# Choosing the Best Site for a Bridge

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Poor location or a structure that is the wrong size can cause a bridge to fail or lead to increased maintenance costs. Bridges can be the most expensive item on a road, and funds to fix or replace a bridge can be difficult to obtain. Therefore, it is important to get it right the first time. Good bridge siting involves many disciplines during the planning phase and National Environmental Policy Act development. The process includes preliminary engineering, hydrology and hydraulics, roadway alignment, and environmental and geological concerns. All of these topics must be addressed to ensure that the structure is appropriate for the site and to satisfy permit requirements of state and federal agencies. Not every agency will have all the required skills to use an interdisciplinary approach. In these cases, the agency responsible for the structure can obtain recommendations or input from state fish and game departments, other state agencies, and federal agencies (U.S. Fish and Wildlife Service, National Marine Fisheries Service, etc.), depending on the site. This paper will focus on construction of new bridges, but the same considerations must be taken into account for bridge relocation or for site adjustments when bridges are reconstructed.

## PRELIMINARY ENGINEERING

Preliminary engineering includes work before and during visits to the site. Preparation for site investigations includes gathering maps, geologic and hydrologic reports, and photographs. Site work includes site investigation, site survey, and geotechnical investigation.

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### Preparation for Site Investigations

Preparations for site investigations include collecting topographical maps, infrared photography, remotely sensed images, geographic information system coverages (land use plans, streams, watersheds, etc.), many years of aerial photographs, and county plats showing landownership in the general area around the bridge. Topographic maps can help to locate the bridge. Infrared maps (Figure 1) may show areas that are prone to being wet and may show problem areas with springs or wetlands. However, depending on the time of year the infrared photographs were taken, they may not be of much help.

A file including many years of aerial photographs is helpful in determining the stability of streams. Stable streams will show up in the same location year after year, while the locations or widths of unstable streams may show changes in photographs taken during different years. County plats and other landownership maps should be used to determine ownership of private lands where the bridge may be located. Permission must be obtained from the landowners before site investigations and surveys are conducted.

### Site Work

Site work includes site investigation, site surveys, and geotechnical investigations. Some sites only require simple site investigations, because the abutment locations and sites are controlled by the highway, railroads, and lined ditches or canals. Usually, these sites are already disturbed and do not have many environmental concerns. They still require the engineer to walk upstream and downstream to look for signs of floating debris, ice damage, and past flooding.

Complex bridge sites require a thorough investigation because of problems associated with floodplains, stream dynamics, wildlife, and so forth. The more complex the site, the more disciplines will have to be consulted. An interdisciplinary team should be formed, which may include representatives of occupations such as structural engineer, bridge engineer, geologist or geotechnical engineer, civil or transportation engineer, fisheries biologist, wildlife biologist, hydrologist, botanist, archeologist, and soil scientist.

Site investigation includes conducting a site reconnaissance by walking the upstream and downstream reaches and talking to long-time residents of the area about flooding and debris jams. The following are some of the questions that should be asked:

- What time of year have the floods occurred? Were they spring or fall floods, or rain-on-snow events?
- How high did the water get? Did the water stay in the stream or jump the banks?
- Does the stream have ice flows, and have there been damming problems?

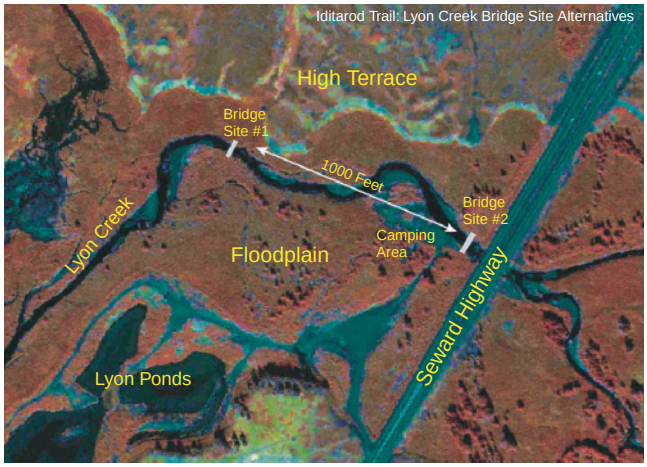


**FIGURE 1 Infrared photograph of proposed bridge locations on the Iditarod Trail in Alaska.**

- Does the stream have floating debris, and how large have the floating trees been?
- Are springs located near the stream? What are the groundwater flows in the area?

During field reconnaissance, the stream should be reviewed for dynamic sections and problem areas that should be avoided, such as deltas, alluvial fans, aggrading or degrading sections, sharp curves, multithreaded channels, sloughs, wetlands, and floodplains. Many pictures (Figure 2) should be taken of the site, banks, stream corridor, and other important features.

A stream bankfull determination should be made in the field. The determination will provide verification for structure span and future modeling efforts. The bankfull flow value will be compared with the $Q_2$ flow value to determine whether modeling outputs are similar to the known $Q_2/Q_{bankfull}$ relationship. $Q$ is the discharge in cubic feet per second for a given stage in the stream or a return interval. Also, a field estimate of the elevation that corresponds to a large flood is valuable. This elevation can be checked with estimates of the $Q_{100}$ flood estimate to verify model projections and ensure that modeling is as accurate as possible. A rule of thumb is to determine the approximate $Q_2$ in the field and double the maximum bankfull depth in a representative channel section to estimate $Q_{100}$. Additional information on bankfull determination can be gained from *Identifying Bankfull Stage in the Eastern and Western United States*, a training DVD-ROM (*1*).

**FIGURE 2 Picture of a proposed bridge location taken from the downstream point of view looking upstream.**

In conducting a site reconnaissance, the stream should be investigated for at least ¼ mi upstream and downstream. The reconnaissance will help identify factors that may affect the structure. For example, a bedrock control stream will have less chance of scour, and the abutments will normally be perched high enough above the water to allow enough clearance for floating debris. The following are other items that require investigation:

- Structures upstream and downstream
  - Size and clearances of structures
  - High-water marks on structures
  - Waterway adequacy and performance
- Channel control structures, such as dams or weirs
- Natural control points—bedrock channels
- Bankfull indicators and high-water marks
- Ice damage, scars, or marks
- Bank and stream stability
- Springs and groundwater flow
- Floodplains and deltas
  - Floodplain widths
  - Drift locations
  - Degrading or scour zones
  - Aggrading or deposition zones
  - Logs in stream, floating debris, and scars on trees
  - Maximum elevation of flood and debris deposits
- Visual geotechnical investigation of soil types and streambed strata
  - Bedrock
  - Boulders and cobbles
  - Gravel
  - Sand
  - Silt
  - Clay
- Flooding (spring or fall floods or rain-on-snow events?)
- Navigational clearance requirements
- Systemic and local incision

All features that are not normally included in a survey map should be flagged to ensure that they will not be missed by the survey crew.

## Site Surveys

A topographic map should be prepared after site surveys conducted with a total station or by using conventional techniques. Total station and conventional surveying are different ways of surveying. Refer to a surveying reference book for detailed procedures for conducting a survey by either method. The recommended survey should be at least

- 300 ft upstream and downstream from the proposed bridge site to provide enough stream reach information for an adequate hydraulic analysis,
- 150 ft on each side of the stream to provide enough information to design road approaches, and
- 50 ft for tops of bank on each side of the stream or for the entire floodplain.

Cross sections should be surveyed for hydraulic modeling and for key features. Key features include

- Proposed centerline and edges of the roadway;
- Major slope changes in the channel, stream centerline, and edge of water;
- Tops and bottoms of banks;
- Floodplains and islands;
- Drift, ice damage locations, and heights of areas damaged by drifting debris and ice;
- Utilities;
- Trails;
- Bedrock outcroppings; and
- Enough topographic points to produce a realistic terrain model.

### Geotechnical Investigation

The amount of geotechnical investigation required depends on the site. The geotechnical investigation should be completed with a geotechnical engineer in collaboration with a soil scientist where available. The site should be probed for soil and bedrock conditions. An easy method is to use the Williamson probe, which is an 11-lb circular hammer and ¾-in.-outside-diameter pipe with a plug. The hammer is dropped for 39 in., and resistance is measure in blows per foot. This method gives the operator an idea of relative density and of the occurrence of soft zones, which will require a more thorough geotechnical investigation. The Williamson probe works best in gravel or sand, but it can be driven through cobbles. Borings are desirable for sites with unacceptable and complex soils or highly fractured shear bedrock faces. Wet and unstable sites and sites with clay and silt soils should be avoided, if at all possible. Bedrock should be assessed for the degree of fracturing, gaps between the fractured surfaces, the material's hardness, and the degree to which it has weathered.

Unsuitable or unacceptable foundation material can cause structures to settle and fail. All major bridge sites should have a geotechnical study completed with at least one boring drilled for each abutment or pier. The type of bridge substructure is site-specific and should be designed in conjunction with a geotechnical engineer. The Michigan Department of Transportation (*2*) provides an example of the requirements for a study. *Geotechnical Testing, Observation, and Documentation* by Davis (*3*) is also recommended.

## HYDROLOGY AND HYDRAULICS

An adequate hydrologic and hydraulic analysis is important. Many structures have been washed away or damaged by floating debris because the stream flow or high-water elevation was not calculated or was calculated incorrectly.

### Hydrology

Hydrology calculations should be completed by a hydrologist familiar with the local conditions and stream flows. These calculations should include at least the $Q_2$ and $Q_{100}$ flows. The stream flow can be calculated on the basis of various models and equations, such as the Hydrologic Modeling System, the U.S. Geological Survey regression equations for stream flows, and *Urban Hydrology for Small Watersheds* (Technical Release 55 of the Natural Resources Conservation Service). The results from these methods should be compared with each other to arrive at a logical solution because discharge calculations are not an exact science; results can differ significantly on the basis of the method used.

Another good method compares the watershed being crossed with an adjacent watershed with similar physical characteristics for which hydrologic data have already been collected. A nearby gauged stream can be used to compare results and calibrate the modeled stream flow. Discharge measurements are a good way to calibrate the flow model for the site under investigation. Harrelson et al. (*4*) show how to conduct stream surveys and make discharge measurements. In addition, a hydrologist should make a pebble count and gather substrate information to allow for estimates of the channel roughness value and scour potential. The channel roughness values, as well as substrate and stream flow information, will be used to calculate the hydraulics for the site.

### Hydraulics

Hydraulic calculations can be performed with many computer programs. Two of the most common are Hydrologic Engineering Center—River Analysis System (HEC-RAS) and WSPRO, a computer model for water-surface profile computations. Any model should be verified to ensure that it represents field conditions. For instance, the model's outputs should be compared with high-water marks, drift locations, streambed strata versus stream velocity, and so forth. Neill (*5*) outlines hydraulic factors to be considered in bridge layout.

Local residents or others who have lived in the area for a long time should be interviewed about historic flooding. The timing of peak flows changes from region to region. For example, southeast Alaska floods in the fall, when the area receives more than 3 in. of rain per day. The Midwest and the West have flooding during spring runoff and sometimes after summer rains, the Northeast may flood during rain-on-snow events, and the Mid-Atlantic can flood during storms spawned by hurricanes. The timing of the peak flows and the reasons for those flows in the bridge area should be determined, and such factors should be considered in the design.

In conducting a hydraulic analysis, the following steps should be performed:

1. Develop a topographic map and cross sections of the stream from the site survey.
2. Use the flow rate from hydrologic analysis as input for the computer model.
3. Backcalculate a Manning's *n* for the stream, if discharge measurements were taken.
4. Use either HEC-RAS or WSPRO to perform hydraulic analysis.
5. Compare results with site investigation field observations: bankfull indicators for $Q_2$, high-water marks for $Q_{100}$, and streambed strata versus stream velocity. Verify information on high water from local residents.

Validating results is important for hydraulic analysis. As the old saying goes, "garbage in, garbage out." Scour should be considered in verifying velocities and streambed strata. A scour analysis should be completed for every stream-crossing project.

Navigational clearance is required in many streams. Most designated wild and scenic rivers will have canoe and boat usage. Navigation clearance must be provided at high water ($Q_{100}$). Minimum

clearance for navigation will depend on the type of boat traffic. Typically, 5 ft of clearance is required for canoes on small streams.

Floating debris (logs, root wads, etc.) presents another problem during floods. The minimum 5 ft of clearance may need to be adjusted after verification of the elevation of floating debris and ice damage. One way to estimate the clearance required for floating debris is by measuring the root wads of large trees. The minimum required clearance can be estimated as half of the root wad's longest dimension plus 2 ft added for safety. An estimate can be made of the root wad's dimensions by measuring the exposed root system on standing trees or trees that have blown down.

## GEOMORPHOLOGICAL CONCERNS

The geomorphology of the watershed and channel plays a key role in the siting of bridges. Basic geomorphological principles allow designers to understand the processes and difficulties present when bridges cross various positions in the watershed. These processes change with location in the watershed and along the reach where the crossing will be located. Channels are extremely dynamic. They respond to changes in the watershed by propagating changes downstream to upstream and vice versa, depending on the channel position in the watershed, the type of disturbance, and the channel types along the stream. To choose the best location for a bridge in this dynamic environment, the designer should address the following questions:

1. Where is the crossing location in the watershed and how does the stream transport water, sediment, and wood at that location?
2. How is the channel configured?
   – What is the degree of channel containment?
   – Is there floodplain conveyance? If so, how much, and are there side channels or flood swales?
   – Can the stream move laterally and affect the crossing during the structure's design life? Are the stream banks adjustable (erodible) or not (nonerodible)?
   – What is the range of vertical fluctuation of the streambed during the structure's design life?
3. How well does the road and bridge alignment coincide with the stream alignment (perpendicular versus skewed bridge alignment with curve widening)?
4. Could geologic hazards or problem landforms affect the bridge?
5. Is the channel stable? Is the channel adjusting to recent large-scale disturbances (such as mass-wasting, debris flows, or floods of record)?

### Where Is the Crossing Location in the Watershed?

The location of a stream reach in its watershed determines its channel morphology and responsiveness to natural or man-made disturbances (*6*). Slope, discharge, sediment (size and availability), and vegetation are the main controlling factors, which also vary with topography and position in the watershed.

Montgomery and Buffington (*7*) divided reach-level response into three main categories:

- *Source reaches* are headwater colluvial channels that store sediment for long periods. These are the source areas for mass-wasting events (landslides, debris flows, etc.) during peak-flow events and saturated conditions. These reaches are extremely high in the watershed and are not usually at bridge site locations.
- *Transport reaches* are typically located on hill slopes and the toe of hill slopes at the edge of valley bottoms. These are higher-gradient streams with stable bed morphology (step-pool or cascade) that pass the sediment to the downstream reaches. Transport-reach streambeds are usually heavily armored with boulders and cobbles, which provide resistance to bed scour and bank erosion. Highly erodible areas can exist in areas controlled by large woody debris.
- *Response reaches* are typically located in the valley bottom. These reaches have a lower gradient with pool-riffle, plane-bed, or regime-type morphology. They have relatively low sediment transport capacity and often respond to changes in sediment supply or discharge with large adjustments in their size, shape, slope, or pattern.

### How Is the Channel Configured?

A channel's configuration provides information that can help determine whether a crossing is at a good, safe location or an expensive, complex location that will require extensive analysis and design. Channel classification has been an excellent tool for describing stream configurations and for interdisciplinary communication.

#### *Channel Classification*

Two main channel classification schemes are in use today: the Rosgen system (*8*) and the Montgomery and Buffington system (*7*). The Montgomery and Buffington system is based principally on watershed position, slope, and the geomorphic description of bed characteristics. The Rosgen system is based on slope, entrenchment ratio, the ratio of bankfull width to bankfull depth, sinuosity, and bed material. Both have utility, but this paper will focus on the Rosgen system for bridge siting. An in-depth discussion of Rosgen's channel classification (Figures 3 and 4) is given by Rosgen (*8–10*).

#### *Terms Used in Channel Classification*

- *Entrenchment ratio* is an index that refers to the degree of vertical containment determined by the flood-prone width ($W_{fp}$) measured at a point 2 times the maximum bankfull depth divided by the bankfull width ($W_{bf}$) (see Figure 5). High confined channels have low entrenchment ratios, and unconfined channels have high entrenchment ratios.
- *Width–depth ratio* is an index describing the shape of the cross section; it is determined as the bankfull width ($W_{bf}$) divided by mean bankfull depth.
- *Sinuosity* is an index describing the degree of meandering in a river; it is calculated as the ratio of stream length to valley length.
- *Slope* is the stream gradient, calculated as the change in vertical elevation divided by stream length.

### What Is the Degree of Channel Containment?

At an ideal bridge crossing, all floodwater and watershed by-products would stay within the confines of the existing channel. Such cross-

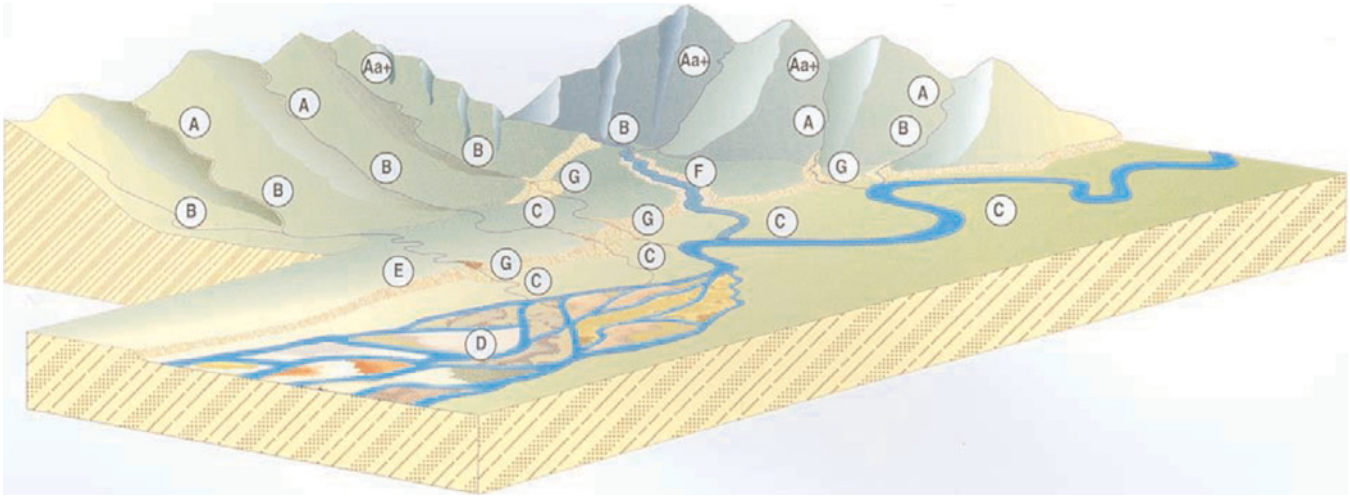


FIGURE 3 Rosgen system showing examples of broad-level delineation of stream types (*9*).

ings would have high banks with a narrow floodplain or none at all. Rosgen's channel classification system illustrates that certain channel types are more vertically contained than others. In channels with low entrenchment ratios [Channel Types A, B, F, and G (see Figure 4)], most of the discharge remains within the confines of the bankfull or active channel area, even during flood events. When a bridge crosses such channels, it is relatively easy to provide good vertical clearance between the stream and the bottom of the bridge's girder. Channels with high entrenchment ratios (Channel Types C, D, DA, and E) tend to have active floodplains with low banks. They will require deep fills for acceptable vertical clearance. Streams with high entrenchment ratios often require additional drainage structures on the floodplain and wider crossings. Bridges built on such streams may pose problems for animals that need to cross the area.

## Is There Floodplain Conveyance? If So, How Much, and Are There Side Channels or Flood Swales?

Identifying how much water flows over a floodplain and to what extent water will cover a floodplain are major considerations when crossings have a high entrenchment ratio (Channel Types C, D, DA, and E). Floodplain conveyance is a balance between open span width, vertical

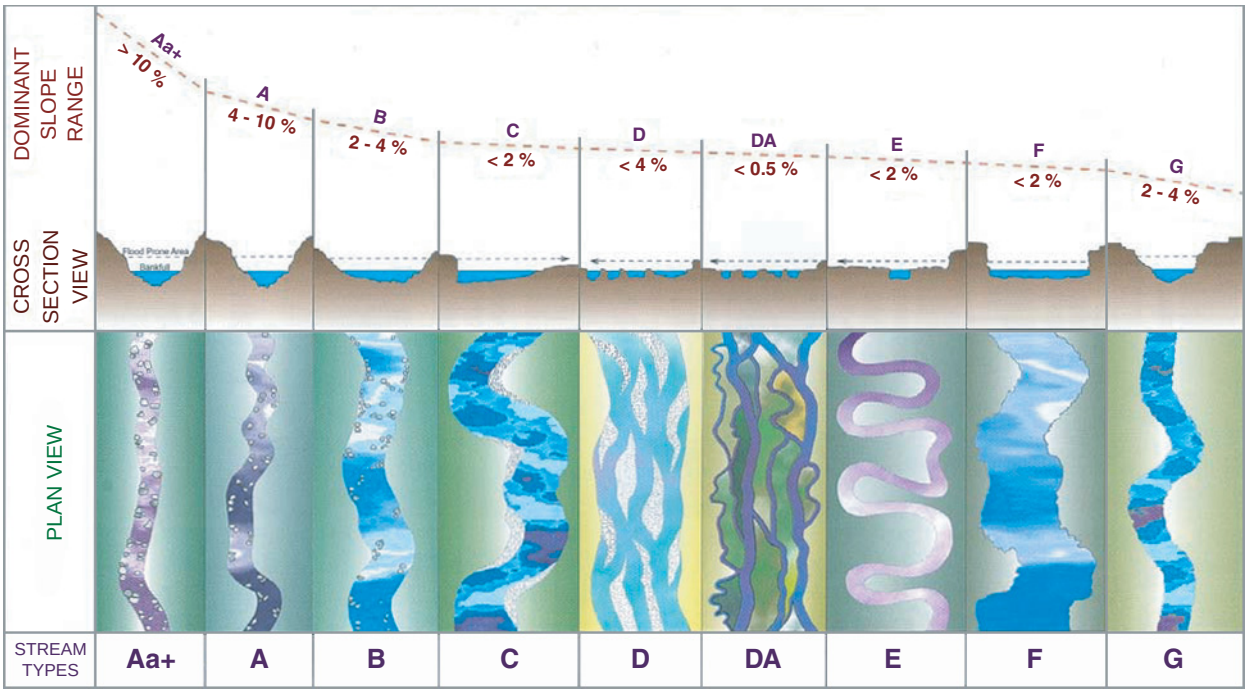


FIGURE 4 Rosgen system showing broad-level stream classification delineation of major stream types (*9*).

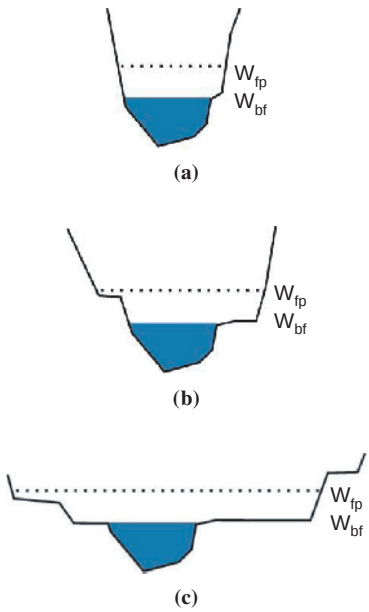


FIGURE 5 Illustration of various entrenchment ratios (ERs): (*a*) entrenched (ER < 1.4); (*b*) moderately entrenched (ER between 1.4 and 2.2); (*c*) slightly entrenched (ER > 2.2).

clearance, and scour. Even when a bridge spans the active channel bed, the bankfull width, or even more of the floodplain, if the floodplain has high conveyance, the bridge opening will constrict the flow during floods, causing higher shear in the bed and deeper scour depths than normal.

If crossings must be located in these channels, riprap or other materials are recommended to prevent excessive scour. If flood channels or swales exist, additional culverts or slab structures can help reduce the constriction caused by roadway approaches that cross the floodplain. The additional culverts also may help preserve floodplain processes at the crossing. Hydraulic modeling, along with field observations of the character of flood deposits (depth and size of the material), can be used to gauge the amounts of flow on the floodplain if a bridge crosses a channel of Type C, D, DA, or E.

## Can the Stream Move Laterally and Affect the Crossing During the Structure's Design Life? Are the Stream Banks Adjustable (Erodible) or Not (Nonerodible)?

All stream channels migrate laterally over time. Because of bank resistance and increased bed shear, confined channels usually migrate less quickly than unconfined channels. If the banks are composed of highly erodible materials (noncohesive, finer-grained sands, gravels, and cobbles), the banks adjust more easily than if they are composed of nonerodible materials (boulders, bedrock, and cohesive materials). Deeply rooted vegetation is also a major factor in the susceptibility of banks to erosion. If deeply rooted native species are present, banks are less erodible. Adjustable and nonadjustable banks can occur in any channel type. Material alone is not always the sole indicator of the likelihood of lateral movement. Streams with low entrenchment ratios and lower width-to-depth ratios (Channel Types A, B, F, and G) tend to have lower migration potential than those with high entrenchment and high width-to-depth ratios (Channel Types C, D, and E). Type E channels and channels with dense, deep-rooted woody vegetation can be stable and migrate laterally slowly.

## What Is the Range of Vertical Fluctuation of the Streambed During the Design Life of the Structure?

Transport reaches usually have heavily armored streambeds (Channel Types A, B, and G), and response reaches have fine-grained, noncohesive streambeds (Channel Types C, D, DA, E, and F). The armored streambeds in the transport reaches indicate that scour is usually localized, and streambeds tend to be more rigid, limiting large vertical changes to the bed. Streambeds in the response reaches tend to aggrade or degrade with changes in sediment supply and discharge. In situations where response reaches are composed of cohesive material (clay), these channels tend to be stable and can be good crossing sites. Establishing solid foundations at such crossings can be expensive, and floodplain issues and stream sinuosity will need to be addressed.

Headcuts may be encountered in a streambed, which migrate upstream, eventually lowering the existing streambed elevation. Depending on their size (depth), headcuts can undermine bridge foundations or materials intended to prevent scour. Characterizing the bed materials (grain size frequency distribution and depth of armor layer) and using a long longitudinal profile to determine headcut locations and the range of potential vertical changes in bed elevations help determine the risk and costs associated with constructing crossings in response reaches.

## How Well Does the Road and Bridge Alignment Coincide with the Stream Alignment (Perpendicular Versus Skewed Bridge Alignment with Curve Widening)?

The orientation of a bridge with respect to the channel affects flow dynamics into, through, and out of the structure. In assessing the flow transitions at a bridge site, both the lateral (cross section) and longitudinal (planform) configuration should be considered. To avoid accelerating flow when the cross-sectional area of flow shrinks as flow enters the crossing, the design width must at least approximate the bankfull or ordinary high-water width. If the area for bankfull flow below the bridge is less than that in the channel, velocity increases, back eddies form, and the channel constriction can reduce the water surface slope above the bridge, impounding water. Likewise, shear stress and the power of the flow under and immediately downstream of the bridge are higher than those that prevail elsewhere in the channel, and scour is likely.

When a wide stream flows into a narrow bridge opening, back eddies can form, constricting the available flow area in the channel. This condition causes observable changes in sediment transport and increases in localized scour. Field evidence of this condition includes aggradation above the structure, usually seen in the longitudinal profile as a flat sediment wedge with little streambed structure or as gravel bars. Bank scour can occur either above or below the site because the changes in cross-sectional area create back eddies, increasing the boundary shear stresses and directing flow into the banks instead of parallel to them. Bed scour commonly occurs downstream and is caused by increased outlet velocities and increased water surface slope.

These effects depend on the specific site configuration, mainly the degree of constriction. The same is true with respect to the approach angle. The ratio of the radius of the upstream bend to the bankfull width (Rm/Wbf) can be used to gauge the constriction. The lower the ratio (Rm/Wbf), the greater the constriction's influence will be on flow conveyance. As (Rm/Wbf) decreases below 2, the velocity distribution becomes more uneven and more of the flow is forced along the outside of the bend. Boundary resistance is reduced on the inside of the bend, and large eddies form just downstream of the apex, impeding flow by reducing the actual effective width in the channel (*11*, pp. 135–144; *12*). The greater the skew angle between the structure and the upstream channel, the greater the flow constriction and the deeper the local scour.

### What Geologic Hazards or Problem Landforms Can Affect the Bridge?

Each bridge site should be evaluated for its proximity to currently or potentially unstable landforms. Even geologic hazards far from the crossing could cause problems. Geologic hazards of concern to bridge crossings include (*a*) slope stability problems such as mass-wasting or debris flows, which can change the river's course or present vertical clearance problems when they pass beneath the structure, and (*b*) inherently unstable landforms such as alluvial fans and earthflows. Alluvial fans may leave an expensive structure in a dry channel, or the landform could migrate during an earthflow, affecting the bridge approaches, damming the stream channel, or creating an excessive sediment load.

Avoiding these types of features is the best policy. Identifying them early in the decision-making process is key. They can be found by interpretation of aerial photographs and by field reconnaissance. In the United States, U.S. Geological Survey professional papers, technical reports, and surficial geology maps are valuable resources in identifying these features. State and local agency maps and reports often are available in more populated areas.

Understanding how an unstable landform can behave over time can be helpful in planning for maintenance needs and in design considerations. For example, active alluvial fans are sediment deposition zones. Their channels change location frequently, sometimes rapidly when sediment and debris deposits cause the channel to seek a lower level. If a crossing is located on an active fan, the channel can be abandoned after an avulsion occurs upstream, or the crossing may fail catastrophically because of sediment or debris deposition. The best crossings in such areas would be below the fan or near its apex. If the crossing must be on an alluvial fan, large channel changes should be anticipated, and the design should minimize the downstream consequences of failure by minimizing diversion potential at the crossing (*13*).

While channel types cannot be used to identify geologic hazards, certain hazards are more common in one area of a watershed than in others. For instance, channel types with high gradients (Channel Types A and B) typically are on hill slopes where debris flows can occur.

### Is the Channel Stable? Is the Channel Adjusting to Recent Large-Scale Disturbances (Mass-Wasting, Debris Flows, Floods of Record)?

The channel should be assessed for stability at both the watershed and reach scales. It is particularly important to identify system-wide instability such as downcutting, because the design will have to account for predicted changes in the channel to achieve long-term stability for the structure. It is best to avoid crossings in unstable channels because the change in width and depth that might occur can be difficult to predict. Systemwide instability usually can be seen in a series of aerial photos as noticeable changes in channel width, rapid growth and movement of depositional bars, alluvial fans at tributary mouths, and so forth (*14*).

Distinguishing large-scale channel change from the noise of "natural" variability in channel width, depth, and slope can be difficult because variability can be large even in channels in quasi-equilibrium (*15*). This distinction usually is made by using a series of historical aerial photos and any other historical accounts of the stream and watershed. Frequently, large-scale channel changes are associated with observable land use changes such as mining, agriculture, subdivision and road development, or logging.

As a rule of thumb, the heavily armored transport reaches (Channel Types A, B, and G with cobble and larger substrates) tend to be more stable and less affected by watershed changes than the response reaches (Channel Types C, D, E, and F).

## ALIGNMENT

Bridges with horizontal alignments constructed perpendicular to the stream are the shortest structures and usually cost less. Perpendicular crossings may require sharp curves, which may cause safety problems on the approaches because of inadequate stopping sight distances and turning radius. If the bridge is not located in a relatively straight section of road, it may have to be widened to allow large trucks to make the turns without damaging the bridge railings. A good horizontal alignment should provide adequate sight distance with required horizontal curves or straight approaches for the design road speed. An ideal bridge approach would allow vehicles approaching the bridge to see oncoming traffic.

Vertical alignments are also important. Bridges with a slight grade will shed water, while water will pond and debris will collect on bridges in the bottom of sag. Gravel and debris on the bridge deck will cause maintenance and safety problems. If the bridge does not shed water, the water may freeze and cause a safety hazard, or the water may encourage rusting or bridge decay.

Flare ditches on the roadway approaches will help prevent pollution by filtering runoff through vegetation before it enters the stream. Crowning the road to drain the water off before the water reaches the bridge will improve the structure's longevity and safety. Less efficient alignments are acceptable when conditions are controlled by large trees, banks, wildlife habitat, or high stream sinuosity. Straightening stream channels and modifying channel alignments are not recommended and require completion of meticulous hydraulic and geomorphological investigations.

## ENVIRONMENTAL CONCERNS

Environmental concerns can shut down a construction project or close the bridge for a period. Among the concerns are timing windows for construction to accommodate the needs of threatened and endangered species, rewatering of the new channel, and the threat of avalanches that could reach the road.

### Wildlife Concerns

A wildlife and fisheries biologist should be consulted to verify whether any threatened or endangered species are found in the area

and, if so, whether mitigation is required. For example, seasonal construction closures for salmon spawning in Alaska or for Indiana bat roosting trees may require construction to occur during specific times (known as windows). Construction closures should be addressed in the construction specifications. Among the animals and conditions that may require construction work windows are the following:

- Fish and aquatic wildlife
  - Salmon
  - Bull trout
  - Cutthroat trout
  - Other threatened or endangered species
  - Other related concerns (passage of aquatic organisms, spawning areas, etc.)
- Terrestrial wildlife
  - Bald eagles
  - Indiana bat
  - Northern goshawk
  - Other threatened or endangered species
  - Other related concerns (nesting trees, rearing areas, etc.)

### Geological and Environmental Concerns

Many geological and environmental problems could cause a bridge to fail or collapse. Rock slides, ice dams, and falling trees are just a few of the things that can damage a bridge. Inadequate freeboard could allow ice or debris to build up and eventually wash out the bridge or damage its beams.

Dead or dying trees that could fall on the bridge and damage or destroy it should be removed. The landowner or land manager needs to give permission before trees are cut down. Because dead trees play an important role in streams, trees cut upstream should be placed in the channel below the bridge, if feasible. Avoid placing bridges under cliffs where falling rocks could damage the bridge deck or railing. Springs or seeps should be avoided. They can cause foundation problems, and wetness may cause increased decay of timber bridges and rusting of steel beams. Wetlands are a concern because of environmental problems associated with building in such areas. The following are among the possible problem areas:

- Geological concerns
  - Avalanche chutes
  - Rock slides
  - Hazard trees
  - Landslides
  - Springs
- Environmental concerns
  - Ice flows
  - Floating debris
  - Falling trees
  - Falling rocks
  - Springs or seeps
  - Wetlands

## PERMITS

The permitting process is an important part of planning a bridge, because crossings are often at environmentally sensitive sites and are generally high-profile projects. All bridges in the United States typically require one or more permits for construction. For some bridges it is best to begin work by checking with the U.S. Army Corps of Engineers and other state and federal agencies that issue the permits to ensure no surprises during permitting. Cesa et al. have prepared a good reference for state requirements and contacts (*16*). It is available from the USDA Forest Service's Wood in Transportation Program. Appendix B of that document provides information for all 50 states on contacts for bridges and low-water crossings.

## SUMMARY

Proper site investigation, attention to geomorphological indicators, and an understanding of how streams and watershed function can help alleviate problems associated with bridge location and construction. Channel classification provides a simple framework to help understand the problems that may exist at bridge locations and to help locate travel routes. Proper bridge siting requires an interdisciplinary approach and common sense in choosing the best bridge site location.

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