Return Intervals for Bankfull Discharge in Ephemeral and Perennial Streams of Central and Southern Arizona

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Stream stability has been defined as the ability of a natural stream channel to carry the water and sediment of its watershed while maintaining dimension, pattern, and profile without aggrading or degrading over time (Leopold 1994). Dimension, as described above, refers to channel geometries, such as width, mean depth, and cross-sectional area, at bankfull discharge. Leopold et al. (1964) characterized "channel forming or channel maintenance flows as moderate, frequent events with return intervals between one and two years." Dunne and Leopold (1978) further describe bankfull stage as "the discharge at which channel maintenance is the most effective ... moving sediment, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels." Work by Andrews (1980) confirmed the role of bankfull discharge as the flow that carries the greatest volume of sediment over time in gravel streams. Channel classification systems and assessment techniques developed for natural channels (Rosgen 1996) are being widely adopted; the effectiveness of these tools depends on the successful field identification of bankfull stage.

The ability to accurately assess the current condition and potential for natural channels is important to land owners and resource managers as well as engineers, hydrologists, biologists, and ecologists. Bankfull stage, the flow that creates and maintains a natural channel, provides a consistent point for field measurement of dimension, pattern, and profile; however, bankfull stage can be difficult to identify in the field.

Research in other areas of the United States has determined bankfull discharge to have a common return interval of between 1 and 2 years with an average of 1.5 years (Dunne and Leopold 1978; Castro 1996). Regional curves that relate bankfull discharge, cross-sectional area, mean width, and depth as a function of drainage area have also been established in the Rocky Mountains, eastern United States, and other regions. These regional relationships describe similar stream processes and define hydrophysiographic provinces or regions that share similar climate, topography, and geology.

The arid southwestern region of the United States is dominated by great variety in climate, topography, geology, and vegetation. Elevations range from near sea level to over 11,800 ft. The region includes portions of the four great North American deserts: the Mohave, Sonoran, Chihuahua, and Great Basin. Higher elevations support the largest ponderosa pine forests in the world. Ephemeral flow is more common than perennial flow. Flow events tend to be shorter in duration with a wider range than in other areas of the country. The central and southern portions of Arizona represent the variability of the region. This study was designed to (a) determine whether natural channels in the study watersheds are maintained by moderate, frequent flow events that are recognizable in the field; (b) describe regional relationships of bankfull discharge; and (c) develop tools for field identification of bankfull stage. Work on the first of these objectives is reported here; work continues in Arizona and New Mexico on the second and third objectives.

Description of the Study

Study sites were selected from the watersheds of the Verde, Agua Fria, Salt, Gila, San Pedro, and Santa Cruz rivers. Minimum criteria for sites were the presence of an alluvial channel that could adjust to the natural processes of its watershed and a recent water record of at least 10 years. All of the 90 stream gages operated by the U.S. Geological Survey within the study watersheds were initially evaluated. Sites were eliminated if they were situated in urban areas, impacted by bridges, highways, and other manmade structures, had short or incomplete water records, were subject to

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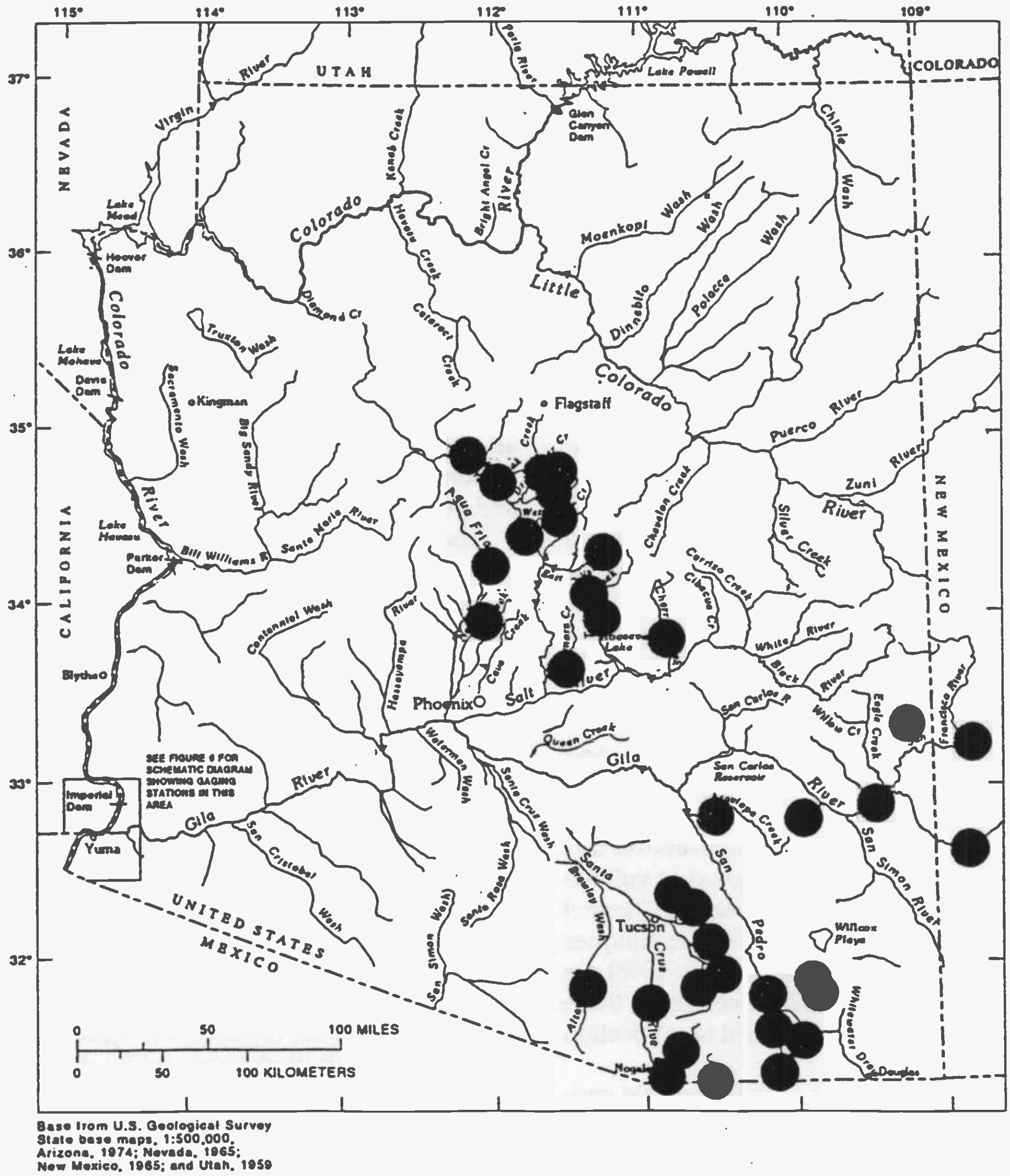

Figure 1. Study sites.

regulated flow (downstream from dams), or were in nonadjustable (bedrock) channels. Eight discontinued USGS gages and four sites administered by the Pima County Flood Control District and USDA Agricultural Research Service were included to increase the geographic range of watershed areas. Twelve ephemeral and 24 perennial streams with watersheds ranging from 5 to 5000 sq mi were selected to provide a range of drainage areas and to cover the geographic study area (Figure 1).

Water record information collected included station description, station analysis, rating table, direct measurements (USGS Form 9-207), and annual instantaneous peak discharges. The Pearson Type III distribution with log transformation of the flood data was used to create annual flood series flood frequency curves for each site (U.S. Geological Survey 1981).

Bankfull stage was identified at each site using procedures described by Dunne and Leopold (1978). The procedures included walking the channel and noting physical features indicative of bankfull stage. Primary indicators included evidence of floodplains, especially point bars, a change in slope along a channel bank, and changes in particle size. Additional indicators such as

Table 1. Central and Southern Arizona Study Sites.

	Station Number	Watershed	Watershed Area (km^2)	(mi^2)	Return Interval (yrs)	Channel Type	Flow	Station Elevation (m)	(ft.)	Status	Agency
Central Mountains											
Beaver Creek near Rimrock, AZ	9505200	Verde	294	111	1.6	C3	Perennial	1225	4020	Active	USGS
Blue River near Clifton,AZ	9444200	Gila	1341	506	1.1	C4	Perennial	1268	4160	Active	USGS
Cherry Creek near Globe, AZ	9497980	Salt	530	200	1.5	B4c	Perennial	975	3200	Active	USGS
Dry Beaver Creek near Rimrock, AZ	9505350	Verde	323	122	1.5	C3	Ephemeral	1126	3694	Active	USGS
East Verde Verde River near Pine, AZ	9507600	Verde	17	6.34	1.4	C4	Perennial	1707	5600	Discontinued	USGS
Frye Creek near Thatcher, AZ	9460150	Gila	11	4.02	1.7	A3	Perennial	1701	5580	Active	USGS
Gila River below Blue Ck near Virden, NM	9432000	Gila	8488	3203	1.2	C5	Perennial	1181	3875	Active	USGS
Gila River near Clifton, AZ	9442000	Gila	10627	4010	1.1	C5	Perennial	1017	3336	Active	USGS
Red Tank Draw near Rimrock, AZ	9505250	Verde	131	49.4	NA	C3	Ephemeral	1189	3900	Discontinued	USGS
Rye Creek near Gisela, AZ	9498870	Salt	323	122	1.4	C4	Perennial	823	2700	Discontinued	USGS
San Francisco River near Glen wood, NM	9444000	Gila	4380	1653	1.4	C4	Perennial	1390	4560	Active	USGS
Tonto Creek above Gun Creek near Roosevelt, AZ	9499000	Salt	1789	675	1.4	F5	Perennial	789	2523	Active	USGS
Verde River near Camp Verde, AZ	9506000	Verde	13274	5009	1.4	B4c	Perennial	876	2874	Active	USGS
Verde River near Clarkdale, AZ	9504000	Verde	9283	3503	1.3	B4c	Perennial	1067	3500	Active	USGS
Verde River near Pauldin, AZ	9503700	Verde	6644	2507	1.7	B4c	Perennial	1255	4117	Active	USGS
West Clear Creek near Rimrock, AZ	9505800	Verde	639	241	1.5	B3	Perennial	1106	3630	Active	USGS
				Average	1.41						
Southern Deserts											
Altar Wash near Three Points, AZ	9486800	Santa Cruz	1227	463	NA	C5	Ephemeral	907	2975	Discontinued	USGS
Aqua Fria River near Mayer, AZ	9512500	Agua Fria	1550	585	1.2	B4c	Perennial	1047	3434	Active	USGS
Aravaipa Creek near Mammoth, AZ	9473000	San Pedro	1423	537	1.1	B4c	Perennial	715	2345	Active	USGS
Canada del Oro near Oracle Jct., AZ	9486100	Santa Cruz	112	42.3	1.7	B4c	Perennial	1036	3400	Active	PCFC
Cienega Creek near Pantano, AZ	9484560	Santa Cruz	766	289	1.5	C5	Ephemeral	1097	3600	Discontinued	USGS
Davidson Canyon	4313	Santa Cruz	134	50.5	NA	C4	Ephemeral	1219	4000	Active	PCFC
New River near New River, AZ	9513780	Agua Fria	181	68.3	1.1	C3	Ephemeral	704	2310	Active	USGS
Rincon Creek near Tucson, AZ	9485000	Santa Cruz	119	44.8	1.7	C5	Perennial	951	3120	Active	USGS
Sabino Creek near Tucson, AZ	9484000	Santa Cruz	94	35.5	NA	C4	Perennial	829	2720	Active	USGS
San Pedro River at Charleston, AZ	9471000	San Pedro	3270	1234	1.1	B5c	Perennial	1205	3954	Active	USGS
San Pedro River near Palominas, AZ	9470500	San Pedro	1964	741	1.1	C5	Perennial	1276	4187	Active	USGS
San Pedro River near Tombstone, AZ	9471550	San Pedro	4585	1730	1.1	C5	Perennial	1128	3700	Discontinued	USGS
San Pedro River Tributary near Bisbee, AZ	9470900	San Pedro	19	7.1	1.1	B4c	Ephemeral	1341	4400	Discontinued	USGS
Santa Cruz River near Continental, AZ	9482000	Santa Cruz	4457	1682	1.6	B5c	Ephemeral	855	2806	Active	USGS
Santa Cruz River near Lochiel, AZ	9480000	Santa Cruz	218	82.2	1.4	B5c	Perennial	1408	4620	Active	USGS
Santa Cruz River near Nogales, AZ	9480500	Santa Cruz	1412	533	1.7	F5	Ephemeral	1128	3702	Active	USGS
Sonoita Creek near Patagonia, AZ	9481500	Santa Cruz	554	209	1.5	B4c	Perennial	1189	3900	Discontinued	USGS
Sycamore Creek near Ft. McDowell, AZ	9510200	Verde	435	164	1.6	B4c	Ephemeral	536	1759	Active	USGS
Walnut Gulch Flume #10	NA	San Pedro	15	5.7	NA	C5	Ephemeral	1615	5300	Active	ARS
Walnut Gulch Flume #9	NA	San Pedro	24	9.1	NA	C5	Ephemeral	1615	5300	Active	ARS
				Average	1.37						

NA: Not Available

changes in vegetation and lichen or water stains, though useful in other climates, were found to be of little value here. Once identified, these indicators were flagged, surveyed, and described for use in the analysis. Additional features such as high and low terraces or consistent vegetation lines were surveyed as well.

A longitudinal profile equal to a distance of 20–40 channel widths and 3–5 cross-sections was surveyed at each site using an electronic distance-measuring total station. Channel thalweg, water surface, bankfull indicators were included in each profile and cross section and benchmarks were surveyed to provide permanent reference points. At least one cross section was staked at both ends to facilitate monitoring of future channel change. Bed and bank material was classified using the Wolman Pebble Count (Harrelson et al. 1994).

Survey information was processed with engineering software to create plan, profile, and cross sections, which provided slope, sinuosity, and channel geometry data. Bankfull indicators were connected along the profile above and below each gage site. When indicators conflicted, field notes were used to decide on the correct elevation. Cross-sectional areas were compared along the profile to check consistency in bankfull determination. The staff elevation of the bankfull stage was noted and related to a staff reading and the associated discharge reading from the ratings table. Return interval was determined from the flood frequency analysis. Bankfull discharges and return intervals were unobtainable at six sites due to extreme changes in channel morphology or incomplete water records. These sites were not included in the return interval analysis. Each reach was characterized using the Natural Channel Classification System (Rosgen 1996).

Results and Discussion

Evidence of bankfull stage can be identified in the field within the natural channels of central and southern Arizona. Return intervals varied from 1 year to 1.7 years with a regional average of 1.4 years (Table 1). There was great variability within the study region. The higher elevations of the central mountains had an average return period only slightly higher than the streams in the southern deserts. However, there was great variability between watersheds. The San Pedro–Agua Fria watersheds had an average return interval of 1.1 years, the Salt-Verde-Gila had an average of 1.4 years, and the Santa Cruz had an average of 1.6 years. There was no detectable difference in bankfull return intervals between ephemeral and perennial streams determined in these field studies.

Conclusions

Bankfull discharge is the dominant flow in the creation and maintenance of natural channels in this region. It is a moderate, frequent event with an return interval that is consistent with the 1.5 year average return interval described by Dunne and Leopold (1978). However, the streams of the study area produced a wide range of values and the average return interval will not provide an accurate tool for predicting bankfull discharge. Dunne and Leopold (1978) suggested that regional relationships exist between bankfull channel geometry and watershed area within regions that share similar climate, topography, and geology. These regional curves may provide an additional tool to aid in field identification of bankfull stage. Work in progress in Arizona and New Mexico to extend and refine bankfull discharge relationships in the Southwest will be reported in the near future.

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