Bankfull Discharge in Mountain Streams in the Cauca Region of Colombia

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Abstract: A flow considered effective or dominant in the process of stable channel forming, is the bankfull discharge associated to frequency between 1 and 2 years with an average of 1.5 year, according to Dunne and Leopold, 1978. Bankfull discharge or forming discharge is the flow which defines the morphological characteristics of the channel such as bars, meanders and curves. In this article, different approximations for channel forming discharge are explored from the morphological and statistical point of view, in order to establish the frequency of the forming discharge for some rivers in the Andes Region of the Department of Cauca, Colombia

Key Words: Forming discharge, bankfull discharge, mountain streams

1   Introduction

Cauca Region in Colombia has specific geologic, topographic and hydrologic characteristic as high slopes, and mean annual precipitation near 3000 mm, that produces particular behavior in the river evolution processes. Usually, the magnitude of the forming discharge does not have associated a specific return period and its determination has been done in a subjective way. In

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this paper, a different approximation to forming discharge determination from morphologic and statistical point of view is explored and the mean frequency for the forming discharge for some mountain streams in the Andean region of Colombia is proposed.

2 Basin Information

Colombia is a country located in the northwestern corner of South America, bordered by two oceans, the Atlantic and the Pacific ocean, and it is plenty of rivers that drain to those oceans and to both the Orinoco and the Amazon basins. The Andes, which is the longest and highest mountain ranges in the world, extends through South America from northern Colombia to southern Chile.

Cauca State is located in the southwestern of Colombia, occupying an area of 31627 km². The main river sources of the country, like Magdalena and Cauca Rivers (Figure 1) are located in this region.

The state has five main watersheds: Patia basin with a drainage area of 5334 km², Magdalena basin has an extension of 3144 km², Pacific basin has 10436 km², Caqueta basin has 4990 km² and finally, the Cauca basin with an area of 7394 km², is the region of interest of the present paper. This region receives a mean annual rainfall of 2500 mm.

Figure 1   Basin Location.

3 Methods

3.1 Forming discharge

The stream morphology is due to the balance between the water force and the bed and bank resistance associated to material and bed forms. As a result of those complex processes, different geometry of channels are observed. The concept of bankfull or forming discharge was introduced by Luna Leopold (1963) as the flow which defines the morphologic characteristics of the chan-

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nel such as bars, meanders and curves. The Uniformism trend in geomorphology affirms that is the frequent bankfull discharge which forms the channel and not the extremes infrequent events.

Different concepts for estimating the forming discharge has been used (EPA, 1998)

- Bankfull discharge
- Specific frequency discharge
- Effective discharge.

3.1.1   Bankfull discharge

The bankfull discharge does not have a constant frequency or neither is the most effective flow; in fact, it has a reference level that can be defined reasonably easy (Knighton, 1984). The simplest definition is referred to the discharge that almost floods the active floodplain, Figure 2, which is a flat adjacent zone to the channel that is flooded with a frequency of approximately two years (Wolman and Leopold 1957). Usually, the average discharge fills the about 1/3 of the channel capacity and it is exceeded just 25% of the time (Leopold, 1994).
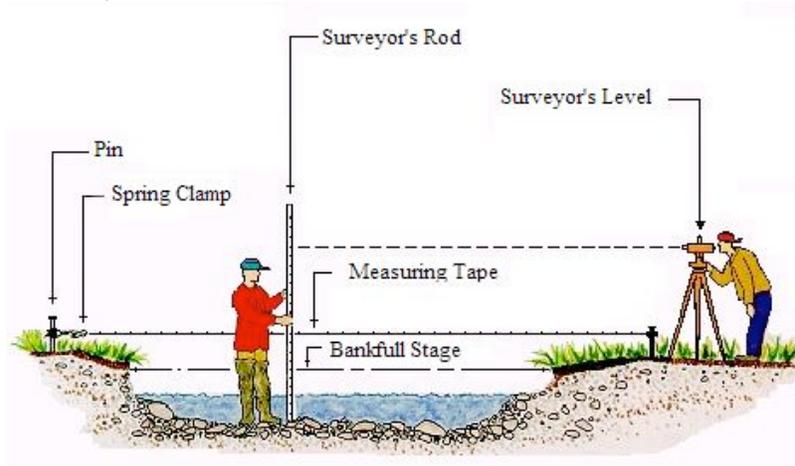

Figure 2. Bankfull level in a typical cross section, modify from Rosgen, 1996

In the forming discharge estimation process is important to determinate the bankfull level, which is associated to changes in slope of the banks, changes in the colors of the soil or even in the vegetation. There are different indicators to define the bankfull level, as follows:

Floodplain: are the best bankfull level indicator, especially in low slope and meandering streams, and it is almost impossible to identify in mountain streams.

Top Level of Point Bar: the bars are depositional features in the internal part of a meander curve. Top level of point bars is the minimum possible level of the bankfull discharge, because it is the beginning of floodplain formation by depositional processes.

Changes in Vegetation: The minimum level of perennial vegetation in the bank or even a change in vegetation density. This indicator is especially deceitful in tropical regions, because the vegetation has a fast regeneration period due to the complex processes of growing associated to enough rainfall and sun exposition through the whole year. When this indicator is used, a lower level of bankfull discharge is frequently selected.

Slope changes in the banks: usually a bank has multiple changes in slope, but a change between an approximated vertical bank to a flat surface is the best bankfull indicator, specially in low slope and meandering streams.

Bank material changes: any variation in particle size distribution from gravel to fine material may indicate a change in the frequency of floods.

Low cut in bank: when the bank has perennial vegetation, the frequent discharge form a cut under the roots that provides a good indicator for deep channels without a well defined floodplain.

Flooding marks: they are tracks of frequent floods, so maybe the high level mark is associated to bankfull discharge.

3.1.2 Specific frequency of forming discharge

Wolman and Miller (1960) suggested that the work done over a time period for a specific event with an associated sediment load, depends from the event frequency. They determined that the maximum work is done by intermediate floods. A critical or dominant discharge in forming stable channels is the bankfull discharge[4] associated to frequencies between 1 and 2 years, with a mean of 1.5 year (Dunne & Leopld, 1978).

In arid regions the bankfull discharge frequency is higher, and gets values with recurrences near 25 year. Most of the British rivers has a bankfull discharge with frequencies between 0.5 and 2 times per year (www.jondot.com). Chow (1988) suggests that the forming channels is associated to 2.33 years return period (Gumbel probability distributions), although the return period could be as high as 10 years. Mejia (2001) determined a return period of 1.3 years for the forming discharge in 29 mountain streams in Antioquia, Colombia.

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[4] Discharge that just fills the channel, at the point the water begins to overflow onto floodplain (Rosgen, 1996).

3.1.3   Effective discharge

The effective discharge is defined as the discharge that carries the largest amount of sediment over a long period of time, Leopold, 1994. The effective discharge is the maximum value obtained by multiplying the frequency of flows and sediment transport rate. The advantage of using the effective discharge instead of forming discharge is on the use of streamflow and sediment data in opposition to estimation using morphologic indicators.

This concept was introduced initially by Wolman and Miller (1960) and represents the individual discharge that is responsible for the main sediment transport over a time period. Although, in fact, there is a discharge range around the effective discharge that also transport an important amount of annual sediment load.

The original proposal considered the suspended sediment load in estimating the effective discharge, although, more recent researches have shown that channel morphology is determined by the gravel sediment load (Leopold, 1994) and many different researchers have used the bed load to estimate the effective discharge (e.g., Leopold, 1994; Andrews and Nankervis, 1995; Emmett and Wolman, 2001). Since there is no records of sediment loads for the streams used in this research, this approach was not used.

3.2   Forming discharge estimative.

Local measurements of the main hydraulic and geometric characteristics in some mountain stable streams were carried out in Cauca region. Specific reaches were selected using some basic criteria: straight channel, stable flows, easy forming channel indicators as floodplains, changes in slope, changes in bank material and type of vegetation. In this particular aspect there were some difficulties that could allow an incorrect estimation of the forming discharge due to the fast growing process of the lichens and riparian vegetation, associated to enough rainfall and sun exposition during the entire year in tropical region, with a time period uncorrelated with forming discharge frequency. Finally, the main change in bank slope was selected as the main indicator for forming channel.

With the hydraulic and geometric measurements, the forming channel discharge was extrapolated using Manning's procedure which consider the term $\dfrac{S^{0.5}}{n}$ to be constant for high level flows, where *S*: slope, *n:* Manning's roughness coefficient. The geometric and hydraulic characteristics of the forming discharge are shown in Table 1.

Table 1   Morphologic and hydraulic data associated to forming discharge.

Stream	*W* (m)	*H* (m)	*A* (m²)	*V* (m/s)	*Q* m³/s
Qui-namayó	12.07	1.99	23.98	3.35	80.35
Cauca	29.00	1.06	30.83	1.89	58.22
Ovejas	16.60	1.23	20.40	2.40	48.93
Ovejas	24.60	1.08	26.62	1.87	49.69
Piendamó	13.52	1.50	20.31	1.19	24.13
Saté	6.71	1.34	9.00	0.77	6.96
Palacé	14.55	1.55	22.50	1.19	26.82
Cofre	15.51	1.14	17.67	0.99	17.56
Cofre	15.03	0.87	13.02	1.09	14.16
Piedras	12.12	0.97	11.79	0.88	10.40
Piedras	10.77	0.81	8.76	0.97	8.52

Bankfull discharge estimators were consistent with the increment of drainage area for different reaches of the same river (this is the case of Cofre, Ovejas and Piedra rivers). This suggests a relationship between the bankfull discharge and the drainage area.

3.3 Forming discharge frequency estimation

Frequency analysis is a probabilistic procedure that uses historic data for estimating the trend of the variable. It is needed for determining the best fit of probability distribution in order to estimate the magnitude of discharge for a specific return period. For improving the confidence of this result there must be good hydrologic data (length and quality of the records). The return period associated to the forming discharge could be estimated applying the frequency factor presented by Chow (1988).

$$Q = \mu + K_T \sigma \qquad\qquad 1$$

Where μ and σ are the first and second order moment from the data and K_T is the frequency factor from the probability distribution with the best fit

To determine the best fit distribution that represents the original data, the typical Goodness of Fit Tests Kolmogorov – Smirnov and Graphic Test are used, and also the Graphic Correlation Coefficient (GCC), Standard Error of Fitting (SEF) (Castro and Hoyos,2004; Vélez,2001 and Chow, 1988).

The hydrologic data used in this paper are concerned to instantaneous maximum flow discharge. The main basin morphometric information and the main statistical parameters of the hydrologic data are presented in the Table 2.

The frequency analysis process was done with the Software HydroStat v. 1.0 that runs in Java (Castro and Hoyos, 2004). The Log Normal distribution's Goodness of Fit Tests are shown in Table 2. CCG values are close to 1 and SEF values are small compared with the mean of the sample; this indicates a correct selection of the Log Normal distribution.

Table 2. Morphometric basin characteristics and main gauging records statistics

River and Gauging Station	Source	Record years	Área km²	μ	σ	Cs	Cv	SK	SKadm	CCG	SEF
Ovejas Abajo - Ovejas	CVC	1964-1999	527.3	121.4	42.03	1.35	0.35	0.1073	0.230	0.974	9.69
Puente Ferrocarril-Quinamayó	CVC	1970-2000	165.5	119.9	65.87	1.71	0.55	0.1621	0.246	0.984	12.2
Julumito - Cauca	CVC	1966-1997	729.1	142.1	49.55	0.99	0.35	0.077	0.236	0.994	5.9
Puente Carretera-Palacé	IDEAM	1970-1997	255.4	43.21	16.27	0.51	0.38	0.0985	0.264	0.988	2.84
Puente Carretera- Piedras	IDEAM	1969-1993	59.2	42.03	31.98	1.69	0.76	0.1048	0.264	0.984	6.52
Puente Carretera – Q. Sate	IDEAM	1971-1993	19.6	8.94	3.72	0.49	0.42	0.0942	0.274	0.982	0.73
El Cortijo Piendamó	IDEAM	1961-1990	153.8	45.62	20.7	1.62	0.45	0.1027	0.240	0.963	5.83
Totoro-Cofre	IDEAM	1961-1993	66.8	10.45	5.78	0.91	0.55	0.0829	0.235	0.991	0.9

μ : Mean of maximum discharge sample

σ : Standard deviation of maximum discharge sample

Cs : Skew of maximum discharge sample

Cv : Variation Coefficient $Cv = \sigma/\mu$

SK : Smirnov Kolmogorov parameter

SKadm : Smirnov Kolmogorof statistic, depends from the length of the series, and the confidence 1- α is 95%

The forming discharge frequency was determined using the Log Normal frequency factor K_T and the statistical parameters of the data (μ mean and σ deviation) in the gauged stream; when the measurement point where not located near gauged station as Cofre, Ovejas and Cauca River, an area correction where implemented. The forming discharge return period is shown in Table 3; there is a consistency between the results for the return period and the bankfull discharge reported by literature (1-2 years), the mean value is 1.4 years.

Table 3   Forming discharge return period

Stream	$Q\,\mathrm{m^3/s}$	T_R **years**
Quinamayó	80.35	1.43
Cauca	58.22	2.45
Ovejas	48.93	1.49
Ovejas	49.69	1.52
Piendamó	24.13	1.08
Saté	6.96	1.50
Palacé	26.82	1.17
Cofre	17.56	1.21
Cofre	14.16	1.10
Piedras	10.40	1.30
Piedras	8.52	1.17

4   Conclusions

The main result from this research is the return period associated to bankfull discharge in mountains streams. The mean estimated value using field and gauged data indicates 1.4 year of recurrence which is consistent to different references.

The vegetation indicator for bankfull level was found to be improper for tropical mountain rivers, since when lichens where used to define the forming level, the discharge associated had a low frequency (3-4 months). This could be explained by the faster vegetation growing in tropical region. Best indicator to bankfull level for mountains stream was found to be the change of bank slope or even the change in bank material.

Bankfull discharges were consistent with the increase of the drainage area for different reaches of the same river as happened in Cofre, Ovejas and Piedra river. This suggests an existing correlation between bankfull discharge and the drainage area to be determined.

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