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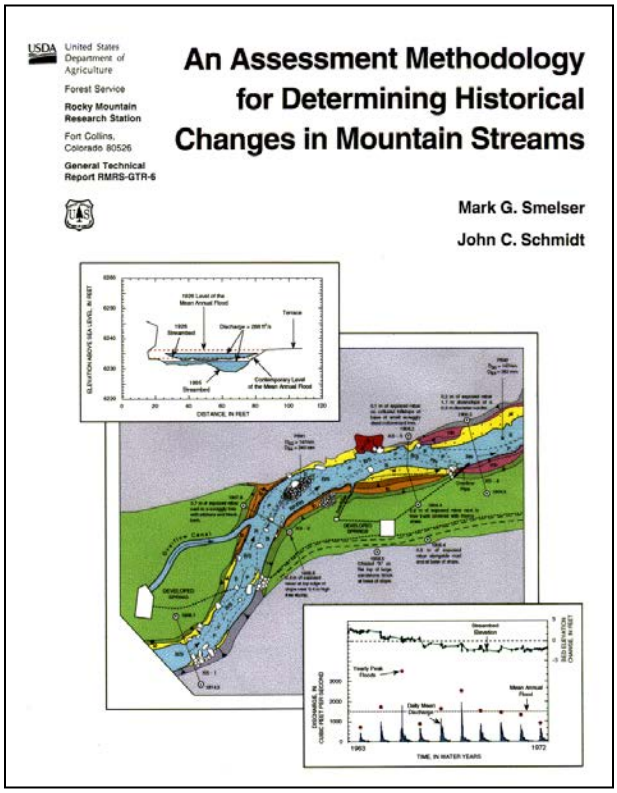
An Assessment Methodology for Determining Historical Changes in Mountain Streams

A recent publication by the Rocky Mountain Research Station, An Assessment Methodology for Determining Historical Changes in Mountain Streams by Mark Smelser and John Schmidt (General Technical Report RMRS-GTR-6) describes ways to analyze long-term stream channel change to better understand fluvial processes in mountainous regions. The methods rely on U.S. Geological Survey (USGS) stream gaging station records. The methods are designed to reconstruct stream channel histories that can be compared to histories of climate change, stream regulation, and land-use. These comparisons are useful for linking geomorphic adjustments to natural cycles, rare events, and land-use activities and thereby allow resource managers to better understand the susceptibility of mountain streams to flow regulation and land use.



Data from the USGS stream gaging network is used because:

- USGS stream gaging data is often the only historic information available for mountain streams,
- the data are quality controlled, accessible, and inexpensive to obtain for analysis, and
- compared to conventional space-for-time or paired-basin studies, these data are less expensive, quicker to analyze, and may be more site specific.

The use of gaging data has unavoidable limitations. Geographical coverage may not be as widespread as desirable because gaging sites are situated to provide the best combination of accessibility, measurement accuracy, and long-term channel stability.

Gaging stations are also frequently located along relatively stable reaches. Thus, when quantifying geomorphic change at a gage site, it is important to recognize that while these sites may be more stable than other parts of the same stream; they are not static or immune to change. For evaluating historical geomorphic change the most desirable gages are long-term stations whose point of measurement has not moved and whose bed and banks are adjustable.

Performing this analysis requires seven different files from each USGS gaging station. All except the recorder tapes are used to some degree in the historical analysis.
1. Miscellaneous working files
2. Discharge measurements
3. Level notes
4. Recorder tapes
5. Station analysis reports
6. USGS water-data reports
7. Statistical analyses of discharge data.

The publication describes the most efficient location and manner of obtaining this data which are widely disbursed throughout the organizational structure of the USGS. Since data collection at USGS gages began as early as 1895, most of the field notes have been archived. Smelser and Schmidt provide much useful information on data retrieval methods and suggestions for efficient tabulation and compilation to facilitate the analysis.

The first step in recognizing geomorphic change is to analyze the station's stage-discharge relation (rating curve). The rating relation depicts the relation between measured discharge and water surface elevation measured at the stream gage. The premise of the analysis is that if the gage datum and streambed elevation remain constant over time, then either the gage datum or the streambed elevation has changed. For the analysis to be useful, all of the data have to be corrected to a common datum.

Figure 1 illustrates the history of gage datum changes at the Ashley Creek gaging station between 1917 and 1996. The figure suggests that substantial adjustment has occurred over the period of record. The adjustment could be due to aggradation, degradation, or gage datum change. Station surveying notes are the primary mechanism for bringing all of the data to a common datum. Based on this information and other analysis, all gage heights are adjusted to the current gage datum. Once the data have been rectified to a common datum level, comparisons of changes in rating curves, streambed elevations, hydraulics geometry, and changes in channel width to a common standard are possible.

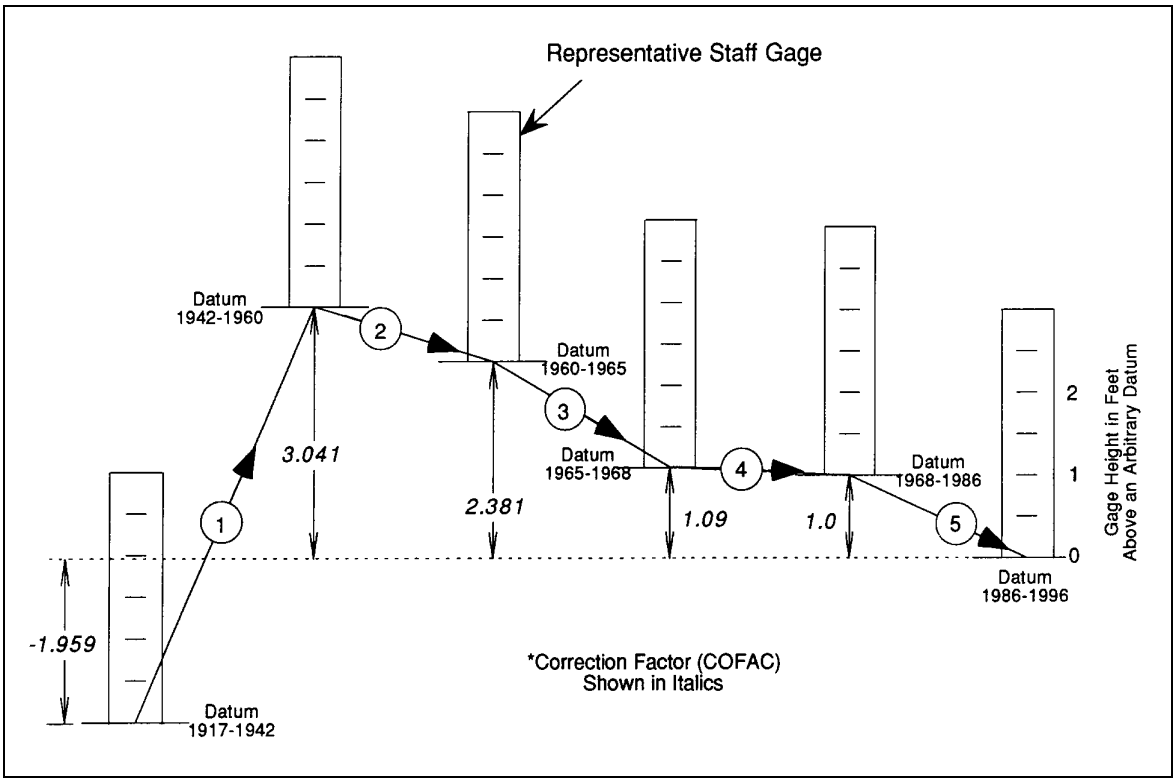


Figure 1. The history of gage datum changes at the USGS Ashley Creek gaging station relative to the contemporary 1996 gage datum.

Figure 2 illustrates the scatter of mean streambed elevation through time prior to correcting for datum changes. The data show 5 jumps (arrows) in the data distribution that are indicative of datum changes.

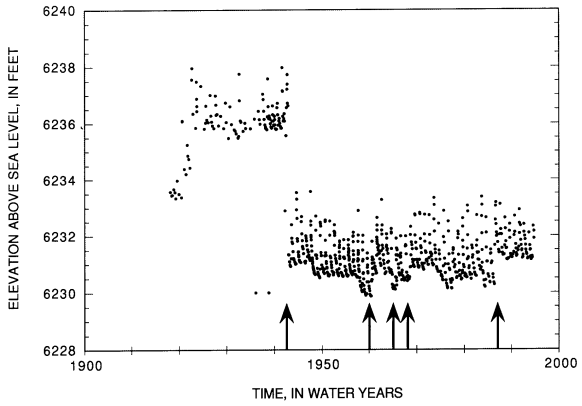


Figure 2. Plot of the mean bed elevation at the Ashley Creek gage without rectifying the gage heights

Figure 3 shows a plot of streambed elevations at Ashley Creek through time corrected to a common datum. All of the measurements were made within 50 feet of the gage. The plot shows that the streambed aggraded during the early 1920s, was stable for approximately 38 years, and then degraded rapidly during the early 1960s. The smooth curve through the data delineates the temporal trend and represents the application of a Stineman smoothing function.

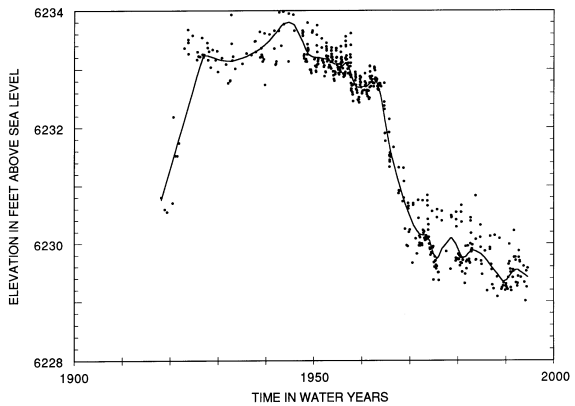


Figure 3. Plot of the mean streambed elevation of Ashley Creek for the period of record (1917-1996) using only measurements made within 50 fee of the gage.

In additional analysis, the authors examine changes to channel geometry (width, depth, velocity), changes to channel cross-section form, and changes in channel width. A common objective is to piece together the various lines of evidence to establish a story of how and why the channel changed.

Once geomorphic change has been documented and the timing of adjustment established, the geomorphic and hydrologic histories are compared and contrasted by examining geomorphic change with respect to hydrographs for the period of record. One outcome of this comparison is to try to determine possible cause and effect hypotheses for channel change. Figure 4, which compares streambed elevation to annual peak discharge, illustrates one such analysis. The plot indicates that changes in the streambed may be related to changes in the hydrologic regime, but peak flood events are not directly responsible for streambed elevation changes.

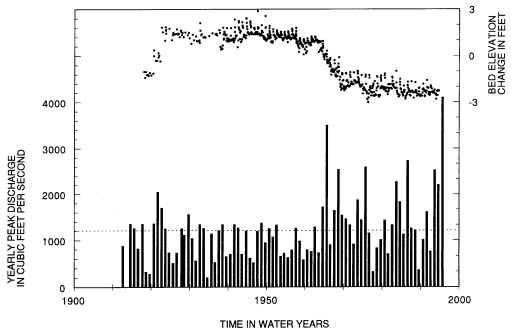


Figure 4. Comparison of minimum streambed elevations of Ashley Creek for the period of record to annual peak discharges.

Smelser and Schmidt also advocate the use of detailed geomorphic mapping to assist with data interpretation and provide specific guidance for mapping. The cover of the publication shows an example of a detailed geomorphic map prepared for the study.

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Designing Forest Stream Crossings using Bankfull Dimensions and the Computer Program XSPRO

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Roads and stream crossings are commonly associated with land use and development on public lands in the mountainous regions of the western United States. When inappropriately placed or sized, stream crossings can have long-lasting detrimental effects on water quality, channel stability, and aquatic habitats (Furniss et al., 1991). Consequently, it is important that aquatic specialists work closely with forest engineers to design and select a crossing structure that is consistent with expected channel dimensions.

On the Fortine District, we are finding that many culvert failures occur because they are either underdesigned or not consistent with prevailing stream geomorphology. In an effort to improve upon the existing situation, we are exploring the use of geomorphic concepts in the design of forest road crossings. Implicit in this approach is the recognition that stream channels adjust to prevailing flow and sediment conditions in the watershed and that stream crossings must allow for the orderly passage of flow and sediment to maintain the long-term integrity of the channel.

This article describes an evolving methodology that we are using on the District to design stream crossings on forest access roads. The process provides an avenue for aquatic specialists to work with engineers to design stream crossings that preserve constant channel dimensions. The technique has been used mostly on small, incised headwater streams (drainage area < 5 km2 with an average bankfull width < 3 meters) as well as on larger fourth order channels (drainage areas of 90 km2 with bankfull width of 7 meters). The process relies upon accurate field measurements of the equilibrium channel and on hydraulic calculations derived from the computer program XSPRO (Grant et al. 1992).

Planning a Stream Crossing

The District uses the following steps to design stream crossings for forest access roads:
(1) assessment of channel equilibrium,
(2) calculation of hydraulic variables,
(3) determination of design flows, and
(4) post-project monitoring.

Assessing Channel Equilibrium

An assessment of watershed condition is a step often omitted in the design process. Many watersheds have experienced some modification in their natural hydrology, riparian, or channel conditions. A watershed assessment determines how the stream may be adjusting to upstream conditions. The assessment provides information that can be used to design a stream crossing that is consistent with existing basin conditions.

Dave Rosgen (1996) describes a channel classification scheme and a hierarchy of inventory and assessment that can be used to determine the existing and potential state of a stream reach. The construction of a stream crossing on an reach that is out of equilibrium often puts the crossing at risk.

Calculating Hydraulic Variables

A hydraulic analysis based on good site surveys, proper reach selection, and careful field techniques is essential (Grant et al., 1992). At a minimum, the site survey should consist of several cross-sections located near the crossing site. Cross-sections should be located in representative reaches that are uninfluenced by the road or outside factors. Information collected at each site should include: cross-section dimensions that extend out onto the floodplain, bankfull dimensions of width and depth, slope, longitudinal profile, particle size distributions, and entrenchment. Harrelson et al. (1994) provide an excellent discussion on how to conduct a site survey.

The data collected during the site survey is entered into the computer program XSPRO. The program determines hydraulic variables such as: cross sectional area, wetted perimeter, hydraulic radius, slope, roughness, velocity, and shear stress. Collecting discharge at the site over a range of flow conditions can be useful to verify the accuracy of the hydraulic modeling.

Understanding bankfull dimensions is an important part of designing a stream crossing. The crossing should be designed to maintain sufficient shear stress to perpetuate sediment transport through the reach. In many cases, this requires that the inlet configuration and crossing structure preserve the bankfull dimensions of width, depth, and slope. Significant deviation from bankfull dimensions can lead to undesirable geomorphic adjustments.

Determining Design Flows

Forest Service direction in the Columbia River Basin currently requires that stream crossings be capable of passing a design flow equivalent to the 100-year flood (Q100) in key watersheds (USDA Forest Service, 1995a). Empirical relationships, channel cross sections, and the computer program XSPRO can be used to estimate the flow volume and cross sectional area of flow events.

The bankfull depth can be related to design flood depth using a dimensionless rating curve (Dunne and Leopold, 1978). The curve shows the relationship between depth (d) at a specific recurrence interval flow to the mean depth at bankfull (d_{bkf}). The ratios of d/d_{kfb} have been constructed by various authors in different parts of the country and are shown in Table 1.

Recurrence Interval (years)	Eastern U.S.	Idaho	Western Cascades, WA	Puget Lowland, WA	Average
1.5	1.0	1.0	1.0	1.0	1.0
5	1.1	1.2	1.3	1.3	1.2
10	1.2	1.3	1.5	1.4	1.4
50	1.8	1.4	2.0	1.7	1.7
100		1.5	2.2	1.8	1.8

Table 1 - Values of the ratio d/d_{bkf}, for various values of recurrence intervals, from four regions in the United States. Adapted from Dunne and Leopold 1978:648. (Note: these units use mean d_{bkf}).

The consistency of the relationship between bankfull depth and depth of a recurrence interval flood is very useful to the design engineer or hydrologist. Once the bankfull elevation has been carefully identified in the field (USDA Forest Service, 1995b), the depth of the design flow can be estimated using the d/dbkf relationship. The d/d_{bkf} relationship, cross sectional data, and XSPRO can then be used to determine the elevation (and cross sectional area) inundated by a given recurrence interval flood. The computer program XSPRO is used to estimate the discharge, cross sectional area, depth, and hydraulic characteristics of the design flow event. The designer must be aware however, that there is variation in the dimensionless ratio values for depth as a function of watershed conditions, stream type, and floodplain shape.

Comparing the geomorphic estimates of design flows determined with this approach with regional empirical flow estimation equations such as Parrett et al. (1983), Omang (1992), or with other techniques is strongly recommended. The comparison will assure that the geomorphic estimates of flood flows are reasonable.

Just as important as determining the magnitude of the design flow is the selection of the appropriate type of crossing structure to be employed. Ideally, the crossing structure should allow overbank flows (floods) to pass unimpeded at the appropriate floodplain elevation and slope. Structures that constrict the flow of water along the floodplain can precipitate upstream deposition and downstream scour. Therefore, streams with a defined floodplain should receive a crossing structure that avoids constricting overbank flows. The identification of channels with a defined floodplain can be made using the entrenchment ratio (Rosgen, 1996).

The entrenchment ratio compares the width of the flood-prone area to the surface width of the bankfull channel. The entrenchment ratio identifies streams with defined floodplains. Streams with a well developed floodplain (entrenchment ratio > 2.2) should have flows greater than bankfull conveyed on the floodplain using either a bridge or a multiple culvert system. Bridges can easily be designed to pass flows along the floodplain and are the preferred choice. However, economic constraints on forest access roads often preclude their use. Therefore, multiple culverts may be an option to consider on small streams with a well defined floodplain. Multiple culvert designs should be used with caution because large flows extending onto the floodplain often carry a large load of organic debris that may plug culvert entrances.

Streams without a well-defined floodplain or incised streams (entrenchment ratio 1.0 - 1.4) can be expected to accommodate design flows in a single culvert since entrenched channels tend to increase in depth more rapidly than in width as discharge increases. Figure 1 shows a culvert installation in an entrenched stream.

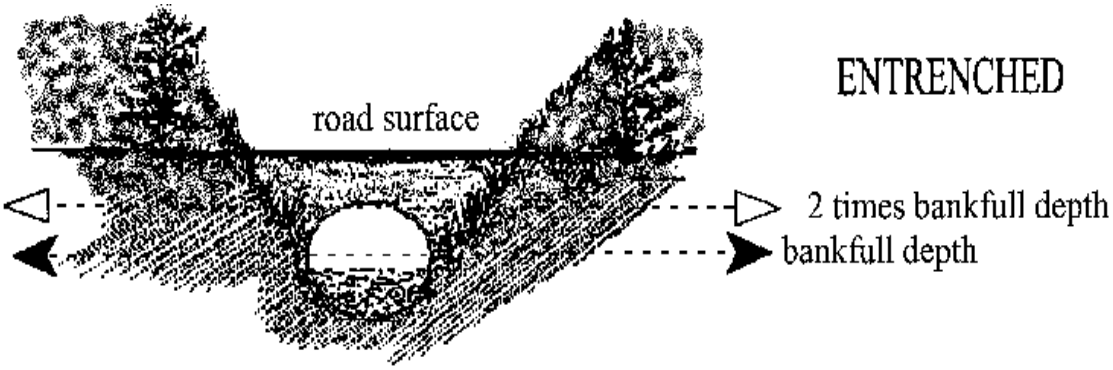

Figure 1. Example of a culvert installation in an incised channel typical of the types of streams where geomorphic design principles are being applied on the Fortine Ranger District.

Post-project Monitoring

To prevent the additional engineering and resource costs associated with failed stream crossings, monitoring should be incorporated into stream crossing designs. The establishment of a permanent benchmark and monumented cross-sections during the site survey facilitates future monitoring. Monitoring information collected through time will aid designers in future projects and may suggest problems before structures fails.

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An improved Windows-based version of XSPRO, called WinXSPRO, is under development by the Stream Systems Technology Center. The software will be available for distribution later this year. Look for an announcement in a future issue of STREAM NOTES.