length of the reach that confirms or challenges your conclusion of channel instability. Indicators of stability or instability should be consistent throughout the reach. In addition, use stable channels in nearby similar landscape positions as benchmarks for comparison.

Recent sediment deposition may suggest a channel is unstable and undergoing aggradation (Pfankuch 1978; Copeland et al. 2001) (figure 4.5). Field evidence can include the following:

- Large, mid-channel bar deposits that have little or no vegetation.
- Loose bed material with fresh surfaces.
- Unusually high percentage of fine material on the streambed.
- Little difference between surface and subsurface streambed materials; poorly **armored streambed**.
- Flood-plain vegetation buried by deposited sediment.
- Upland dry-site vegetation located low on the bank or dead on the flood plain (indicates recent channel filling).

Evaluating bank stability is often key to determining whether a channel is stable or unstable. Field evidence can include:

- Substantial and consistent bank caving, toppling, or **slumping**.
- Irregular channel width and scalloped banks.
- Unstable undercuts.
- Tension cracks at elevations above bankfull.
- Shallow-rooted, sparse, or weak bank vegetation.
- Artificial bank armoring (riprap) may indicate past bank instability.

High, unstable banks can also be associated with channel incision or gullying (figure 4.6). If a headcut has reached the existing culvert, you may find a distinct difference in bank height and stability between the up- and downstream channels. (See appendix A.7.2 and section 5.3.4 for descriptions of typical channel type changes associated with incising channels.)

Figure 4.5—Massive gully erosion upstream (figure 4.6) caused channel filling and flood-plain sedimentation in this depositional reach, eastern Colorado.

Figure 4.6—Channel widening after recent incision, eastern Colorado.

One useful procedure for rapidly assessing channel stability in the vicinity of road-stream crossings is by Johnson et al. (1999). Their procedure, which builds on several earlier methods (Pfankuch 1978; Simon and Downs 1995; Thorne et al. 1996; Rosgen 1996), is based on 13 qualitative and quantitative indicators, each of which is rated with a point system (table 4.2). These ratings are weighted and added, producing an overall stability rating for the channel at the crossing. Some of the site variables (11 through 13) help in evaluating channel response to the existing structure. Johnson et al. (1999) provide guidance on interpreting the results to identify the type of instability (lateral, vertical, large transport/deposition of debris or sediment) and stabilization needs at the site. Any reach-based assessment procedure like this should be interpreted in the context of larger-scale stability issues, such as regional incision. The team can then focus its efforts during the detailed site assessment on the major risks at the site.

4.4.1 Construction Issues

During the initial review, identify features that might limit construction access. Show them on the site sketch, and flag them to ensure that the site assessment survey will include them. Such features include:

- Utility corridors, buried utility lines.
- Wetlands.
- Soft soils.
- Critical habitats.
- Steep slopes.
- Rights-of-way.
- Property boundaries.
- Existing landings, opportunities for storage and staging areas.
- Roadway lines-of-sight.

4.5 ASSESS SITE SUITABILITY

The team can now make a first assessment of site suitability for the crossing. Again, if possible, avoid locations where rapid channel change can be anticipated (figures 4.7 and 4.8). Crossings in dynamic reaches have a higher *potential* for failure than a stable site. If the *consequences* of failure would also be high, seriously consider relocating to a more stable site. The cost of moving the road may be more than offset by the lower risk of damage to the road or to high-value habitats and by the lower maintenance requirements.

Table 4.2—Stability indicators, descriptions, and ratings (Johnson et al. 1999, used with permission of the American Society of Civil Engineers)

TABLE 1. Stability Indicators, Descriptions, and Ratings

Stability indicator (1)	Ratings			
	Excellent (1–3) (2)	Good (4–6) (3)	Fair (7–9) (4)	Poor (10–12) (5)
1. Bank soil texture and coherence	Clay and silty clay; cohesive material	Clay loam to sandy clay loam	Sandy clay to sandy loam	Loamy sand to sand; noncohesive material
2. Average bank slope angle (Pfankuch 1978)	Bank slopes <3H:1V (18° or 33%) on both sides.	Bank slopes up to 2H:1V (27° or 50%) on one or occasionally both banks.	Bank slopes to 1.7H:1V (31° or 60%) common on one or both banks.	Bank slopes over 60% common on one or both banks.
3. Vegetative bank protection (Pfankuch 1978; Thorne et al. 1996)	Wide band of woody vegetation with at least 90% density and cover. Primarily hard wood, leafy, deciduous trees with mature, healthy, and diverse vegetation located on the bank. Woody vegetation oriented vertically.	Medium band of woody vegetation with 70–90% plant density and cover. A majority of hard wood, leafy, deciduous trees with maturing, diverse vegetation located on the bank. Woody vegetation oriented 80–90° from horizontal with minimal root exposure.	Small band of woody vegetation with 50–70% plant density and cover. A majority of soft wood, piney, coniferous trees with young or old vegetation lacking in diversity located on or near the top of bank. Woody vegetation oriented at 70–80° from horizontal often with evident root exposure.	Woody vegetation band may vary depending on age and health with less than 50% plant density and cover. Primarily soft wood, piney, coniferous trees with very young, old and dying, and/or monostand vegetation located off of the bank. Woody vegetation oriented at less than 70° from horizontal with extensive root exposure.
4. Bank cutting (Pfankuch 1978)	Little or none evident. Infrequent raw banks less than 15 cm high generally.	Some intermittently along channel bends and at prominent constrictions. Raw banks may be up to 30 cm.	Significant and frequent. Cuts 30–60 cm high. Root mat overhangs.	Almost continuous cuts, some over 60 cm high. Undercutting, sod-root overhangs, and side failures frequent.
5. Mass wasting or bank failure (Pfankuch 1978)	No or little evidence of potential or very small amounts of mass wasting. Uniform channel width over the entire reach.	Evidence of infrequent and/or minor mass wasting. Mostly healed over with vegetation. Relatively constant channel width and minimal scalloping of banks.	Evidence of frequent and/or significant occurrences of mass wasting that can be aggravated by higher flows, which may cause undercutting and mass wasting of unstable banks. Channel width quite irregular and scalloping of banks is evident.	Frequent and extensive mass wasting. The potential for bank failure, as evidenced by tension cracks, massive undercuttings, and bank slumping, is considerable. Channel width is highly irregular and banks are scalloped.
6. Bar development (Lagasse et al. 1995)	Bars are mature, narrow relative to stream width at low flow, well vegetated, and composed of coarse gravel to cobbles.	Bars may have vegetation and/or be composed of coarse gravel to cobbles, but minimal recent growth of bar evident by lack of vegetation on portions of the bar.	Bar widths tend to be wide and composed of newly deposited coarse sand to small cobbles and/or may be sparsely vegetated.	Bar widths are generally greater than 1/2 the stream width at low flow. Bars are composed of extensive deposits of fine particles up to coarse gravel with little to no vegetation.
7. Debris jam potential (Pfankuch 1978)	Debris or potential for debris in channel is negligible.	Small amounts of debris present. Small jams could be formed.	Noticeable accumulation of all sizes. Moderate downstream debris jam potential possible.	Moderate to heavy accumulations of various size debris present. Debris jam potential significant.
8. Obstructions, flow deflectors, and sediment traps (Pfankuch 1978)	Rare or not present.	Present, causing cross currents and minor bank and bottom erosion.	Moderately frequent and occasionally unstable obstructions, cause noticeable erosion of the channel. Considerable sediment accumulation behind obstructions.	Frequent and often unstable causing a continual shift of sediment and flow. Traps are easily filled causing channel to migrate and/or widen.
9. Channel bed material consolidation and armoring (Pfankuch 1978)	assorted sizes tightly packed, overlapping, and possibly imbricated. Most material >4 mm	Moderately packed with some overlapping. Very small amounts of material <4 mm	Loose assortment with no apparent overlap. Small to medium amounts of material <4 mm	Very loose assortment with no packing. Large amounts of material <4 mm
10. Shear stress ratio [Eqs. (3)–(4)]	$\tau_o/\tau_c < 1.0$	$1.0 \leq \tau_o/\tau_c < 1.5$	$1.5 \leq \tau_o/\tau_c < 2.5$	$\tau_o/\tau_c \geq 2.5$
11. High flow angle of approach to bridge or culvert (Simon and Downs 1995)[a]	$0° \leq \alpha \leq 5°$	$5° < \alpha \leq 10°$	$10° < \alpha \leq 30°$	$\alpha > 30°$
12. Bridge or culvert distance from meander impact point (Simon and Downs 1995)[b]	$D_m > 35$ m	$20 < D_m \leq 35$ m	$10 < D_m \leq 20$ m	$0 < D_m \leq 10$ m
13. Percentage of channel constriction (Simon and Downs 1995)	0–5%	6–25%	26–50%	>50%

Note: Ranges of values in ratings columns provide possible rating values for each factor.
[a] α = approach flow angle to bridge or culvert.
[b] D_m = distance from bridge or culvert upstream to meander impact point.

Brewster Creek Road Culvert Replacement,
Lolo National Forest, Montana
Example provided by Traci Sylte

Where Brewster Creek exits its narrow valley onto a wider, flatter flood plain, it deposits sediment and forms an alluvial fan (figure 4.7). The Brewster Creek road crosses near the head of the fan where sediment begins to deposit as the grade flattens.

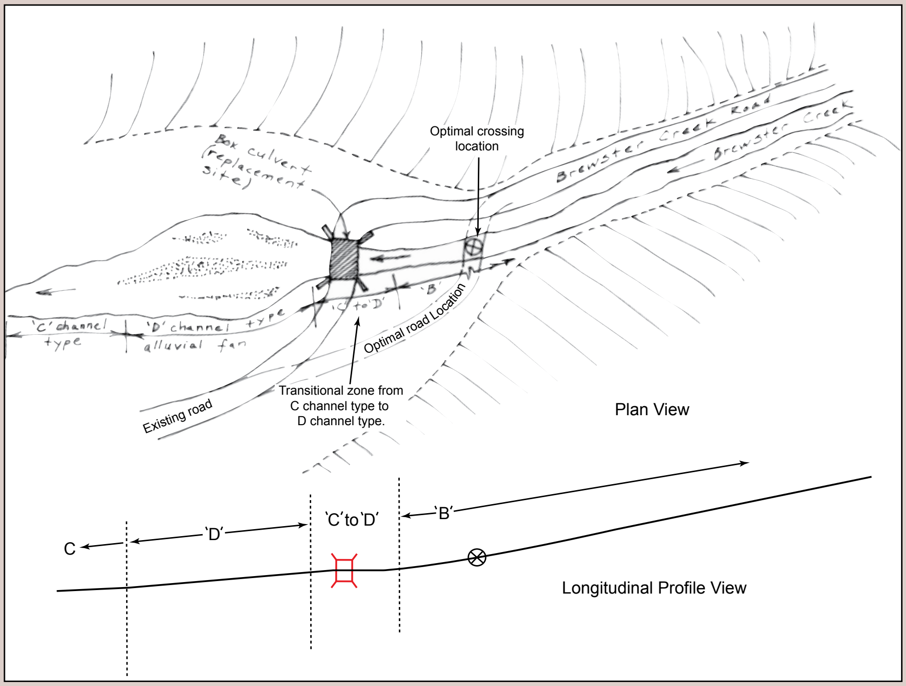

Figure 4.7—Brewster Creek crossing plan-view sketch. Original drawing by Traci Sylte.

The previous culvert, approximately half as wide as the bankfull channel, was full of sediment. As a result, the stream frequently overflowed the road. The forest replaced the culvert with a new bottomless box culvert in the same location. The new structure, which spans the bankfull width, was designed for fish passage. It was also designed to pass the 100-year flow, with some free board under the deck.

Figure 4.8—Brewster Creek road replacement box culvert, filled to 85 percent of its rise after 1 year.

The year after construction, the new culvert also filled with sediment to about 85 percent of its rise. The stream still overflows the road frequently. A simple recognition that the crossing was located in a depositional zone, coupled with an easy road-location change to only 150 feet upstream (figure 4.7), could have avoided this problem.

Although stream simulation is possible at many risky sites, special design considerations are necessary. To mitigate such risks, make every effort to thoroughly understand current stream conditions and potential changes during the life of the project. Designing a structure that accommodates those changes and minimizes the potential for and/or the consequences of failure at such a site will take more effort and care. Both the design process and the structure itself may be more expensive than at simpler sites.

4.6 DEFINING PROJECT OBJECTIVES AND INITIAL DESIGN CONCEPT

Together with considerations of traffic access needs, maintenance requirements, safety, and funding, the geomorphic hazards and ecological values identified during the initial review provide the basis for defining preliminary project objectives. These objectives are preliminary because they may change as the team learns more about the site constraints and opportunities during the site assessment (chapter 5). Throughout the predesign phases of the project, the entire team—as well as the manager—should be involved as objectives are set or revised in light of new information. In cases where objectives conflict, priorities may be reshuffled. To make sure the objectives and priorities are clear and that all participants understand them in the same way, write objectives, and document any changes as they occur.

Objectives should respond directly to the risks and resource values associated with the project—by minimizing both the potential and consequences of failure, in accordance with the importance of the resources. For example, if conditions force a crossing to remain near high-quality spawning habitat, an important objective would be to minimize the risk of degrading that habitat; the project team might therefore consider a lower-risk structure, such as a valley-spanning bridge. If regional channel incision is occurring, one objective may be to preserve the crossing as a local **base-level control**. To minimize the risk to aquatic populations, at least partial passage could be provided by installing a bypass fishway or a fish ladder.

Some examples of ecological project objectives follow. Refer back to section 2.4 for a more detailed discussion of these objectives. [Road safety, traffic interruptibility, and other transportation system objectives also enter into a full objectives statement.]

- Provide passage for aquatic organisms.
- Minimize the risk of culvert plugging. On channels where the risk of plugging by wood, sediment, or ice is very high, objectives might be to minimize both the probability of plugging (by providing a large opening) and the consequences (by designing the structure to sustain overtopping flows and prevent stream diversion).

- Maintain flood-plain functions and continuity. Where flood plains have important habitats formed during **overbank flows**, maintaining the natural flooding regime and providing for flood-water continuity down the valley may be important.
- Accommodate channel shifting. Where meanders are migrating rapidly across the flood plain, design the structure to accommodate channel movement as much as possible (see section 6.1.1.3).
- Provide terrestrial wildlife passage. Accommodate animals that use riparian areas for movement where traffic volume and/or fill height make crossing the road infeasible.
- Maintain grade control. Where a headcut is progressing upstream and the existing crossing is protecting upstream habitats, you may decide to maintain that protection. You might make the same decision where an undersized culvert backs up water and sediment, creating an unusually valuable wetland habitat. In cases like these, stream simulation may not be feasible, so the installation may require special measures, such as a fish ladder, ramp, or side channel, to provide for passage of some or all aquatic species.
- Restore a degraded channel. Where a channel has incised downstream of the existing culvert and degraded important habitat, an objective might be restoring both passage and habitat. This work would involve restoring the channel such that the transition across the road crossing is as nearly seamless as possible.
- Maintain a barrier against invasive exotic species. With this objective, stream simulation is not a design option. Undersized culverts sometimes function as partial or full **barriers**. Culverts not specifically designed for exclusion, however, may not be 100-percent effective, because some individual animals may be able to negotiate them at some flows.

Identifying preliminary objectives does not imply that the final design must fully achieve them. New information may cause the team to modify them, and more detailed project objectives will be formulated after the detailed site assessment. By this time, though, some of the site conditions or objectives that preclude stream simulation as a design option (maintaining a barrier), or that call its feasibility into question (maintaining a grade control) are known. The team probably has an initial idea of the type of structure (culvert or bridge) necessary for achieving the objectives.

Another result of the initial assessment is that the project's complexity is now known, and the team can judge the appropriate level of detail for the site assessment and design efforts (see box below). Stable and straightforward sites do not require great detail for ensuring structure stability and aquatic organism passage. However, where the risk factors or project objectives make the project more complex or where traffic can only be briefly interrupted during construction, a higher level of effort is justified.

Factors Determining Level of Site Analysis

1. Site history: Has the crossing structure failed before? Has it been a continual maintenance problem? What is the channel condition (historic and existing)?

2. Watershed history: Are there known active or historic geohazards (earthflow, landslides, etc.) in the watershed or in adjacent watersheds with similar characteristics (rock types, soils, vegetation, climate)?

3. Location: Where in the watershed is the site located, and on what type of landform) alluvial fan, glacial outwash plains, hillslope, etc.)?

4. Design life, road management objective, project constraints: Is this a highway or a logging road? What is the desired design life of a the structure? Are options at the site constrained by power lines, rights-of-way, property boundaries, or other infrastructures?

5. Channel type: What is the channel type? Is it sensitive to changes or fairly stable?

6. Is the channel incised or incising?

7. Consequences of failure: What will occur if the structure fails? What is the spatial relationship to sensitive resources (fish, riparian, vegetation, property, etc.), and how would failure impact them? What are the consequences of failure in terms of resources, monetary costs, loss of access, public safety?

4.7 DOCUMENT YOUR FINDINGS

Summarize the important findings from the watershed and reach review in a convenient format (narrative, map, form) for the project file. This documentation will continue to provide large-scale context and reminders of important offsite conditions throughout the project process, and will help you verify the level of detail needed for assessment. Include a complete set of photos taken from permanently marked photo points.

4.8 INITIAL REVIEW EXAMPLE

The following Mitkof Island, Alaska, example shows how a Tongass National Forest team documented the initial review and used it for risk assessment, site suitability determination, validation of project objectives, and preliminary decisions on structure type and design method. [The example uses the Rosgen (1994) channel classification system.]

For this example, information gathered in the office included:

- Location.
- Existing structure.
- Access and travel management.
- Area description.
- Geology.
- Soils.
- Vegetation.
- Site history.
- Slope stability.

The project team performed the following local-reach-scale assessments during their reconnaissance field visit:

- Channel types.
- Channel stability.
- Large woody debris risk.
- Risk of sediment retention.
- Streambank sensitivity.
- Site proximity to important or sensitive resources.

Initial Geomorphic Assessment for Crossing 6235-17.59

(Information provided by Bob Gubernick)

Location: Mitkof Island, Southeast Alaska, Road 6235, milepost 17.59.

Existing Structure: The existing culvert does not pass spawning adults or juvenile salmonids due to a 1.9-foot perch at the outlet. Beaver activity occurs in the area, with a dam located in the culvert inlet (figure 4.9). This culvert is scheduled for replacement.

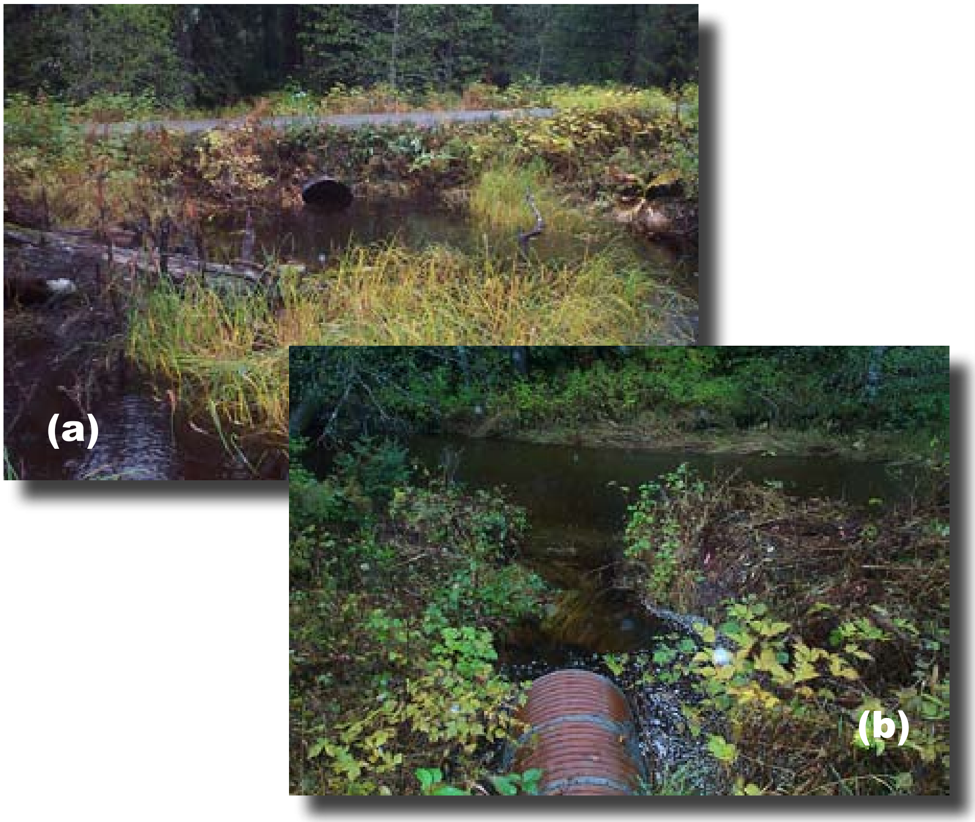

Figure 4.9—Existing culvert on Road 6235, milepost 17.59 (Tongass National Forest). (a) Culvert inlet. (b) Culvert outlet.

Access and Travel Management: Road 6235 is a permanent, high-use mainline arterial road (maintenance level 3), so traffic interruptions cannot be tolerated. The road must be safely passable by low-clearance vehicles in all weather conditions.

Area Description: The site is in a narrow valley bottom below a uniform hillslope. Descending the hillslope, the channel is steep and moderately incised. It enters the mainstem channel soon after reaching the broader, flatter flood plain. The crossing site is located near the slope transition between the hillslope and the wide flood plain.

Interpretation: The site is a response reach that may be subject to sediment deposition at the transition to a flatter slope. Large vertical adjustments can occur.

Geology: The area is composed of sedimentary deposits (marine greywacke, mudstone, and conglomerates), andesitic-to-basaltic volcanic rocks, and regionally metamorphosed equivalents of these strata (source: Gerhels and Berg 1992).

Interpretation: Sedimentary and metasedimentary materials can vary greatly in durability and are usually platy in shape.

Soils: The hillslope soil is in the Kupreanof series (origin is weathered sedimentary rock). The valley bottom soil is silty **alluvium** (source: forest GIS layer).

Interpretation: Kupreanof series soils have high silt contents. On steep slopes, they are susceptible to translational landslides, which can initiate a debris flow or torrent. Check slope stability characteristics.

Vegetation: The hillslope is dominated by a mixed conifer series (Sitka spruce, western and mountain hemlock, cedar). The valley bottom is a sedge and bog plant community adjacent to the main channel. A mountain hemlock/blueberry series lies further from the channel (source: forest GIS layer). The area is primarily pristine (99+ percent), with only a small managed section (source: air photos 1985 and 1998). The forest anticipates no new management activities.

Interpretation: All plant series are composed of dense, deeply rooted vegetation that stabilizes banks and limits **lateral migration**.

Site History: The original culvert was installed in the late 1960s. Periodic beaver activity has caused continual maintenance problems (source: maintenance records and personal communication from maintenance foreman).

Interpretation: Beaver activity will limit options. To minimize long-term maintenance needs, consider structures with wide openings such as bridges or embedded box culverts with removable lids (vented fords). To avoid making the crossing more attractive to beavers, design will have to minimize road elevation.

Slope Stability: Air photos (1963, 1979, 1985) show no indications of slope instability (landslides, debris flows).

Hillslopes above the site range between 18- to 36-percent slope, decreasing to 16 percent on the lower slopes. The moderate slopes, available lower-slope run-out length of 1,500 feet, and lack of activity in 40 years of the photo record indicate that the site has extremely low risk from debris flow or landslides (figure 4.10).

Interpretation: Slope stability is not a concern. Vertical clearance (to accommodate debris flows) is not an issue.

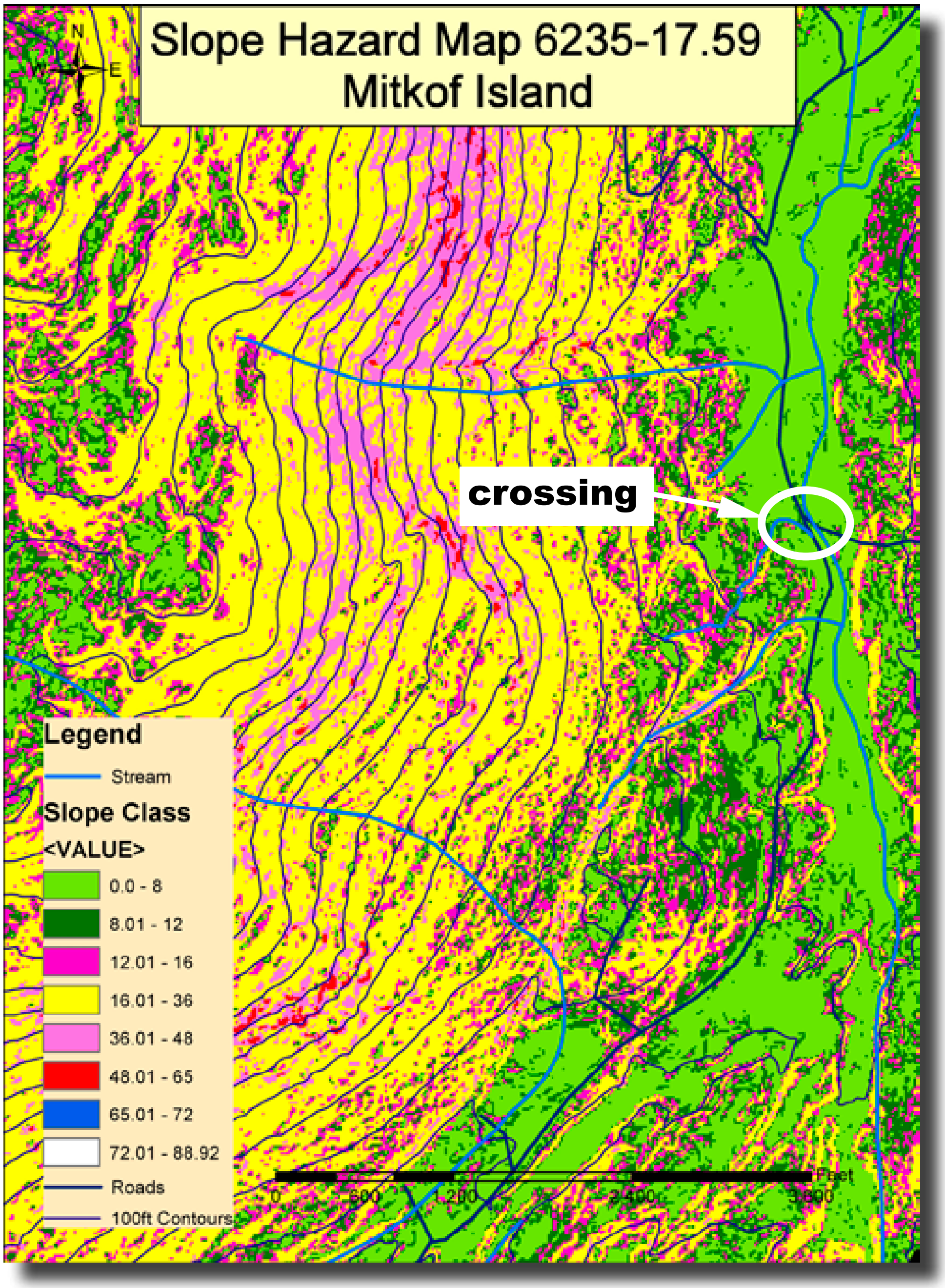

Figure 4.10—Map of slope classes above crossing. Slopes are mostly moderate in the upper watershed, and the risk of slope instability is low. Tongass National Forest GIS layer.

Channel Types:

- Hillslope: high-gradient, step-pool channels composed of bedrock, boulders, and/or cobbles (Rosgen A1a to A3).
- Valley bottom (above site): riparian wetland; low-gradient pool-riffle channel composed of silt and clay, with beaver activity (E6).
- Valley bottom (below site): moderately sloped pool-riffle channel composed primarily of gravels (C4).

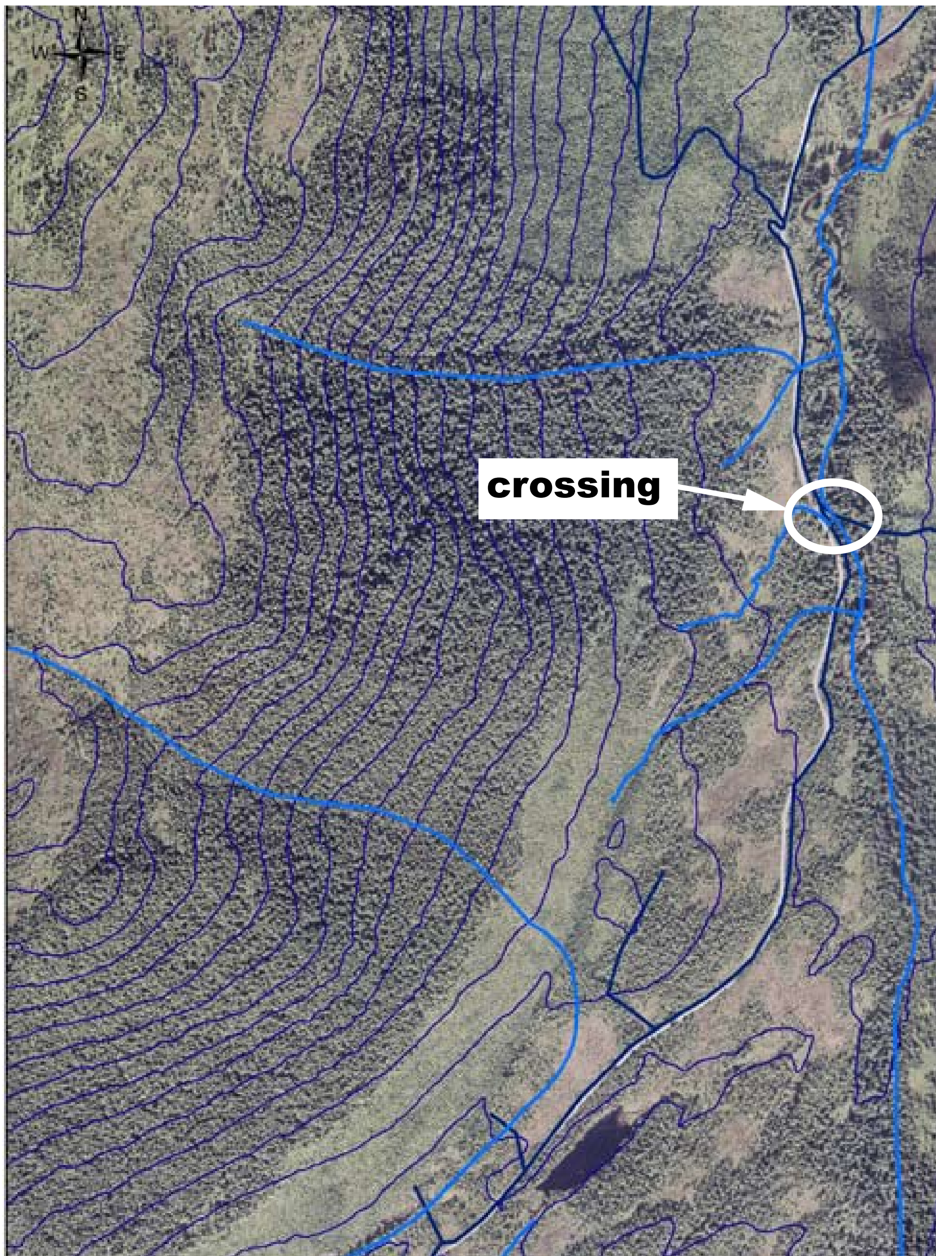

Figure 4.11—1985 aerial photo.

Channel Stability: The channel above the site is not visible on the 1963, 1979, or 1985 aerial photos (figure 4.11). Below the site, the channel appears stable, with no observable change in the photos. Neither the sequence of aerial photos nor the reconnaissance field visit shows any evidence of rapid channel change in either the tributary or the mainstem.

Interpretation: No system-wide base-level adjustments are visible or anticipated. No major adjustments in design are needed.

Large Woody Debris Hazard: Wood in the steep section of the channel is large (greater than 1-foot diameter) and is generally either well-embedded or in stable debris jams. Little debris transport is anticipated, and the site is far enough away from the edge of the valley bottom that the risk of plugging by large wood transported from upslope is low. However, the risk of plugging resulting from beaver activity is high.

Interpretation: Opening should be large, because of beaver activity.

Risk of Sediment Retention: Hillslope: low (**transport channel**). Valley bottom: high (**response channel**).

Interpretation: The beaver pond is an aggradational zone. If the pond is removed, the fine material also may need to be removed for water-quality protection.

Streambank Sensitivity: Sensitivity is low for both uplands and lowlands. Deep-rooted vegetation holds banks together both on the hillslope (mixed conifers) and on the flood plain (sedge, berry brush, and occasional conifer). Sedge and berry brush are extremely deep rooted and dense in the immediate up- and downstream reaches.

Interpretation: Banks can adjust to minor changes without destabilizing. Minor alignment changes should not pose a problem.

Site Proximity to Important or Sensitive Resources: Immediately adjacent to site (30 feet downstream) is high quality salmon-spawning habitat.

Interpretation: Proximity to spawning habitat means that site design should have a high safety factor. Sediment control is a major concern, given close proximity of the upstream pond.

Overall Risk Assessment: Based on the stability of hillslopes, the channel types in the area, and on the photo record, overall risk is low.

Project Objectives:

- Provide free passage for aquatic species, sediment, and woody debris (stream-simulation design).
- Use culvert or low-profile bridge if cost effective. (Keep approach fills low. If selecting a culvert, design road for overtopping and minimize risk of sedimentation from beavers' plugging the culvert.)
- Minimize the installation's attractiveness to beaver by using as large an opening as possible.
- Remove beaver dam, but try to maintain some water depth upstream if possible.
- Minimize sediment released to the downstream spawning area during construction and over time.
- Maximize flood-plain connectivity by installing additional culverts in side channels and flood swales.