STREAM SYSTEMS TECHNOLOGY CENTER

STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

April 1993

Would the REAL BANKFULL Please Stand Up!

Dunne and Leopold point out in their book, Water in Environmental Planning:

> "The bankfull stage corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphological characteristics of channels."

Technical literature in such diverse applications as fisheries inventories, engineering studies, riparian surveys, and sediment studies commonly references bankfull measurements. Ideally, a channel feature used as an index to discharge will rely on unique, recognizable features of the channel. Although simple in concept, field identification of bankfull stage is often difficult. The purpose of this article is to explore the variety of ways in which channel characteristics and bankfull stage have been defined in the past with the intend of moving toward more consistent usage of terminology.

Judge Behrman of Colorado's Water District 1 noted the disparity of viewpoints among technical experts about bankfull in his "Memorandum of Decision and Order."

> "The use of the term 'bankfull' is one of the somewhat confusing aspects of this case. The applicant and its experts use it in the sense employed by Dr. Leopold. In their usage bankfull flow is essentially the same as the channel forming flows. It is frequently attained when water reaches a point somewhat below the top of the physical bank of a stream. On the other hand the objectors and their experts use 'bankfull' in the sense of reaching the top of the physical bank of the stream."

To fully understand bankfull, one needs to understand floodplains and terraces in the scientific context of the geomorphologist rather than in the context of engineering.

From an engineering perspective, floodplains are the broad valley flats adjacent to rivers which are subject to flooding This view is concerned with the economic damage that results from a variety of potential overbank flows, such as the 100-year flood. Using this terminology, there is an infinite number of floodplains, for example, the 100-year, 50-year, etc. The most meaningful bankfull for the engineer is therefore the valley flat.

In contrast, the most meaningful level for the fluvial geomorphologist is what some call the "active floodplain," or more commonly, simply the floodplain. Fluvial geomorphologists in general define only one floodplain; the one constructed under the present climate regime along the river's current banks by relatively frequent discharges.

STREAM NOTES *is produced quarterly by the Stream Systems Technology Center, Fort Collins, Colorado.*

The PRIMARY AIM *is to exchange technical ideas and transfer technology among scientists working with wild-land stream systems.*

CONTRIBUTIONS *are voluntary and will be accepted at any time. They should be typewritten, single-spaced, limited to two pages in length. Graphics and tables are encouraged.*

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IN THIS ISSUE

Most rivers banks have a relatively flat area commonly referred to as the floodplain. The river constructs the floodplain in the present climatic regime and overflows it at times of high discharge. The valley floor often also contains additional flat areas at higher elevations, alternatively called benches, terraces, or the inactive floodplain. The term terrace is the preferred one for these abandoned floodplains. They are considered abandoned because they are inundated so rarely that they are no longer actively growing under present alluvial processes.

Modern floodplains on mountain streams tend to be narrow, often only three feet wide. Deposition from overbank flows and lateral sediment deposition at the inside of meanders build the floodplain as the channel moves across the valley. In some areas, the valley flat may be the floodplain while in others, the floodplain may actually be a 1 to 3 meter wide surface, lower than the valley flat, contained within the banks of the channel. The channel below the floodplain usually has little or no vegetation. Floodplains tend to be very confusing since they may be discontinuous, often only evident on one border of the channel, or completely absent.

Entrenched channels are examples of a situation where the valley flat is not synonymous with bankfull. Even though the higher valley flat level has well delineated bank tops, water rarely inundates it, if ever under present climatic conditions. Entrenched ephemeral channels are another example of a high apparent reference level which can deceive the observer because it lacks relationship to the present flow regime. In these situations, bankfull stage is found within the entrenched channel and generally identified by vegetation or grain size change indicators.

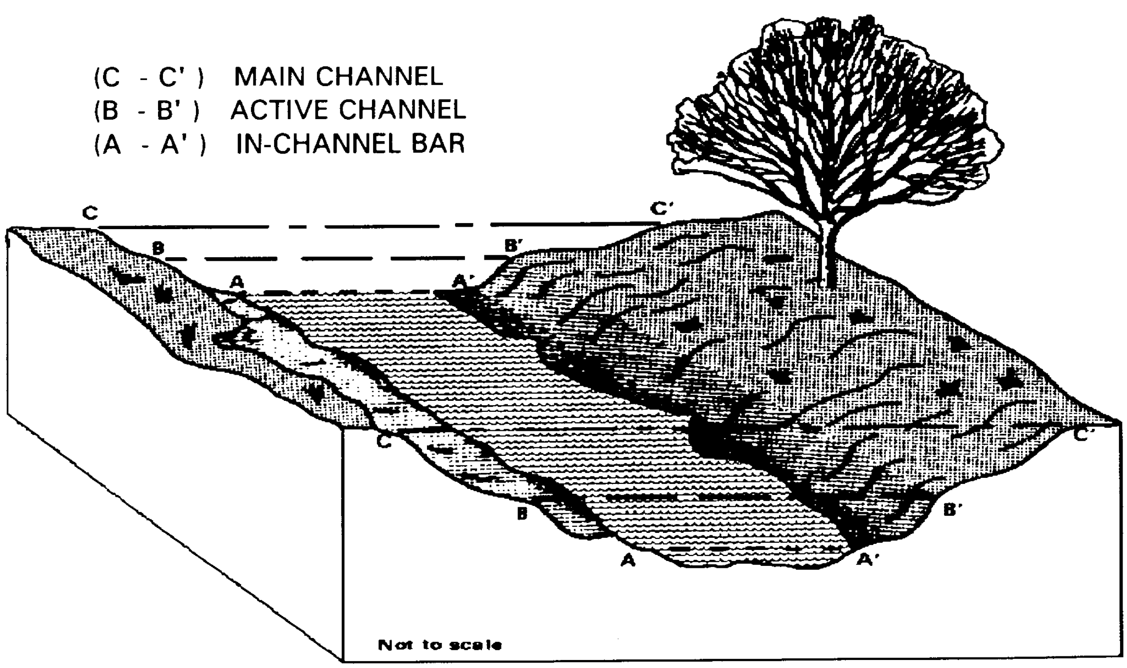
Kenneth Wahl of the U.S. Geological Survey in his 1984 publication, "Evolution of the Use of Channel Cross-Section Properties for Estimating Streamflow Characteristics," discussed three geomorphic channel reference levels:

1. Within-channel bars,
2. Active channel section, and
3. Main-channel section.

The three reference levels are illustrated in the figure below adapted from Wahl (1984).

Within-Channel Bars

Studies in Nevada, California, Colorado, Utah, Kansas, and the Missouri River basin have used within-channel bar features. Within-channel bars are generally defined as the tops of channel or point bars. In mountain rivers, this is the wide gravely-bouldery strip, which dries up during the low-water period. Several studies also use vegetation criteria such as having the channel below the reference line generally free of non aquatic vegetation.



Active Channel

Studies in the western United States, the Missouri River basin, Montana, Kansas, New Mexico, Ohio, and Tennessee have used the active channel, a feature somewhat higher than in-channel bars. The active channel is described by Osterman and Hedman (1977) as "a short-term geomorphic feature subject to change by prevailing discharges. The upper limit is defined by a break in the relatively steep bank slope of the active channel to a more gently sloping surface beyond the channel edge. The break in slope normally coincides with the lower limit of permanent vegetation so that the two features, individually or in combination, define the active channel reference level. The section beneath the reference level is that portion of the stream entrenchment in which the channel is actively, if not totally, sculptured by the normal process of water and sediment discharge."

Main Channel Section

Studies in Wyoming, Idaho, Montana, and Western mountain areas have used the main channel section. The main channel section is variously defined by breaks in bank slope, the edges of the floodplain, or the lower limit of permanent vegetation. Hedman and Osterkamp in their 1982 publication, "Streamflow Characteristics Related to Channel Geometry of Streams in Western United States," use the terminology bankfull when referring to this level. They define it as the level of the active floodplain or the stage at which overbank flooding occurs.

Comparing the above definitions with the various description of bankfull stage, it is evident that the main-channel section and the bankfull section are the same for perennial streams.

Garnett Williams of the U.S. Geological Survey in his 1978 paper "Bank-Full Discharge of Rivers" identified 10 different definitions for bankfull flow used in earlier studies and immediately proceeded to add an eleventh definition, his own. He points out that the eleven different bankfull levels could yield up to eleven different solutions for the quantity of bankfull discharge. Especially for wide rivers, small differences in stage have significant influence on the value for bankfull discharge.

Six of the bankfull definitions require recognition of sedimentary surfaces:

1. The height of the valley flat (*Nixon, 1959; Woodyer, 1968; Kellerhals, 1972; Dury, 1973*).
2. The elevation of the active floodplain (*Wolman & Leopold, 1957; Leopold & Skibitzke, 1967; Emmett, 1972, 1975*).
3. The elevation of the low bench (*Schumm, 1960; Bray, 1972*).
4. The elevation of the 'middle bench' for rivers having three or four overflow surfaces (*Woodyer, 1968*).
5. The elevation of the most prominent bench (*Kilpatrick & Barnes, 1964*).
6. The average elevation of the highest surface of the channel bars (*Wolman & Leopold, 1957; Hickin, 1968; Lewis & McDonald, 1973*).

Two of the definitions require observations or measurements of boundary features:

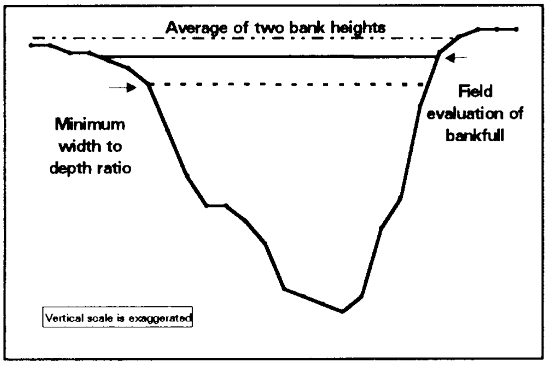
7. The height of the lower limit of perennial vegetation, usually tress (Schumm, 1960; Sigafoos, 1964; Speight, 1965; Nunnally, 1967; Bray, 1972).
8. The elevation of the upper limit of sand-sized particles in the boundary sediment (Nunnally, 1967; *Leopold & Skibitzke, 1967)*.

Three of the definitions required measured cross sections:

9. The elevation at which the width/depth ratio of the cross section becomes a minimum (*Wolman, 1955; Harvey, 1969; Pickup & Warner, 1976*).
10. The stage corresponding to the first maximum of the bench index, as defined by Riley (*1972*).
11. The stage corresponding to a change in the relation of cross-sectional area to top width (*Williams, 1978*).

Williams eliminated six of the above from further study for a variety of reasons. The valley flat (#1), the active floodplain (#2), the minimum W/D ratio (#9), the Riley bench index (#10), and the cross-sectional area versus width relation (#11) received further evaluation. The valley flat was eventually also eliminated as infeasible because of its lack of existence in some cases, the difficulty of defining it, or its high relative level in entrenched channels.

The cross section diagram at the top of the next page illustrates alternative bankfull levels that might be identified from the above definitions. One can readily see that slight differences in elevation among the various levels make large differences in discharge.



Williams encourages investigators to clearly specify the overflow surface (active floodplain, valley flat, etc.) they use as their definition of bankfull. Williams visually identified the active floodplain in the field as bankfull stage corresponding to flow records. For gaged sites, Williams suggests obtaining bankfull discharge from the station's rating curve, with bankfull gage height determined from a longitudinal profile of the floodplain along the entire reach. At ungaged sites, bankfull discharge can be estimated from the empirical equation developed in his paper ($Qb = 4.0Ab^{1.21}S^{0.28}$) or from the Manning equation, with the resistance coefficient *n* estimated at the field site for bankfull flow.

Forest Service Bankfull Definitions

The following bankfull definitions apply to the Forest Service channel maintenance procedure. Bankfull stage is the water surface elevation which fills the self-formed channel to the level of the active floodplain. Bankfull stage corresponds to the level where flooding begins. Therefore, floodplains inundate whenever streamflow in the adjacent alluvial channel exceed bankfull stage. The floodplain in this context is the relatively flat surface adjacent to the alluvial channel, which is being formed or constructed from sediment deposited by streamflow from the stream in its present condition and in the present regime and climate. In some areas, the floodplain may be the valley flat while in other areas, such as mountain streams, the floodplain may be a narrow (1 to 3 meter wide) inconspicuous overflow surface contained within the channel banks.

The Forest Service's channel maintenance procedure field determination of bankfull stage relies on several indicators rather than just one. Hydrologists look for an integrated combination of the limit of perennial vegetation, elevation of depositional features, change in grain size, break in slope, and other features. These indicators are interpreted through professional judgment to reach a decision as to the best estimate of bankfull stage. Comparison to bankfull flows at nearby gaging stations often provides a useful guide to the consistent identification of the correct bankfull stage.

For additional background information on this subject see:

Hedman, E.R. and W.R. Osterkamp, 1982. Streamflow characteristics related to channel geometry of streams in western United States. U.S. Geological Survey Water-Supply Paper 2193. 17 p.

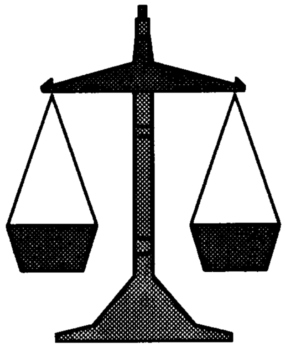
Wahl, K.L., 1984. Evolution of the use of channel cross-section properties for estimating streamflow characteristics. U.S. Geological Survey, Selected Papers in the Hydrologic Sciences, 1984, U.S. Geological Survey Water-Supply Paper 2262, pp. 53-66.

Williams, G.P., 1978. Bank-full discharges of rivers. Water Resources Research 14(6):1141-1154.

Thomas Dunne and Luna B. Leopold, 1978. Water in environmnetal planning. W.H. Freeman and Company, New York.

Meaningful reliance on bankfull as an indicator of flow depends on a rigorous and diligent application by the field hydrologist. Less than a rigorous application will provide haphazard results that discredit the method and observer.

COLORADO WATER DIVISION 1 COURT CASE DECIDED



On February 12, 1993 Judge Robert Behrman issued a **"Memorandum of Decision and Order"** pertaining to Forest Service Federal reserved water rights claims for channel maintenance flow purposes in the Platte River basin in Colorado's Water Division 1.

The United States, acting through the Forest Service, claim for instream flows based on the Organic Act interpretation of favorable conditions of water flows was challenged by the State of Colorado and water conservancy districts in northern Colorado that divert water from National Forests. The government argued that it needed to keep a certain amount of water in the National Forests to protect stream channels and timber. Opponents feared future development of water storage projects would be nearly impossible if the water rights were granted.

The case which started in 1976, went to trial in 1990, and closing arguments were made in March 1992. During the one year duration of the trial, the opposing sides brought forth 45 witnesses and 1,500 exhibits for the court's evaluation. The case was unusual in that about 60 percent of the testimony dealt with highly technical matters of hydrology and geomorphology.

The following represents the paraphrased views of the Court and not necessarily those of the Forest Service.

Judge Behrman denied the reserved water rights claims of the Unites States for channel maintenance purposes. The court, however, granted the United States reserved water rights for administrative sites and fire-fighting purposes.

In reaching his decision, the judge relied heavily on wording of the Supreme Court from the Rio Mimbres decision (United States v. New Mexico, 1978) in which the Court stated, "Congress intended that water would be reserved only where necessary to preserve the timber or to secure favorable water flows for private and public uses under state law." Expanding on this, Judge Behrman concluded that "development was a primary aim of the forest legislation, and the Supreme Court of the United States has determined that domestic and irrigation use was the principal purpose of Congress in securing favorable water flows."

The judge noted that the South Platte basin contains more than 70 percent of the population of Colorado which depends on water stored in numerous reservoirs in the plains and on National Forest lands. He felt that storage higher in the watersheds is important to the maintenance of equable flows throughout the season of use. He noted that the Creative and Organic acts stressed the importance of discouraging flood flows at the time of spring runoff and encouraging flows later in the season. The judge concluded that the effect of granting the claims of the United States would accentuate flood flows in the springtime. He saw this as the exact opposite of what was desired by those who were influential at the time of the enactment of the Creative and Organic Acts.

The judge remarked that the Forest Service has broad powers to regulate the construction of irrigation structures within the National Forests and to control the ability of others to make diversion within the forests. He concluded that the permit system has over the years proven adequate to control development to an extent consistent with the purposes of the National Forests. In summary, the judge concluded that without reserved water rights the Forest Service would have to make a case-by-case evaluation of claims, an approach he judged to be technically preferred.

Judge Behrman concluded that Congress and the early administrators of the National Forests were aware that diversion would have some effect on stream channels. He thought the goal of maintaining channels in their present condition to be "impossible if the policy of making national forests available for use, including recreational purposes, is to be continued." In summary, he concluded:

> "It is this court's view that channel maintenance is necessary to effectuate a purpose of the national forests. But such maintenance is required only to a reasonable degree consistent with both the requirements of stream flows and the necessities of efficient irrigation and domestic use. Intelligent administrative regulation can achieve such maintenance in the future as it has for nearly one hundred years, while flexibility of use of the national forests and their resources can be maintained."

In commenting on the technical evidence and field trips conducted during the course of the trial, Judge Behrman concluded:

"In summary, it is the court's view that although the field trips and the evidence showed some changes in stream characteristics which may be as a result of the diversions in question, those changes did not seriously impair the integrity of stream channels. Such changes, even if they were caused by diversions, are well within the bounds which a reasonably informed person must have contemplated when diversions in the national forests were allowed in the first place. Considering that some of those diversions are a century or so old, they cannot be viewed as a threat to the purposes of the national forests."

The judge stated that no evidence was introduced of any substantial additional flood damage caused because of presently existing diversions. He also contested the notion that streams in the National Forests would be totally dried up, citing the nature of Colorado water law which makes this a practical impossibility.

Finally, the judge concluded that the United States failed to identify the minimum flows necessary for channel maintenance stating that "the methodology ... fails to define 'the precise quantity of water necessary to satisfy such purposes' even assuming that the theories of the applicant regarding the necessity of the claimed flow is correct."

He specifically identified:

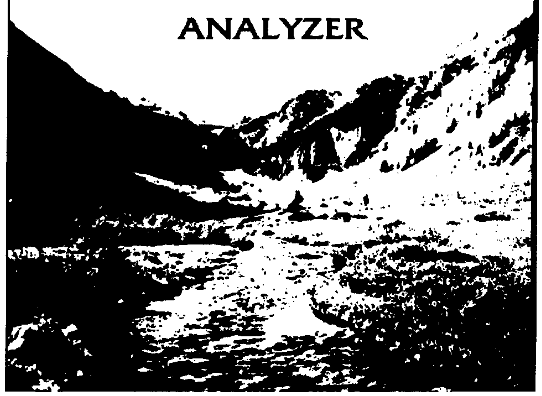
1. The method used to estimate bankfull at the quantification points is fatally flawed.
2. The method used to predict average annual runoff at quantification points is inaccurate.
3. The methods used by applicant to estimate bankfull and mean annual runoff at quantification points give hydrologically inconsistent results.
4. The chapter 30 procedure was used in situations to which it was not intended to apply.
5. The claimed water rights would fail to give applicant the flows it desires.
6. The applicant inferentially admits the inaccuracy of its quantifications, and that the amounts claimed in its present applications are not the minimum amounts required.

In his decision Judge Behrman recognized the technical difficulties faced by the Forest Service. He concludes, "It was confronted with a monumental problem, one that is perhaps insurmountable."

The decision and any future actions are currently being studied by the Forest Service, the Office of the General Counsel, and the Department of Justice.

XSPRO:

A CHANNEL CROSS-SECTION ANALYZER



Since release of BLM/FS Technical Note 387 and the XSPRO Channel Cross-section Analysis Program (Version 1.1), the authors have discovered an error in the output table that occurs when metric units are selected for the analysis. All values in the output table are in metric units, except for average stream velocity. Although the units listed at the top of the velocity column are meters per second, the values are given in feet per second and have not been converted to metric units. The error is not carried into the discharge column, which gives correct discharge values in cubic meters per second. However, a simple application of the continuity equation ($Q=V*A$) reveals that the velocity values must be converted from feet per second to meters per second for the equation to be satisfied. The error in the output table will be corrected in subsequent releases of the XSPRO program; however, the schedule for revisions to the program is uncertain at this time.

Should you discover any other errors with the program or experience any other problems with its execution, please document the error or the key stroke sequence you used and send the information to the STREAM TEAM. The information will be used to improve future revisions of the program. Likewise, if you have suggestions for changes to the program, send them to the STREAM TEAM for consideration during the revision process.

DR. BURCHARD HEEDE RETIRES

Dr. Burchard Heede retired recently after 34 years with the Rocky Mountain Forest and Range Experiment Station. During that time, he authored over 80 papers dealing with gully rehabilitation, soil erosion control, stream dynamics, and geomorphic relationships affecting erosional processes.

Dr. Heede began his career with the Rocky Mountain Station in 1958 where he conducted a pioneering research effort on the Alkali Creek Watershed Rehabilitation Project in western Colorado. The project serves as a landmark research and demonstration project on the implementation of engineering and vegetation principles for gully control purposes.

Most technical specialists in the Forest Service are familiar with Dr. Heede's state of the art publication, "Gully Development and Control," (USDA Forest Service Research Paper RM-169) which came out of this effort. Over time, Burchard extended his early work on gully formation and control into a unified body of knowledge which addressed the environmental and geomorphic implications associated with watershed restoration.

Dr. Heede is also well known for his work with stream channel dynamics. Burchard developed an overview publication, "Stream Dynamics: An Overview for Land Managers," (USDA Forest Service General Technical Report RM-72) specifically targeted toward land managers to help them analyze a stream's behavior and expected future development.

Dr. Heede was frequently requested to provide guidance and recommendations on erosion and stream related projects to all of the land management agencies. The technology developed by Burchard has been effectively transferred to the user community not only because of the soundness of the principles developed, but also because of Dr. Heede's sensitivity and responsiveness to user requests and needs.

Just before the end of his distinguished career, Dr. Heede received the Forest Service's Distinguished Science Award for sustained research productivity and technology transfer. We wish to extend our thanks and appreciation to Burchard for a job well done and wish him all the best upon his retirement.

Editorial Policy

To make this newsletter a success, we need **voluntary contributions** of relevant articles or items of general interest. YOU can help by taking the time to share innovative approaches to problem solving that you have developed.

Please submit typed, single-spaced contributions limited to two pages. Include graphics and photos that help explain ideas.

We reserve editorial judgments regarding appropriate relevance, style, and content to meet our objectives of improving scientific knowledge. Send all contributions to: Stream Systems Technology Center, Attention: STREAM NOTES Editor.

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STREAM NOTES

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IN THIS ISSUE